The PLANETARY REPORT

Volume XXVI Number 4 July/August 2006

A Mystery Solved

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From The Editor

It's been a nasty, hot summer here at Planetary Society headquarters in Pasadena, California. The annual phenomenon known as June gloom, when late night and early morning clouds keep the hot sun out and local temperatures down, was absent this year. As we sit and sweat, or crowd air-conditioned buildings, people are asking: Is this our future? Have we humans changed Earth's climate unintentionally?

There's no way to answer such questions without science. Yet this summer, we've also been fighting the biggest political battle in our organization's history, as we struggle to save science in NASA's program.

While we lobby Congress to restore funds to science, we must fight a rear-guard action at the same time: people who say that studying other planets is expendable science, because it doesn't help solve problems on our own world.

They couldn't be more wrong. In The Planetary Society, we know that. But how do we convince people that our admittedly special-interest agenda is not a self-serving one? For this issue of *The Planetary Report*, we asked eminent Earth scientist Charles Kennel to consider if a strong NASA science program is expendable.

You'll read his answer: "The science of Earth is needed as never before." Indeed, it is inextricably linked to the science of other worlds. We fight to save that.

—*Charlene M. Anderson*

On the Cover:

This color composite of multi-spectral Landsat images reveals a huge, previously undetected crater in Egypt's western desert, near the border with Libya. The outer rim of the double-ringed crater is 31 kilometers (about 19 miles) in diameter, making it the largest crater-shaped feature in the Great Sahara of North Africa. Image: Courtesy of Boston University Center for Remote Sensing

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Members' Dialogue

The Conversion Debate

I agree with Phillip Woellhof's opinion in the May/June 2006 issue of *The Planetary Report*. The United States signed the metric convention in 1878, so it is time to abandon the imperial measurements. Planetary science is the cutting edge of science, and *TPR* should lead the way in this matter too. As long as there are imperial measurements in the magazine, no one will ever learn the metric system. Join the world—go metric!
—BJÖRN JOHANSSON,
Uppsala, Sweden

Didn't the whole nation try to switch to metric at one point in the 1970s and it was an utter failure? I support the format used by the Planetary Society and have advocated it in the organizations I belong to that have weekly newsletters and other publications. We are not all in tune with the metric system, and probably never will be, but we do know feet, yards, and miles—for better or worse.
—STEVE ROBINSON,
Westwood, California

I understand the frustration that many people feel because the US still uses imperial measurements. A universal system of measurement is necessary in this globalized world, and it only makes sense that the system be the one used on most of the planet—metric. But the United States currently uses the imperial system, and although the Society has members worldwide, I'll bet that the majority of your members are US citizens.

In answer to those who blame the failure of *Mars '99* on the fact that two measurement systems are still in use, we have only to count the many successful space missions that have not been hampered in the least by this reality. *Mars '99* failed because of a breakdown in communication. The Planetary Society should not concern itself with the particular units used to get a spacecraft to Mars, Europa, or anywhere else. We all have the same goal, which is to get to these places.

Math, done correctly, will all end up in the same place. What's important is communication. These are the most ambitious projects that humans have ever embarked on, and it's vital that we are on the same page. The language on that page is not important—that we understand it is. Keep doing what you do best, which is to disseminate information. By showing the conversions in the magazine, you communicate that information to everyone.
—T. CHURCHMAN,
Altadena, California

Thank You

I want to tell you how touched my wife and I were by Stuart Atkinson's poem "The Spirit of Exploration" in your May/June 2006 issue.

I suppose it's natural to personalize things like the twin rovers (and *Sojourner*). We continue to be amazed at the truly heroic efforts of these "little guys" and, of course, all the incredibly talented and committed people behind them. This poem expressed our feelings better than anything we have ever seen.

We hope that, indeed, someday these amazing robots will be retrieved, cleaned up, and displayed as the first explorers of a new home for the human race on Mars.

Thank you very much.
—KARL GERDS and
BETH HOUSTON,
Natick, Massachusetts

The Planetary Report Online

My personal archives only go back to 1994, so I hope the entire *TPR* archives will be put online so people can experience missions concluded before their time. I imagine the issues dealing with *Voyager 2*'s arrivals at Saturn, Uranus, and Neptune were particularly glorious. Of course, the photos and mission data are all available online, but I'd love to read the Society's reactions as these missions happened. When was *TPR* first published?
—BRIAN ALTMEYER,
Rancho Cucamonga, California

Our first issue was published at the end of 1980. It started off with an essay by Carl Sagan titled "The Adventure of The Planets," and the rest of the issue focused on Voyager *at Jupiter and the approach to Saturn.*

We plan to get the entire archive posted in PDF format. As we go back in time, it gets harder to work with older files. Eventually, we'll need to scan the older printed copies, so keep checking. We'll add issues as we convert them to PDFs.
—Jennifer Vaughn,
Director of Publications

We Make It Happen!

by Bruce Betts

Expedition to Europa on Earth: Ellesmere Island

It's difficult to find a pure analog on Earth for Jupiter's moon Europa, with its airless atmosphere at –300 degrees Fahrenheit (–185 degrees Celsius), but one can find partial analogs on Earth that may simulate important aspects of Europa. One of the best is a unique place on Ellesmere Island in the high—make that *really* high (80 degrees north)—Canadian arctic. The Planetary Society provided key funding that enabled an expedition to this field site in June and July 2006.

Left: Team member Damhnait Gleeson collected spectral data from a helicopter hovering over the sulfur spring.

Right: The discharge stream flows away from the sulfur spring site at Borup Fiord Pass down the front of the glacier.

Photos: Stephen Grasby

As I write this, a team of four has just arrived on site and is providing updates to The Planetary Society on its progress. You can read more about this adventure at *planetary.org/explore/topics/planetary_analogs/*, and we will have a more detailed report on the expedition in a future issue of *The Planetary Report*. These reports will follow in the future, but I wanted to let you know now that we were invited to be part of this exciting opportunity, which ties not only to our commitment to the exploration of planetary analogs but also to our current campaign advocating a dedicated mission to Europa.

The Borup Fiord Pass area on Ellesmere Island has glacial springs that produce sulfur deposits containing hardy bacteria. Viewed from the air, the yellow stains of active sulfur springs, seeping from a 200-meter-thick glacier on the island, somewhat resemble dark, mineral-rich patches that splotch the icy surface of Europa. The presence of sulfur-loving bacteria in a cold (at least by Earth standards) environment makes this site even more intriguing.

The four-person team is led by Stephen Grasby of the Geologic Survey of Canada. Other expedition members are Benoit Beauchamp, executive director of the University of Calgary's Arctic Institute of North America, who first noticed the sulfur springs staining the glacier; Damhnait Gleeson, a doctoral student at the University of Colorado in Boulder, who works with Europa expert Bob Pappalardo of the Jet Propulsion Laboratory; and University of Calgary graduate student Marie-Eve Caron.

The expedition is making helicopter sweeps over the glacial ice of Borup Fiord Pass, where the springs are located, and taking in situ trips to sample the seeping minerals, waters, and bacteria. A key goal for Gleeson is to perform spectral analysis of the site using techniques analogous to those planned for Europa. Check our website for much more information and stunning images.

Gene Shoemaker Near-Earth Object Grants

The Planetary Society is once again seeking proposals for its Gene Shoemaker Near-Earth Object (NEO) Grants program, while past winners continue their amazing productivity.

In 1997, the Society began the Shoemaker NEO Grant program in honor of planetary geologist Eugene Shoemaker, who pioneered our understanding of the role of impacts on Earth and who dedicated much of his life to NEO research. The purpose of the Shoemaker

NEO Grant program is to increase follow-up and discovery of near-Earth objects by providing seed funding to dedicated amateurs, observers in developing countries, and professional astronomers. This funding often allows researchers to greatly increase the scope of their programs. In late July, those wishing to propose projects can find details about the new call for proposals at *planetary.org/programs/projects/neo_grants/*.

Meanwhile, our 22 past winners, who span the globe, have continued their work on many of the most prolific and impressive NEO observation programs in the world, thanks in part to our grants. They are especially critical in the NEO world for astrometric follow-up of NEOs: helping to know exactly where NEOs go after they are discovered and therefore to determine accurate orbits, because it doesn't help to know that an NEO exists if you don't know whether it will hit Earth. A small sampling of past grant recipients is highlighted below.

Peter Birtwhistle, England: Modifications to the telescope funded by the 2005 Shoemaker Grant have resulted in 45 percent more light being collected than before. Birtwhistle contributed astrometry data (accurate position measurements) to more than 190 discovered objects, including 84 first confirmations of newly discovered objects and 8 objects observed at magnitude +21.0 or fainter. A number of fast-moving NEOs were followed, including three that were tracked while they were closer than the Moon!

John Broughton, Australia: He has focused on the less scrutinized southern sky. In addition to various other discoveries farther away, he discovered three potentially hazardous NEOs. He also has developed methods and software being adopted by others.

David Higgins, Australia: His 2005 grant enabled full automation of the observatory and far more observing. He has determined the lightcurves for more than 40 objects, including discovery of the binary nature of three minor planets, among them 6084 Bascom. The binary nature of this object was captured using the camera funded by the Gene Shoemaker grant, the first discovery for this camera. Bascom was discovered by Gene and Carolyn Shoemaker 21 years earlier—a fitting coincidence.

Roy Tucker, United States: He submitted more than 73,000 asteroid and comet astrometric observations in 2005 alone. He also has discovered various objects in recent years and was a codiscoverer of Apophis, the asteroid that will come closer to Earth in 2029 than our geostationary communications satellites and that still has a small chance of impact in 2036 (stay tuned for a new Planetary Society project related to Apophis).

Best wishes to our past winners for more great work, and to our next round of proposers. Thanks as well to you—our members—who make this work happen.

Bruce Betts is director of projects at The Planetary Society

What's **Up?**

In the Sky—August and September

The Perseid meteor shower peaks on August 12, but seeing it will be a challenge as there is a nearly full Moon. A very partial lunar eclipse occurs on September 7 and will be visible from most of Europe, Africa, Asia, and Australia. On September 22, there will be an annular solar eclipse as seen from portions of the South Atlantic Ocean and a partial eclipse visible from most of South America and western Africa. Jupiter is the brightest starlike object in the evening sky, moving from high in the sky to low in the west by the end of September. Venus, in the east, is brightest in the predawn sky but drops below the horizon in September. In early August, Mercury is near Venus, and in late August, Saturn is near Venus. Saturn rises higher in the predawn east in September.

Random Space Fact

Pluto's moon Charon is a whopping half the size of Pluto. The next-largest duo is the Earth-Moon pairing, but our Moon is only a quarter the diameter of Earth.

Trivia Contest

Our March/April contest winner wishes to remain anonymous. We send our congratulations!

The Question was: On what body in the solar system will you find a crater named Sagan, after Planetary Society co-founder Carl Sagan?

The Answer: The crater Sagan is a 98-kilometer- (59-mile-) diameter crater located on Mars a few hundred kilometers south of the *Mars Pathfinder* lander (renamed the Carl Sagan Memorial Station) at the northeast end of Valles Marineris.

Try to win a free year's Planetary Society membership and a Planetary Radio T-shirt by answering this question:

What is the name of the lander, scheduled to land on Comet Wirtanen in 2012, that is part of the European Space Agency's Rosetta mission?

E-mail your answer to *planetaryreport@planetary.org* or mail your answer to *The Planetary Report*, 65 North Catalina Avenue, Pasadena, CA 91106. Make sure you include the answer and your name, mailing address, and e-mail address (if you have one).

Submissions must be received by October 1, 2006. The winner will be chosen by a random drawing from among all the correct entries received.

For a weekly dose of "What's Up?" complete with humor, a weekly trivia contest, and a range of significant space and science fiction guests, listen to Planetary Radio at *planetary.org/radio*.

DON'T ABANDON SCIENCE AT NASA

BY CHARLES F. KENNEL

Left: For more than a decade, this iconic image from the Eagle Nebula has represented the power of NASA's Hubble Space Telescope (HST) to capture the awesome beauty of our universe in images so spectacular that they qualify as works of art. These ethereal, pillar-like structures—reminiscent of undersea coral—are actually columns of cool, interstellar hydrogen gas and dust in which new stars are born. This image was taken in April 1995 with the Wide Field Planetary Camera 2.

Image: NASA/ESA/Space Telescope Science Institute (STScI) /J. Hester and P. Scowen

When NASA was launched nearly half a century ago, the chill of the Cold War was palpable.

NASA's founding in 1958 rallied the country around a science and engineering effort that would supplant a fear of Soviet domination with a new vision of the role of science and education in American life. Neil Armstrong's giant leap for humankind 11 years later climaxed the history-altering race to the Moon. It also launched the idea that nearly anything was possible out in the great expanse of space. Certainly no space initiative since has inspired the patriotism of the lunar landings, nor has any other space-based objective motivated such a revitalization of science and education.

By now, NASA and its achievements are woven intricately into our lives. Today's children cannot remember a time without satellites or when the name NASA wasn't instantly recognizable. Even the most challenging space successes are taken for granted, and we forget where many things in our daily lives came from. Want to know whether to take an umbrella to work? Need directions to a new restaurant? Have a favorite program on satellite TV? Be thankful for NASA's achievements in satellite technology, which make possible today's weather reports, mapping technology, and television broadcasting.

NASA science has become part of everyday life but also provides extraordinary events. Millions of people around the world shared the excitement of scientific exploration on the Internet by watching the nearly lifelike images of the Mars Exploration Rovers. The Hubble Space Telescope sent back images that became works of art. The never-ending quest for knowledge about stars, galaxies, other planets, and especially Earth is one of the hallmarks of contemporary culture.

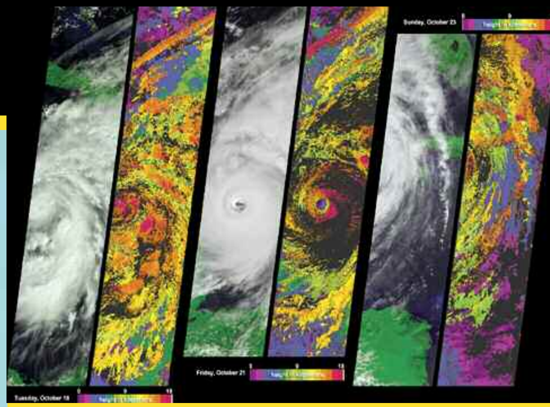
Science is at the very heart of NASA's long-term success; thus, it is troubling to hear of the serious problems embodied in the agency's budget. A long-brewing issue that many have seen coming has finally come to a crisis: the need to replace the space shuttle with new and improved heavy-lift vehicles. At the pace currently planned, such an endeavor could consume the entire NASA budget. Although this unavoidable effort to replace an outmoded transport system is a necessary component of the agency's future, it would be tragic if it came at the expense of scientific research programs.

As the director of Scripps Institution of Oceanography at the University of California, San Diego for the past nine years, I have seen the extraordinary value that scientific initiatives hold for the future of Earth. Satellites, by measuring tiny increases in the sea level, have produced the first complete map of features on the ocean bottom thousands of meters below the surface.

***Above:** These frames offer a sampling of the nearly 10,000 galaxies in the Hubble Space Telescope's Ultra Deep Field image, the deepest visible-light view of the cosmos ever taken. At left, three galaxies just below center are colliding, their shapes distorted by the brutal encounter. This chaos chronicles a time when the universe was younger and less ordered. The smallest, reddest galaxies in the left panel may be among the most distant known, existing when the cosmos was only 800 million years old. The spiral galaxy in the panel at right existed 1 billion years ago.*

The Ultra Deep Field image is composed of 800 exposures taken over the course of 400 HST orbits around Earth. The total amount of exposure time was 11 days, between September 24, 2003 and January 16, 2004. *Image: NASA/ESA/S. Beckwith (STScI) and the Hubble Ultra Deep Field Team*

***Top right:** Today, Earth science missions such as NASA's Gravity Recovery and Climate Experiments (GRACE) are taking sensitive measurements of our planet's gravity and climate to monitor changes in the oceans, ice sheets, atmosphere, and land. Recent analyses of GRACE data indicate that the Antarctic ice sheet may have lost mass equivalent to between 19 and 40 trillion gallons of water. This photo of Antarctica's Riiser-Larsen ice shelf was taken in December 1995.* *Image: NASA/GRACE/DLR/Ben Holt Sr.*



***Right:** NASA's advances in satellite technology have made possible such things as increasingly accurate weather reports. In October 2005, NASA's Multi-angle Imaging SpectroRadiometer (MISR) took this sequence of images and cloud-top height observations of Hurricane Wilma as it progressed across the Caribbean. Each pair in the sequence shows a photo-like view of the storm at left and a matching color-coded image of cloud top height at right. Cloud top heights range from 0 (purple) to 18 (red) kilometers (11 miles) in altitude. Information on cloud top heights may help scientists predict the intensity of hurricanes.* *Image: NASA/Goddard Spaceflight Center/Langley Research Center/JPL/MISR*

Today's missions, such as NASA's Gravity Recovery and Climate Experiments and the Ice, Cloud and Land Elevation Satellite, probe the state of the planet and help reveal a wealth of information about how the oceans, ice sheets, atmosphere, and land are interacting and changing over time. Such knowledge can help us further understand the complexities of the climate system and how important changes—from El Niño events to global warming—are affecting the environment and potentially changing our daily lives now and for future generations.

Earth science has shown us that in the past 50 years, human beings have transformed the surface of Earth as never before. In the coming half century, these impacts will become more acute, as the United Nations predicts a global population of some 10 billion people on Earth using about eight times the energy currently consumed. An increased demand on resources such as energy and fresh water inevitably will lead to increased demands for scientific solutions. The science of Earth is needed as never before.

It is just as vital to keep efforts alive that seek answers about the possibility of life on other planetary bodies. We need to bring samples back to Earth from Mars. We need to search for life in the water under the ice of Jupiter's moon Europa. We need to look for planetary systems around other stars in search of a small Earth-like abode for life. We need to understand how stars, galaxies, and our whole universe formed and are evolving. We need to understand where we came from and where we are going.

When the next astronauts land on the Moon, the Internet will take us there with them. Exploration will be up close and personal. But the Moon, a very interesting geological laboratory, has no life.

One can hope that people around the world will continue to ask the biggest question of them all: how life arose on Earth and might develop elsewhere. Thanks to NASA's planetary probes, we now know that only one planet in the solar system is hospitable to advanced life—there is no place like home. Perhaps that's the greatest discovery of all.

Charles Kennel is the ninth director of Scripps Institution of Oceanography, University of California, San Diego. He has just completed his second term as chair of the NASA Advisory Council and chairs its science committee.

Images of Earth from space are another relatively new part of our daily lives. On September 18, 1977, 13 days after Voyager 1 *launched, it looked back at its planet of origin and captured this picture of a crescent-shaped Earth and Moon—the first image of its kind ever obtained by a spacecraft.*
Image: JPL/NASA

World Watch

by Louis D. Friedman

S.O.S.—Save Our Science! Campaign Update

Following the just-concluded STS-121 flight by space shuttle *Discovery*, NASA plans to fly 16 more shuttles to finish the core International Space Station (ISS) assembly. A 17th shuttle flight is being programmed for repair of the Hubble Space Telescope. These flights must be completed by October 2010, the planned retirement date for the shuttle fleet. This is a tall order for the aging three-vehicle fleet, especially because before 2010, one of the orbiters will be retired and its parts used for maintenance of the other two.

Until this year, NASA had never budgeted the cost of returning the space shuttle to flight, including the necessary safety improvements and planning the remaining 17 flights. When the cost was finally figured, it came in $3 billion over the amount that had been allocated in NASA's 2006 plan for fiscal years 2007 to 2010. The Bush administration declined to make available this extra money for NASA; at the same time, it ordered NASA to fulfill the 17-flight plan. This meant NASA had to re-budget, taking money from other programs. NASA chose to take much of that money from space science, particularly from planetary exploration.

Planetary Society members are familiar with the issue. You've received our letters, followed the S.O.S.—Save Our Science! campaign on our website, and read about it in the press. We urged you to contact members of Congress and ask them to restore funding for research and analysis programs and important missions that otherwise would be lost. You responded tremendously, and we have progress to report.

The U.S. House Appropriations Committee passed a budget bill for NASA that restores $75 million of the $330 million in science cuts. The bill approves a new start for a Europa mission and development work on the *Terrestrial Planet Finder*. It wasn't everything we asked for, but it was a lot, and we have evidence that the reason Congress acted favorably was the tremendous public outcry, led by our members, over the attack on space science and planetary exploration.

Grassroots action was effective, but the Society's campaign also aimed for a higher public profile. We held a special briefing on Capitol Hill with *Titanic* Director James Cameron, Society Vice President Bill Nye, planetary scientist Heidi Hammel, and myself. Cameron, an ocean explorer, is a great advocate of ocean exploration, and the lure of an extraterrestrial ocean on Europa especially excites him. His IMAX documentary *Aliens of the Deep* features terrific computer animation of a future mission to explore under the Europan ice.

Cameron is a devoted friend of The Planetary Society and an enthusiastic participant, as is Bill Nye, in our Save Our Science! campaign. They joined many other notables, inside and outside the Society, in signing provocative newspaper advertisements that we placed in *The Washington Post* and in the congressional paper, *Roll Call* (see example at right).

Representative John Culberson (R-TX) joined Cameron, Nye, Hammel, and me at our event to give forceful support to restoring NASA science funding and getting the Europa mission approved. Because he sits on the House Appropriations Committee, his support proved to be extremely valuable: he lobbied on the inside for the position that we lobbied for on the outside. We owe him special thanks.

Now the US Senate must act. We also have an ally there: Senator Barbara Mikulski (D-MD), a champion of space science and minority leader on the Senate Appropriations Subcommittee dealing with NASA. Following our congressional briefing, she met with us privately and expressed strong support for our science agenda and a Europa mission. Senator Mikulski is working to get an emergency supplement of $1 to $2 billion for NASA to cover the never-budgeted shuttle costs. This would negate the need to rob science to pay for the shuttle and undermine the rest of the NASA program.

We will be engaging you, Planetary Society members, again as the fiscal year 2007 appropriations bill makes it way through Congress. We expect the Senate to act before the end of summer. Then, differences between the House and Senate versions must be reconciled before a final bill can be sent to the president for signature. It could be well into the next fiscal year before the bill becomes law, and there may be many twists and turns ahead, especially in an election year. Please check our website frequently for updates and to stay involved. If you are not receiving our e-mail newsletter

Together, We Make A Difference

On behalf of The Planetary Society's officers, board of directors, and staff—and indeed on behalf of the scientific and technical community involved in space science and exploration—I want to thank our members for the financial and grassroots support to Save Our Science.

Our large membership and broad outreach distinguish The Planetary Society, and the S.O.S. campaign reminds us that we have many friends inside and outside our organization. We ask each of our members and all our friends to make us even stronger and more effective by spreading the word and encouraging others to join our organization. There are many places to read about and watch space exploration, but The Planetary Society is where you can do something about space exploration. After all, we make it happen. *—LDF* and action alerts, you can sign up for them on our website.

A Little Background

Sadly, the administration's decision to fund the shuttle by cutting science has reopened the "manned" vs. "unmanned" spaceflight debate that had been dormant for years. Some characterize the current budget battle as a struggle between science and exploration, restricting the latter word to mean human spaceflight after the shuttle is retired. We reject such artificial divisions. In fact, we regard robotic missions, human spaceflight, science, and exploration as one continuous endeavor, with robotic spacecraft blazing the trail for human explorers of the solar system.

In NASA's organization, there is a Science Directorate and an Exploration Systems Directorate. In the bureaucratic world, these groups often compete. Thus, some in that world label our Save Our Science! campaign as competitive with exploration. But The Planetary Society does not engage in turf wars. We are fighting for space exploration as hard as for science. An old NASA maxim said that "exploration without science is tourism." We agree.

We were early champions of the administration's "Vision for Space Exploration" to reform the U.S. human spaceflight program, but that vision had strong science underpinnings that included many robotic space science goals, including Europa exploration and a *Terrestrial Planet Finder*. All of that was gone in the administration's proposed fiscal year 2007 budget, so when we fight to Save Our Science, we are fighting for the Vision as well. (On our website, you can read the op-ed I wrote on this subject for *Space News*.)

NASA's exploration program has a goal of sending humans beyond Earth orbit; we believe in this goal. NASA Administrator Mike Griffin has made building the Crew Exploration Vehicle his first priority. We support that. We also support NASA's international commitments to complete the space station assembly. But if NASA tries to accomplish these goals by putting aside the robotic missions of science and exploration, it will not only weaken its program but also lose public support. The administration has other choices available. The Planetary Society's Save Our Science! campaign sees beyond the narrow goal of saving science programs. Its ultimate goal is to extend human presence into the solar system.

Louis D. Friedman is executive director of The Planetary Society.

VEILED CRATER IN THE EASTERN SAHARA

The Sahara's Great Sand Sea is a vast, unbroken mass of dunes in southwestern Egypt near the border of Libya. Pieces of a mysteriously pure and beautiful greenish gold glass lie scattered on the desert surface between the sand dunes. The origin of these desert gems, often called Libyan Desert Glass (LDG) but more recently called silica glass because of their nearly pure silica composition, has puzzled scientists for decades. Photo: Yarko Kobylecky

BY FAROUK EL-BAZ AND EMAN GHONEIM

It was a day devoted to video recording. The time ordinarily would have been devoted to evaluating sites for groundwater exploration in eastern Arabia using satellite images. A crew had arrived from a television channel in England (TV-6) to interview the senior author of this article for a program that will follow the trail of a piece of glass carved into an amulet 3,330 years ago. The amulet, in the shape of a scarab, was among the treasures uncovered by Howard Carter in 1922 when he unveiled the tomb of the boy king Tutankhamun. It was believed to have been carved from a piece of pure glass identical to fragments known to exist in the far reaches of the Western Desert of Egypt near the border with Libya. But what was the source of this mysterious, beautiful, and pure glass?

The video crew had already visited the site, between the mega-dunes of the Great Sand Sea, where fragments of this silica glass are strewn on the desert surface. The exposed rock is the so-called Nubian sandstone (from Nubia, the region of southern Egypt and northern Sudan), which is composed of nearly pure quartz (SiO_2) grains. Members of the crew had interviewed researchers who proved that the almost pure silica composition of the glass was the result of its origin from a meteorite impact. The Nubian sandstone would have been the perfect source of the glass—if it melted at high temperatures (more than 1,600 degrees Celsius/3,000 degrees Fahrenheit), which might result from the huge shock of such an impact.

The story would have had a neat ending if anyone

When Howard Carter discovered the treasure-filled tomb of King Tutankhamun in 1922, he found this precious metal and gemstone amulet. Carter assumed that the green scarab at center was carved of the gemstone chalcedony. In 1998, Italian mineralogist Vincenzo de Michele used a refracterometer to examine the content of the scarab and determined that it most surely consists of silica glass. Researchers later determined it to be 28 million years old. Photo: Egyptian National Museum, Cairo, Egypt/The Bridgeman Art Library

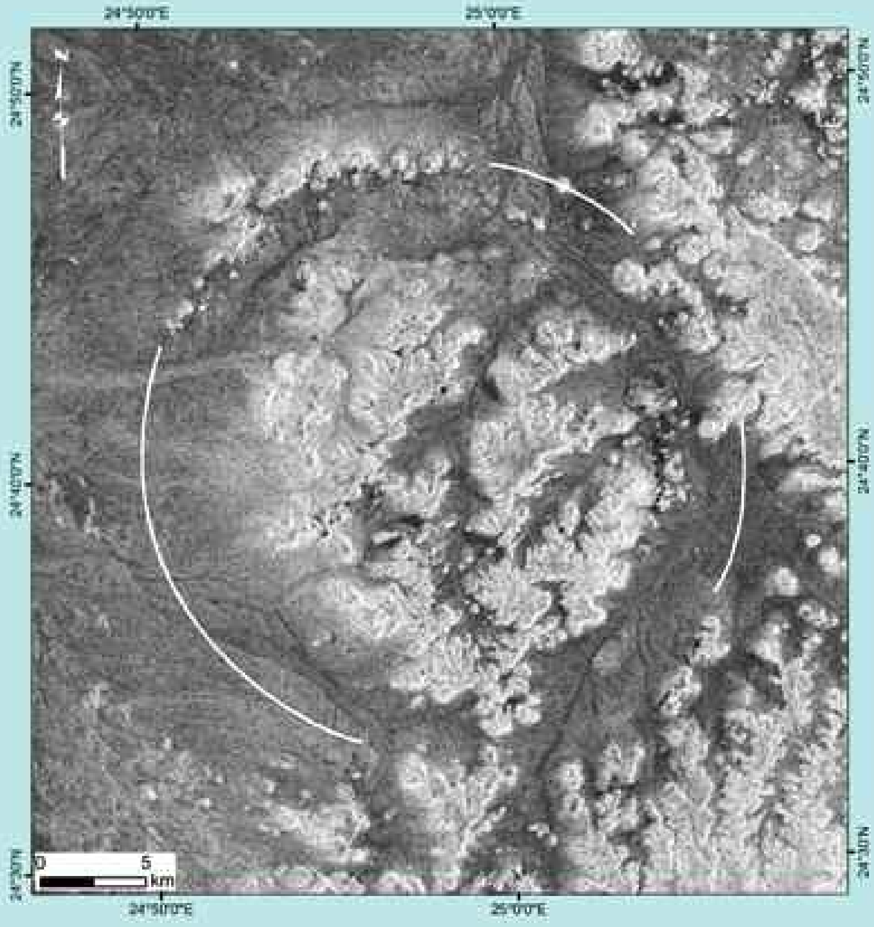
The locations of the crater and the silica glass–rich region of the Great Sand Sea appear on this map. Farouk El-Baz named the crater Kebira, which is Arabic for "large." The name also relates to the crater's location at the northern edge of the Gilf Kebir. Map courtesy of Boston University Center for Remote Sensing

knew of an impact crater large enough that lay close to the mapped extent of the silica glass, but no such crater had ever been found. The only impact features in the eastern Sahara are too small and too far away to have played a part in forming the desert glass. This is exactly the point that the video crew wanted the senior author to make on film, based on his 30 years of experience in studying features of the deserts of Egypt.

After a nearly full day of recording, the second author had prepared a display of satellite images that illustrate the Western Desert of Egypt and its characteristics. The video crew appreciated the bird's-eye view, filmed interesting scenes, and packed up to leave in the late afternoon. The last image of the silica glass region remained on the computer screen. As we stared at it, slowly but surely, we began to see how the geologic features could fit a circular pattern. "Look at that double-ringed structure. . . . It is an impact crater." Eureka!

Crater Characteristics

Soon after identifying the circular structure, we began to scrutinize the available space-borne data, including multispectral images from Landsat, Radarsat data, and sections of topographic profiles from the Shuttle Radar Topography Mission (SRTM). As displayed in Landsat images, discontinuous exposures of rock form a clearly circular rim. The circle straddles the border between Egypt and Libya, and it is centered at about 24.5 degrees north and 25.0 degrees east. The northern segment is the most developed, being composed of an arcuate



Kebira revealed itself to the authors via a circularity that previously had gone undetected in satellite images such as this Radarsat view and the Landsat image on the cover. A major river, long since dried up, once coursed through the center of Kebira. The crater's vast area suggests that it may have been formed by a meteorite the size of the entire Meteor (Barringer) Crater in Arizona, which is 1.2 kilometers (0.75 miles) wide. *Image: Landsat*

The giant dunes of the western portion of the Great Sand Sea as they appear from Earth orbit. This Landsat image of the silica glass region is a composite of multispectral bands. *Image: Landsat*

pattern of protrusions. Other segments are traced by separated blocks, while the eastern part falls on the northwestern edge of a plateau that is part of the Gilf Kebir highlands known as Abu Ras ("the headed one" in Arabic). No rock exposures appear on the western side; the terrain tilts westward from the highest levels on the east.

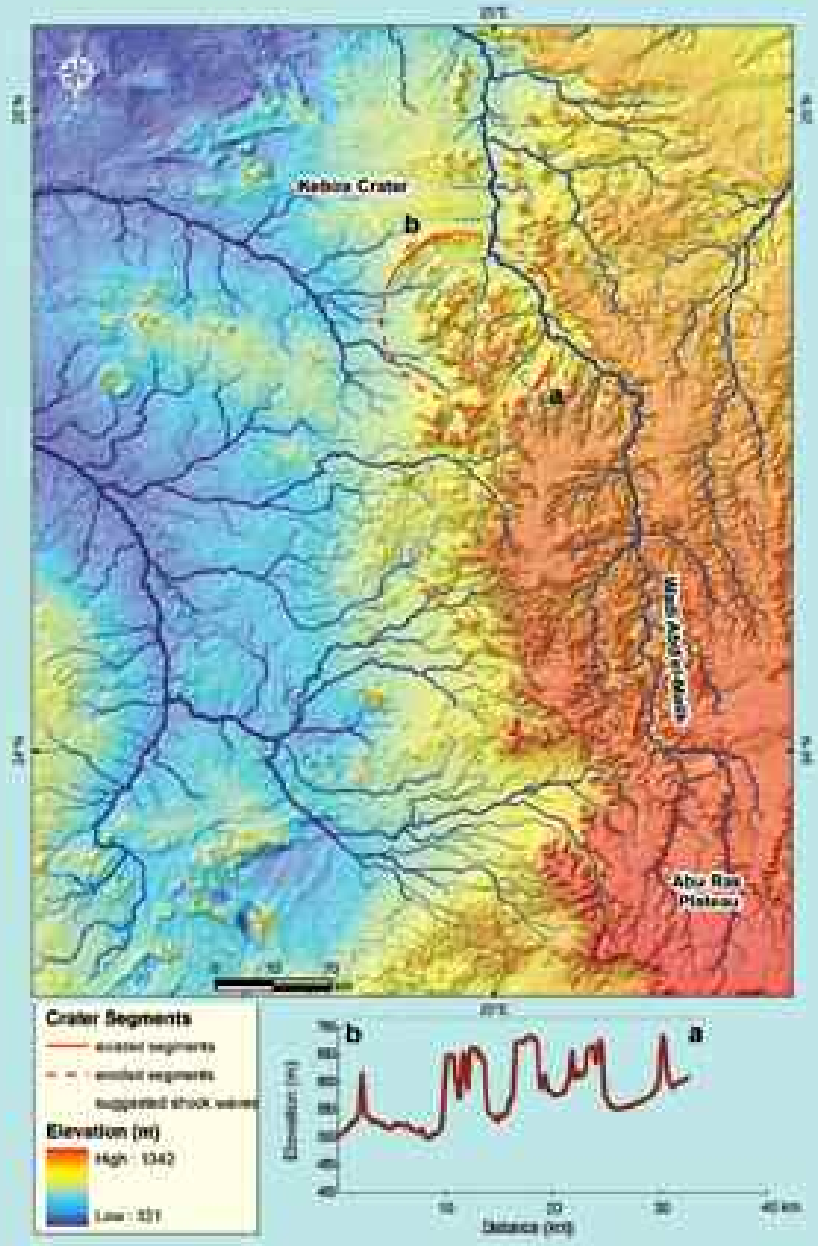
The circular feature is 31 kilometers (19 miles) in diameter and is 750 square kilometers (nearly 300 square miles) in area—the equivalent of 170,000 football fields. This makes it the largest crater shape in the Great Sahara of North Africa. That is why we named it Kebira, from the Arabic word meaning "large."

The inner structure, about 17 kilometers (11 miles) in diameter, is composed of three major prominences (each about 5 kilometers, or 3 miles, across) and several smaller exposures. One of the latter, near the middle of the pattern, is reminiscent of the central peaks that commonly occur in lunar craters of this size and larger. The central prominences are, on average, 30 meters higher than the blocks arranged in the outer crater rim.

Radarsat data clearly show that the inner ring masses present rougher surfaces. This indicates that they are

made of a denser rock that has stronger signal return; thus, they appear brighter than the surroundings.

The structure's overall morphology betrays considerable modification of the original surface by fluvial (water) erosion. The now-dry course of a major river, active in a cooler, wetter past, runs through it. Turbulent waters originating in the highlands of Abu Ras eroded the southern and eastern parts of the pattern. Furthermore, soft sediments were deposited in the valley, called Wadi Abdel Malik, which emanates from the highlands to the south. This pattern was clearly displayed in



This Shuttle Radar Topography Mission (SRTM) map shows the pattern of fluvial erosion in the area surrounding, and south of, Kebira crater, as well as the elevation of the terrain.
Data: NASA and NIMA

elevation data from the SRTM.

Based on the space-borne data, we were able to construct a geomorphological map. To identify exposed surface materials, we classified the multispectral Landsat data. The classification proved that segments forming the arcuate outer rim, as well as prominences of the inner ring, are composed of the same material as that of the plateau: Nubian sandstone. This negates the possibility that the circularity was created by volcanic eruption or other protrusions from the subsurface.

The map also shows that the coarse-grained gravels

Stone Age humans used silica glass to make cutting tools such as knives and axes. When hit with a rock at particular angles, the high-quality glass flakes into sharp-edged blades. Archaeologists have dated some of these tools at between 18,000 and 30,000 years old. Photo: James P. Tobin

This assortment of silica glass fragments was collected in the southwestern corner of the Great Sand Sea from an area about 10 by 10 meters in size. The piece at bottom center is roughly 3 by 2 centimeters (about 1.2 by 0.8 inches) in size. Photo: Wael Abed

surrounding the topographic prominences are compositionally related to the finer sediments farther downhill. This indicates a systematic erosion of the highlands and the deposition of the gravels near the prominences, whereas finer sediments were carried farther away.

The highly effective fluvial erosion of the region raises the prospect that the circular structure and its inner ring may be only remnants of some uniquely selective erosional pattern. If that turns out to be the case, it would be very difficult to explain the process that would have resulted in the observed pattern of rock exposures, which strongly resembles a classic impact crater.

Escaping Recognition

The morphological pattern strongly suggests that the structure is the eroded remnant of an impact crater. An outer rim and a more rugged inner ring are easily explained by an impact. Whether or not this is the case, this pattern should have been discovered long ago and field checked as a possible source of the nearby silica glass field. The mystery of King Tut's glass amulet would have been solved if earlier investigators had recognized the circular pattern.

The senior author has studied Landsat images of Egypt since they were first acquired in 1972. A mosaic was made of 65 images covering all of Egypt to map its major morphological features, with emphasis on the interplay between fluvial and aeolian (wind) processes. Uncanny similarities between features in southwest Egypt and those of Mars inspired much of these early investigations (see "Is It Earth or Is It Mars?" in the January/February 1988 issue of *The Planetary Report*). Since then, many investigators have continued to examine satellite images in the course of numerous research projects.

Throughout that time, none of the many researchers had noticed that circular pattern, let alone deduced its cause. The reasons that the structure has escaped recognition include the following:

- The feature straddles the border between Egypt and Libya; mappers on either side of the border would have encountered only half of it and therefore would not have recognized the complete pattern.
- The structure is so large that human eyes could not easily relate its discontinuous components to one another.
- The rock exposures are so old—at least tens of millions of years—that the region has been considerably modified by erosion.
- The passage of a river, long ago, through the northern end of Abu Ras plateau has masked the northern edge of the highlands and modified their appearance beyond recognition.

For these reasons, this is a case of interaction between what the eye is directed to see and what the brain interprets that to be. It is also quite possible that the recent search for the origin of the silica glass made the circular pattern more noticeable.

Silica Glass

Between massive sand ridges along the western edge of the Great Sand Sea, transparent to translucent fragments of pale yellow-green glass occur on the gravel surface. In 1934, the Egyptian Desert Survey explored the region of the Western Desert of Egypt in which these fragments (from flakes a few millimeters in length to football-sized chunks) are located, and it mapped the region approximately 100 kilometers (60 miles) long and 50 kilometers (30 miles) wide. Because the land west of the Nile was known as the Libyan Desert to British army officers and explorers of the time, the glass was called the Libyan Desert Glass, or LDG. More recently, the name has been modified in the literature to desert glass, and more commonly, silica glass, because of its pure silica composition.

Although the glass only recently attracted scientific attention, it has fascinated humans from prehistoric times. Archaeologists have shown that it was utilized during Paleolithic (Old Stone Age) times, between 18,000 and 30,000 years ago. Prehistoric people put its concoidal fracture to practical use; when hit by a rock at various angles, it produced sharp edges for cutting tools.

When an amulet made of the silica glass was found in the tomb of Tutankhamun in 1922, it gained notoriety. This revived interest in what it was, where it was found, and how it was used. The mapping expedition of 1934 established the extent of its location within western Egypt, but the expedition did not solve the mystery of whence the silica glass came.

Based on the shapes of its fragments and its chemical composition, the glass was suspected to be the result of an impact in the host rock of sandstone. It was not believed to be of extraterrestrial origin, like some tektites that originated from impacts on the Moon or Mars, because it lacked aerodynamic striations from entry into Earth's atmosphere. The minor traces in the silica glass of iridium and similar elements indicated a meteoritic origin; however, no crater had been identified that would explain the distribution of the glass.

Field Investigation

If indeed the newly discovered pattern is the result of a meteorite impact, then we need to undertake field studies to uncover undisputable scientific evidence. We must do the following:

- Study the geomorphology of Kebira's pattern, both along the outer boundary and inside the structure.
- Delineate the effects of fluvial processes that modified the northern tip of Abu Ras plateau.
- Investigate the results of aeolian activities and their interplay with fluvial features in space and time.
- Look for remnants of the possible impact, such as shatter cones in the host rock and planar features in the quartz grains.
- Search for any remnants of extraterrestrial material that might be mixed with the surface material surrounding the structure.
- Identify any additional locations of the silica glass beyond the mapped region of its distribution.

Even today, people can't resist the ornamental value of this enigmatic glass. At top is an elephant carved of a large piece of LDG, and a fragment has been wrapped with gold wire to create the pendant at left.

Photos: TOP GEO (elephant), wwwsciencemall-usa.com (pendant)

We are now planning a field excursion to the region as an exploratory mission. If enough indications warrant an extensive survey, a team of specialists will conduct the necessary research over the required period. Naturally, this effort would require extensive logistical support because of the size and location of the site and its exceptionally harsh environment.

If the structure indeed proves to be the result of a 1.5-kilometer (about 1-mile) meteor hitting the surface of Earth tens of millions of years ago, then solving the mystery of the glass would be worth all the trouble. How often do we have an opportunity to relate something like the scarab of King Tut to the wonders of remote sensing? It would tell us volumes about the role of meteorites in the evolution of Earth and the attendant human history—something that lies squarely in the domain of The Planetary Society.

Farouk El-Baz, a geologist and director of Boston University's Center for Remote Sensing, is a Charter Member of The Planetary Society. Eman Ghoneim is research associate at the same center. For more information, visit www.bu.edu/remotesensing/.

Interstellar Dust:

The Hunt for the Building Blocks of the Universe

by Amir Alexander

Light-years from any star or planet, in the vast expanses that separate one star from the next, space is not quite as empty as it seems. Even in those dark regions, where nothingness seemingly prevails, something, nonetheless, *is.* It is hard to detect, but astronomers still know that it's there. How? Because it makes trouble. It gets in the way of our observations of distant objects, distorts what we see by absorbing certain wavelengths of radiation, and blurs our view of neighboring stars. When we look toward the center of our galaxy, it gets even worse—a screen seems to block us from these star-rich regions, dimming our view of even the brightest stars. Something definitely is out there in that space between the stars, dense in the center of the galaxy, thinner but noticeable in the outlying regions, and always interfering with our orderly observations.

Instead of brooding over what they might have observed if this troublesome interstellar substance did not get in the way, some astronomers have focused on what they can learn about this strange substance, getting clues from the interference itself. First they concluded that this "stuff" is made of tiny grains, because only such particles would reflect and deflect light in the ways observed. They also found that the particles affected different parts of the spectrum of visible light differently—blue light was scattered more than red light, causing objects to appear redder than they would otherwise.

This meant that the particles were minuscule—smaller than the wavelength of visible light—and therefore affected the shortest wavelengths more than the longer ones. By closely monitoring the precise frequencies of the spectrum that were lost in the passage through empty space, astronomers were able to measure the sizes of different types of these grains, all ranging from less than 1/100th of a micron to 10 microns in size. (A micron is one millionth of a meter, and for comparison, a particle of smoke is about 1/10th of a micron in size.) Together, these particles form a most diffuse and insubstantial substance—interstellar dust.

For observational astronomers, interstellar dust is mostly an inconvenience, but for scientists studying the origins and evolution of the universe, it is much more. In fact, these minuscule mineral grains floating in "empty" space are responsible for much of the world we see around us.

According to current theories, the Big Bang, around 13 billion years ago, created only the simplest and lightest elements—mostly hydrogen, some helium, and traces of lithium and beryllium. The heavier elements that make up our world were all formed later on—in the cores of burning stars. But how were such elements disseminated throughout the universe, ending up on small, rocky planets such as ours? The surprising answer is through interstellar dust. These insignificant-seeming particles flow through interstellar space, carrying with them the essential components that make stars and planets possible.

From the Cores of Aging Stars

Interstellar dust is formed through several different processes that take place during the lifetime of stars. Our own Sun, for example, is about halfway through its main phase, which is expected to last for another 5 billion years or so. During this stage, the Sun burns hydrogen in its

This view of the Milky Way's center would not be available without the Spitzer Space Telescope's dust-piercing infrared "eyes." Cold interstellar dust dims visible light from our galaxy's heart by a factor of 1 trillion, normally rendering such stellar observation impossible. Infrared light, however, can shine through the dust. This new infrared mosaic reveals hundred of thousands of (mostly old) stars amid fantastically detailed glowing dust lit by younger, massive stars.
Mosaic: NASA/JPL-Caltech/S. Stolovy (SSC/Caltech)

core, combining hydrogen atoms into helium atoms in a process of nuclear fusion. When this process approaches completion and a substantial part of the core of a star is composed of helium, the pressure generated by the fusion process in the core is diminished, and the outer layers of the star begin to press in upon the core.

This gravitational contraction in turn heats the core even more, causing the outer envelopes to heat up and expand. At this point, a star becomes a red giant; our own Sun will encompass the orbits of Mercury and Venus. The core, meanwhile, will reach a temperature of 100 million degrees Kelvin, and the helium nuclei will begin fusing into carbon nuclei. At the end of the process, the carbon core of the star will be surrounded by a shell in which helium is still being fused into carbon, with that shell in turn surrounded by an envelope in which hydrogen is converted into helium.

Stars at this stage of their life span are known as Asymptotic Giant Branch (AGB) stars, and they are highly volatile. Their shells contain, in addition to hydrogen, helium, and carbon, portions of the heavy elements formed in the stellar core. They are inherently unstable, and their pulsing will create a withering solar wind a billion times stronger than what our Sun generates today. In a relatively short time (about 1,000 years), the entire shell will be ejected into space, joining the gas and dust in the interstellar medium.

Most stars are likely to share the life sequence of our Sun. Following a prolonged main sequence period, they will briefly flower into red giants and shed much of their mass before finally fading into small and astoundingly dense white dwarfs. Truly heavy stars, more than eight times as massive as the Sun, have an even more dramatic fate in store.

Unlike the Sun, which remains in its main sequence stage for 10 billion years, gradually converting the hydrogen in its core into helium, these giants race through their main sequence stage in a fraction of that time. A star of 15 solar masses, for example, completes its main sequence stage in only 10 million years, a thousand times faster than the Sun! When this process is complete, the star's core contracts under the gravitational pressure of the outer layers and heats up to a hundred million degrees. The extreme heat and pressure then initiate a new nuclear reaction in the core—the conversion of helium to carbon. Repeated cycles see the core converted into a series of increasingly heavy elements—neon, magnesium, silicon, sulfur, and eventually iron and nickel.

At this point, the cycle of conversion ends: iron, unlike the lighter elements that preceded it, does not release energy when it undergoes nuclear reactions but instead absorbs it. For a star, this means that an iron core no longer produces the internal pressure needed to counteract the weight of the outer layers of the star pressing in upon it. Within milliseconds, the star collapses in upon itself, and when its center can contract no more, it produces a catastrophic explosion. This is a supernova, which, when seen from Earth, appears as a bright new star in a place where none (or only a very faint star) appeared before. A supernova not only blasts the heavy elements formed in the star out into interstellar space but also initiates its own nuclear reaction, producing even heavier elements. All of this, in the form of fine grains, becomes the stuff of interstellar dust.

AGB stars and supernovae of this type (known technically as type II supernovae) are two of the most common sources of interstellar dust, although there are others as

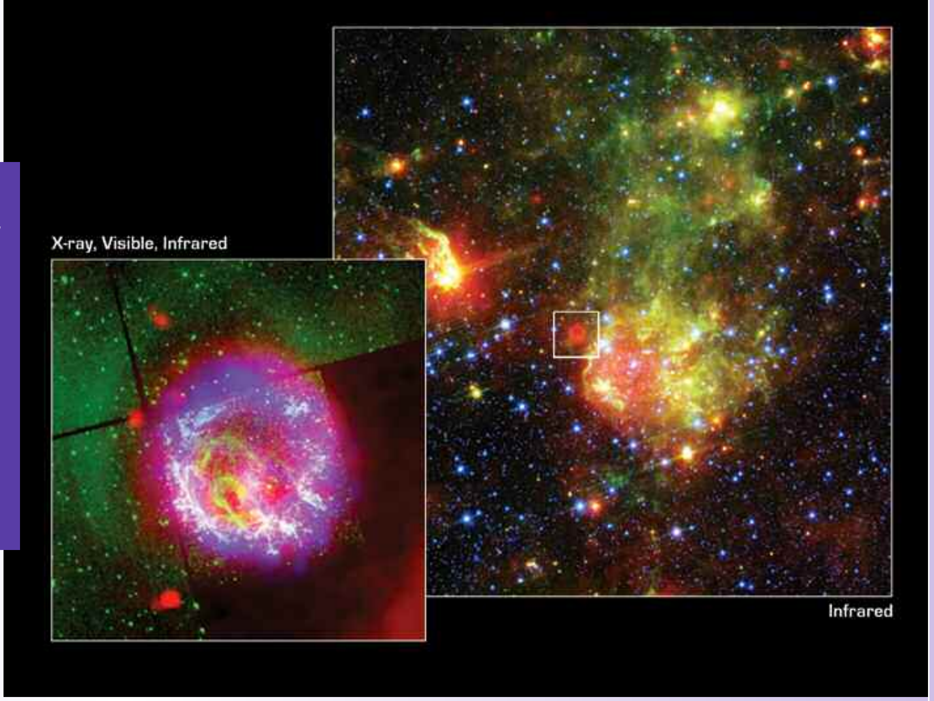
Stardust@home: Join the Hunt for Interstellar Dust Particles!

Scientists examining the *Stardust* return capsule need the public's help to find precious samples of interstellar dust. For more information about how you can participate in this remarkable project, check out The Planetary Society website at *planetary.org/programs/projects/stardustathome/*

Supernovae are responsible for much of the interstellar dust matter in the universe. Some of these particles go on to combine with interstellar gas and other dust to form the huge, swirling disks of debris that will coalesce into new stars and planets.

The white box in the image at right surrounds the remnant of a supernova in the Large Magellanic Cloud, about 200,000 light-years from Earth. The Spitzer Space Telescope took this image in three separate infrared wavelengths. At left, the close-up in the inset better shows the hot red bubble of dust surrounding the remnant, called E0102. This image was taken in X-ray, visible, and infrared wavelengths by the Chandra X-ray Observatory and the Hubble and Spitzer Space Telescopes.

Images: NASA/JPL-Caltech/S. Stanimirovic, UC Berkeley (right), and NASA (left)



well. All of them involve the expulsion into space of grains of heavy elements formed in the cores of stars. Once they are out floating in the vast emptiness of space, they may join with other dust particles and interstellar gas and become a swirling cloud of interstellar debris. It was precisely such a cloud of gas and dust that condensed to form our Sun and planets, just as similar clouds condensed to form other second-generation stars. These seemingly insignificant particles of interstellar dust are, in other words, the fundamental building blocks of the universe.

The Hunt Begins

Scientists are eager to get hold of interstellar dust grains, believing that studying them could shed much light on some of the big questions of science: where did we come from, how did our world become what it is, and where is it heading? Until the spacecraft *Stardust* returned with its samples on January 15 of this year, it was not clear where any interstellar dust could be found. In fact, it was not even clear how any particle, if found, could even be identified as a grain of interstellar dust.

Scientists did have one good lead to go on: when interstellar dust grains form in the cores of stars and are then ejected into space, they carry the signature of the event that produced them. Depending on the nature of this event, the proportions of the different isotopes of any given elements are somewhat different. (Isotopes are different varieties of the same type of atom, all completely identical in their chemical behavior but differing slightly in their atomic weight.) According to existing models, the proportions between the different isotopes in a dust grain formed in a supernova will differ from the proportions of the same isotopes in a grain formed in an AGB, which in turn will differ from isotopic proportions in grains formed in other ways. This, scientists reasoned, should help in identifying these elusive particles if they can, in some way, be located.

In the 1950s, the first mass spectrometers were developed that were capable of measuring isotopes in small samples. At first, scientists set their sights on meteorites, looking to see if these objects from outer space had their own unique isotopic signature. It quickly became clear that the isotopic composition of meteorites differed not at all from that of Earth itself. These solar system objects, it seemed, came from the same atomic "soup" that gave birth to the Sun, Earth, and the other planets in our solar system.

Burning Down the Haystack

For the next 30 years or so, despite intense effort, nobody was able to identify individual grains of ancient interstellar dust. But in the 1980s, scientists at the University of Chicago, led by Ed Anders, and at Washington University in St. Louis, led by Ernst Zinner, finally managed to extract grains of unusual isotopic composition from meteorites. They used highly corrosive chemical agents to isolate mineral grains that seemed as if they could not possibly have come from the homogeneous dusty cloud that gave rise to the solar system. Composed of micro diamonds, aluminum oxide, and silicon carbide, these grains' isotopic distribution bore the telltale marks of their birth: ancient supernovae and red giant stars that shone brightly and then flickered out billions of years ago, before the birth of our solar system.

The work of Zinner, Anders, and their colleagues was a landmark in the study of interstellar dust particles. For the first time, scientists on Earth had mineral grains from distant stars that could be compared with the solar system elements scientists know so well. Nevertheless, serious limitations had to be kept in mind when studying these unusual dust grains.

First, there was the matter of the process used to extract the minerals from the meteorites in which they were found. The procedure involved the use of extremely corrosive chemical agents, which destroyed most of the rock in order to preserve the interstellar particles within. The process is so extreme that Anders referred to it as "burning down the haystack to find the needle." It is quite possible that just as the chemicals corrode the meteorite, they also destroy some interstellar grains that are not recognized as such.

A second, related, problem is that in all likelihood, the samples collected in this manner are not at all representative of "normal" interstellar dust particles and are, in fact, highly unusual. This is because the procedure recognizes grains as being of interstellar origin only when their isotopic proportions are extremely different from the proportions in Earthly minerals. If the proportions in an interstellar dust particle are only moderately different from, or actually similar to, what one finds on Earth, this method would never identify the particle as being a grain of interstellar dust. The end result is that the samples produced through Zinner's chemical process are atypical and highly skewed.

Stardust's Pristine Particles

The only way to obtain a true and unbiased sample of interstellar dust is to go where it is—space—and collect it there. That is precisely what *Stardust* did.

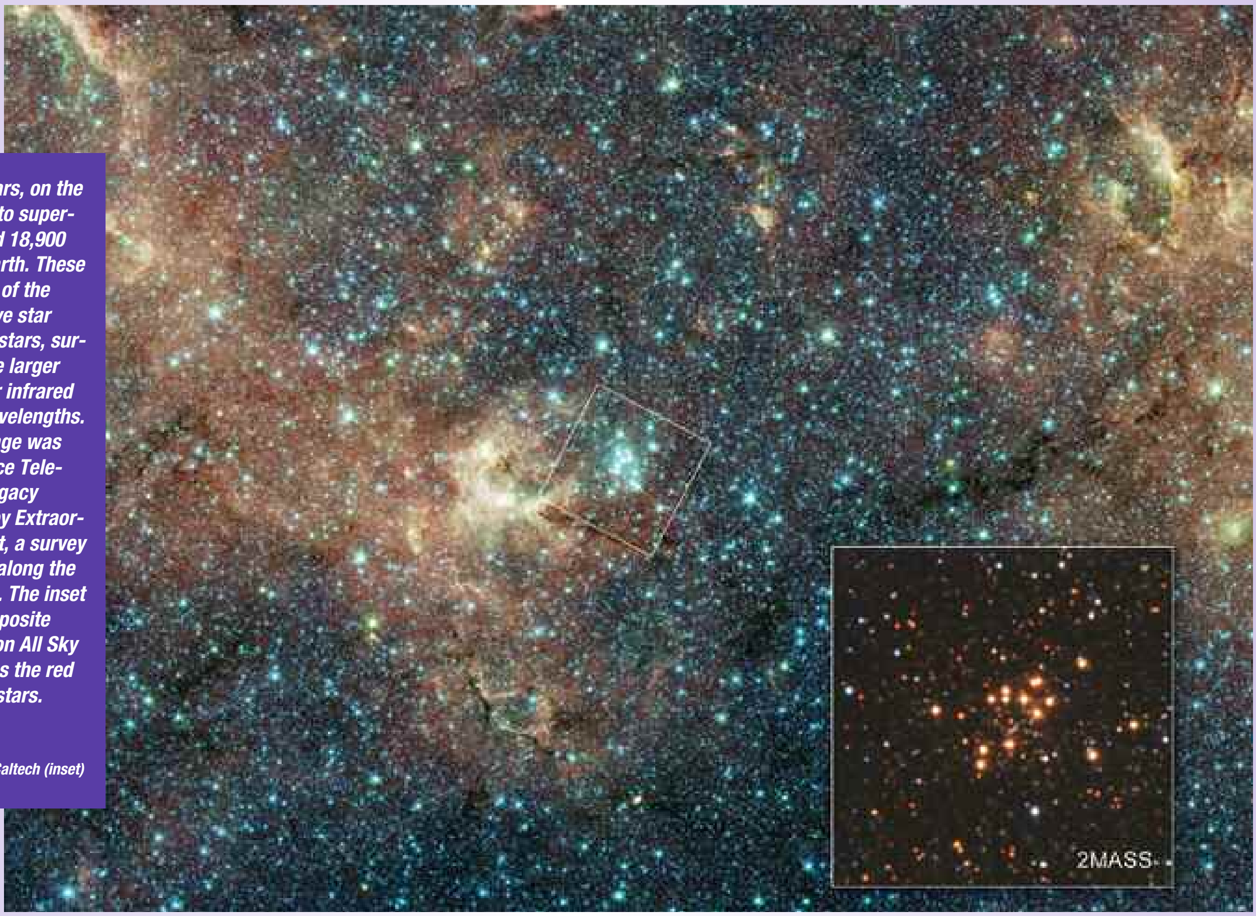
Two previous missions, *Ulysses* and *Galileo*, had already detected the flow of dust particles into the solar system. Scientists could tell it came from interstellar space because it was not affected by the presence of any planet and because it flowed from precisely the same direction as neutral interstellar gas, which had been detected before. It was, in other words, a stream of interstellar dust flowing right at our doorstep, and *Stardust* was sent out to collect it.

On two occasions during its seven-billion-mile journey, between February and May 2000 and again from August to December 2002, *Stardust* passed through the dust stream and spread out its collector. The stream is so thin, however, that scientists believe that even with seven months of exposure, *Stardust* in all likelihood captured only a few dozen grains of interstellar dust.

But this, really, is all that scientists need. With a pristine and unbiased sample of interstellar dust, they can find out if and by how much the elements of our own world differ from others throughout the galaxy. They can study these relatively recent building blocks of the universe and compare them with those ancient particles frozen in time for the last 4.5 billion years—since the birth of the solar system. Has the universe changed? Is it evolving in a particular direction? Or, to put it in a less scientific but more evocative way—where did we come from, and where are we going?

The precious particles on *Stardust* do not have all the answers to these eternal questions. But, scientists believe, they just might have some important clues.

Amir Alexander is a writer and editor for The Planetary Society's website, planetary.org. *He also coordinates the Stardust@home project for The Planetary Society.*



A group of supergiant stars, on the threshold of explosion into supernovae, has been detected 18,900 light-years away from Earth. These dying stars reside in one of the Milky Way's most massive star clusters. The supergiant stars, surrounded by the box in the larger image, emit most of their infrared light at shorter (blue) wavelengths. This color composite image was taken by the Spitzer Space Telescope for the Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE) project, a survey that penetrates the dust along the thick plane of our galaxy. The inset image, a false-color composite taken with the Two Micron All Sky Survey (2MASS), confirms the red supergiant status of the stars.

Images: NASA/JPL-Caltech and NASA/NSF/2MASS/UMass/IPAC-Caltech (inset)

Questions and Answers

I have always been interested in how geologic processes on Earth are equated to processes on Mars, Titan, Venus, and other remote bodies. In particular, I would like more clarification on statements like "these features on Mars must have been created X number of years ago." I would like to know how scientists adapt the terrestrial way they usually measure things to alien worlds.

Further, has anyone given any thought to the differences in other bodies' gravities and if, or how, those differences might affect their geologies?
—Bill Spillman
Floyd, Virginia

The only way to date specific formations—without collecting actual rock samples—is to use the fact that nature is "stamping out" craters on all planets. We start with the Moon, where we know how many craters have been produced in 3.6 billion years on the flat lunar lava plains. This gives us the crater production rate for the Moon. From there we try to estimate (using asteroid and comet statistics) how many impacts happen on the body being studied, relative to the Moon.

The results from this crater-counting method are clearest for Mars. The Mars/Moon impact ratio is somewhere around 2:1, so it takes roughly half as long for Mars to accumulate the same number of impacts as the Moon. Thus, if we count craters on a geologic formation on Mars, such as on the broad lava plains of Amazonis Plantitia or Tharsis, we can estimate rough ages for these features.

This technique for determining the production rate for craters has had two major successes. In 1965, before the *Apollo* program, I used discoveries of impact craters in Canada to estimate the cratering rate in the Earth-Moon system. I estimated about 3.6 billion years as the typical age of lunar lava plains, a number that turned out to be right, based on *Apollo* rock samples.

In the 1970s, while working on the *Mariner 9* mission, my colleagues and I used crater counts on Mars to estimate ages of "only" a few hundred million years for the younger, broad lava plains on Mars. Many people thought that this was far too young, that Mars could not have volcanic activity in the last 10 percent of its history. But in the 1980s, we recognized meteorites found on Earth to be from Mars, and most of them are lava and igneous rocks from 170 to 1,300 million years in age. We don't know what sites they came from on Mars, but they do seem to prove that the planet has widespread lava plains of that age. Venus, as well as Titan and other outer solar system satellites, are trickier cases to solve because it is harder to know what the rate of impact on those bodies is relative to the Moon.

The answer to your second question is "Yes." Differences in gravity are not an overwhelming factor in determining the appearance of geologic features. For example, the angle of repose of loose soil or gravel on a hillside doesn't depend on gravity, and features such as sand dunes, volcanoes, and river channels look about the same on Mars as they do on Earth. But gravity does appear as a "second-order" factor in many of the models and equations that deal with phenomena on other worlds such as water flow, glacial flow, gradual deformation of ice-rich soils, and the precise size of a crater made by a given asteroid impact.
—WILLIAM K. HARTMANN,
Planetary Science Institute

The little shed that houses the OSETI observatory does not appear to be insulated. [See "The Planetary Society Optical SETI Telescope" in the May/June 2006 issue of **The Planetary Report.*****] How will this affect the delicate instruments during cold, wet northeastern winters?***
—Madge Bennett
Princeton, New Jersey

When you open an observatory dome, you don't want differences of temperature to cause images to blur, from turbulent flows of hotter (or cooler) air; therefore, observatory domes are not insulated, including ours. With OSETI's full roll-off roof, any differences in temperature are quickly equalized soon after the roof is opened each night.

The control room, where the electronics live, is well insulated. To keep the equipment happy, temperatures are kept in a favorable range by both an air conditioner and electric heaters. As for the detector package itself, which is attached to the telescope in the unheated dome (or shed), we've enclosed it in a sealed box, with a large desiccator attached. That keeps it dry (there's a humidity sensor inside, so we can check). We've installed heaters as well, to keep the whole thing somewhat warmer than ambient temperature to discourage any condensation, keeping the inside both cozy and dry. Even with the sides off, the measured humidity during the recent record rains has stayed below 60 percent because of the built-in heaters, which we've set to 150 watts. As an added measure, we installed four radiant dome heaters, which can be turned on remotely or by computer control in situations of condensing moisture.

We've worked hard for six years to build and launch this system, and we're as concerned about temperature and humidity as you are—and, thanks for thinking of us!
—PAUL HOROWITZ,
Harvard University

Factinos

Visible light images of Saturn's moon Enceladus were used to make this illustration of warm, low-density material rising to the surface of the south pole from within Enceladus' icy shell (yellow) and its rocky core (red). The white area at the south pole is part of the giant plume of icy material that* Cassini *imaged streaming from the south pole.
Illustration: NASA/JPL/Space Science Institute

Saturn's tiny, icy moon Enceladus may have rolled over, literally. This would explain why the moon's hottest spot is at the south pole (see illustration above). *Cassini* recently observed icy jets and plumes, indicating active geysers, spewing from the satellite's unusually warm south polar region. The researchers, Francis Nimmo of the University of California, Santa Cruz, and Robert Pappalardo of the Jet Propulsion Laboratory, propose that the reorientation of the moon was driven by warm, low-density material rising to the surface from within Enceladus. "The mystery we set out to explain was how the hot spot could end up at the pole if it didn't start there," said Nimmo.

"It's astounding that *Cassini* found a region of current geological activity on an icy moon that we would expect to be frigidly cold, especially down at this moon's equivalent of Antarctica," said Pappalardo, who worked on the study while at the University of Colorado.

Rotating bodies, including planets and moons, are stable if more of their mass is close to the equator. "Any redistribution of mass within the object can cause instability with respect to the axis of rotation. A reorientation will tend to position excess mass at the equator and areas of low density at the poles," Nimmo said. This is precisely what happened to Enceladus.

Nimmo and Pappalardo calculated that a low-density blob beneath the surface could cause Enceladus to roll by up to 30 degrees and put the blob at the pole. The rising blob (called a diapir) may be in the moon's icy shell or the underlying rocky core. Either way, as the material heats up, it expands and becomes less dense, then rises toward the surface. This rising of warm, low-density material could also help explain the high heat and striking surface features, including the geysers and the "tiger-stripe" region suggesting fault lines caused by tectonic stress. A similar process may have occurred on Uranus' moon Miranda, they said. Their findings appeared in the June 1, 2006 issue of *Nature*.
—from NASA/JPL/Space Science Institute

Scientists have found what they think is a huge slab of Earth's crust near the planet's core. Alex Hutko of the University of Santa Cruz and Edward Garnero of Arizona State University found the slab by monitoring seismic waves. These waves—recorded in the United States—were generated by earthquakes in South America that reflected from deep inside Earth's mantle. The discovery supports the theory that Earth's crust is constantly recycled deep into the planet, as molten material from below simultaneously pushes up to refresh the surface.

The slab of crust is about 200 kilometers (125 miles) deep, at least 200 kilometers wide, and about 400 kilometers (370 miles) long in the north-south direction. The researchers said its consistency was more like a giant, folding mush of taffy. "If you imagine cold honey pouring onto a plate, you would see ripples and folds as it piles up and spreads out, and that's what we think we are seeing at the base of the mantle," said Hutko, who is lead author on an article describing the findings in the May 18, 2006 issue of *Nature*.

"It's the first hard evidence from direct imaging to support the idea that ancient seafloor makes its way down to the bottom of the mantle," Hutko said.
—from *LiveScience.com*

Gravity measurements from NASA's twin Gravity Recovery and Climate Experiment (GRACE) satellites have detected a structure more than 480 kilometers (298 miles) wide, more than 1.6 kilometers (about 1 mile) under the surface of the east Antarctic ice sheet. The structure could be a crater more than twice the size of the Chixulub crater in Mexico, which was caused by the impact believed to have killed the dinosaurs.
—from *New Scientist*

Society News

Visit Your Local Planetarium

Planning a trip with the kids this summer? Or perhaps checking out what the city you live in has to offer? How about including a visit to a planetarium? Did you know that the Society offers its members planetarium admission discounts? Check out *planetary.org/join/planetariums.html* for a list of planetariums participating in our planetarium discount program—discounts range from 15 to 100 percent off admission prices.

If there is a planetarium near you that is not on our list, please let me know at *tps.vz@planetary.org*—perhaps it too will join the program! We hope you include in your summer plans a guided tour through the constellations and planets in the evening sky!

—Vilia Zmuidzinas
Event & Projects Coordinator

Planetary Radio Is on the Air

The Planetary Society's audio coverage of space exploration has expanded at lightspeed over the last year. More than 75 public radio stations have added the weekly program to their schedules, with more picking it up every week. Listeners also catch the series directly from Earth orbit via XM Satellite Radio. Planetary Radio is in the middle of its second year with this industry leader, which enjoys a fast-growing base of nearly 7 million subscribers.

Each new show can be downloaded from our website, *planetary.org/radio*, but thousands of listeners seem to prefer the convenience of the Planetary Radio podcast. Apple iTunes announced that the half-hour of news, information, interviews, special event coverage, and good clean space fun is one of the most popular science programs in its podcast directory.

In the last few weeks, Planetary Radio has checked in with *Mars Reconnaissance Orbiter*'s Rich Zurek, extrasolar planet hunter Christophe Lovis, and Europa scientist Bob Pappalardo; discussed planetary protection with NASA's John Rummel and neutrino detection with Art McDonald; and heard from Canadian scientist Stephen Grasby while he was conducting a Europa analog expedition in the high arctic. If you missed any of these shows, you can still catch them at *planetary.org/radio.*

We hope you join Bruce Betts, Emily Lakdawalla, host Mat Kaplan, and special guests on their next audio outing.

—Mat Kaplan, Planetary Radio Producer and Host

Double Your Gift!

Did you know that your employer might help you double—or even triple—your donation to The Planetary Society?

That's right! Many companies encourage their employees' charitable giving through matching-gift programs, so please check with your human resources department to see if your company supports such a program.

Call or e-mail Andrea Carroll, Planetary Society Director of Development, at (626) 793-5100, extension 214 or *andrea.carroll@planetary.org* if you have questions.

Thank you for your extra effort—and your extra support!

—Andrea Carroll,
Director of Development

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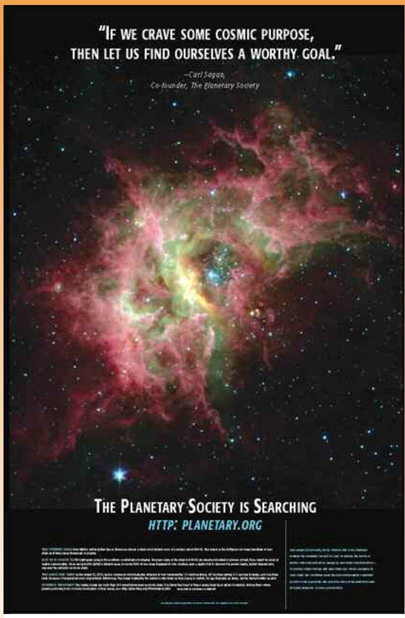
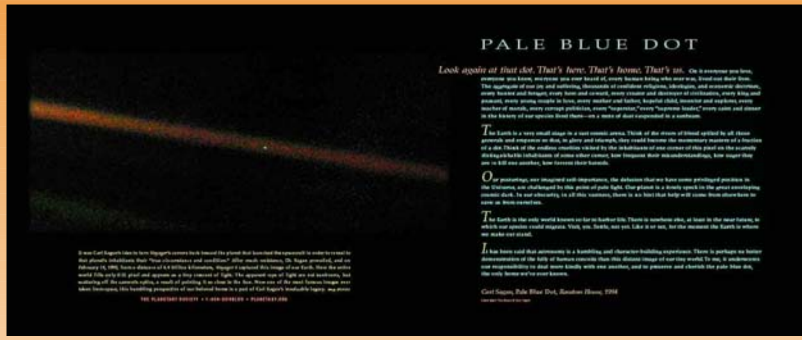
The Awe and Mystery of the Cosmos!

Nebula Poster
This awe-inspiring image from NASA's orbital Spitzer Space Telescope shows a false-color infrared view of nebula RCW 49—a birthplace for many hundreds of new stars and likely many thousands of planets. This stunning poster features one of Carl Sagan's poignant statements: "If we crave some cosmic purpose, then let us find ourselves a worthy goal." 22" x 34" 1 lb. **#315 $13.50**





Pale Blue Dot Poster
In February 1990, *Voyager 1* looked back at its home planet for the first time. The image of Earth as a tiny bluish dot inspired Carl Sagan to write one of his best-known essays, which starts off his book *Pale Blue Dot*. The poster features Carl's timeless words and the full frame of the profound image captured by *Voyager 1*.
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Marketplace

Geysers of Enceladus depicts the recently discovered cryovolcanism on that diminutive Saturnian moon. The geysers are the source of Saturn's oxygen-rich E ring. They spew out water, which then dissociates into hydrogen and oxygen. *Cassini* team members advised artist Michael Carroll on such details as ice textures and plume shapes for this painting.

Michael Carroll is a Fellow of the International Association of Astronomical Artists. He and Rosaly Lopes of the Jet Propulsion Laboratory are working on a book titled *Alien Volcanoes*, which will be published later this year by Johns Hopkins University Press.

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