The PLANETARY REPORT

Volume XXV Number 4 July/August 2005

A Smashing Success!

A PUBLICATION OF THE PLANETARY SOCIETY

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Features

Huygens' January 14 landing on the surface of Titan was a great accomplishment, showing us never-before-seen views of the mysterious moon. But the in-depth examination of the intriguing moon has only just begun. Scientists are still studying *Huygens*' data, and the *Cassini* orbiter is completing the first year of its 4-year tour of the Saturnian system. As it dances through a complex series of orbits, *Cassini* repeatedly turns a close eye to Saturn's haze-shrouded moon Titan. Here, longtime Society friend Toby Owen—a planetary scientist and one of the architects of the *Cassini-Huygens* mission—explains what *Cassini-Huygens* has taught us so far about Titan and its tantalizing atmosphere, which resembles that of early Earth.

We watch for asteroids and track these space rocks orbiting around our Sun, hoping we never find one on a collision course with Earth, but history tells us one eventually will come our way. When we do find that near-Earth object on a dangerous path toward Earth, will we be ready to protect ourselves? How will we do it? We could send explosives to space in an attempt to destroy the threat. Or, as *Apollo 9* astronaut Rusty Schweickart suggests and explains here, we could send a craft to gently nudge it into a new orbital path. The discussion of exactly how to handle an NEO headed for Earth continues, and there are many differing opinions. The Planetary Society is part of this discussion, working with Rusty and others to help come up with a solution.

Departments

From The Editor

"Dream no small dreams for they have no power to move the hearts of men."

Goethe said it first, but Thomas O. Paine was fond of quoting it, and I've taken it as my personal motto for The Planetary Society. Tom was the administrator of NASA during the first *Apollo* landings and a director of The Planetary Society until his death in 1992. When we face setbacks—as with the loss of *Cosmos 1*—I conjure up Tom's voice saying those words and resolve not to give up.

In my book, there are three types of dreams: the unconscious at its nightly play, ideas that will never become reality, and blueprints for an achievable future. The solar sail belongs in the last category. We lost *Cosmos 1* at the very beginning of its journey, when the Volna rocket failed to lift it to its intended orbit. But as far as we are concerned, our attempt to achieve the first solar sail flight is not a failure, it is merely a dream deferred. We will try again.

Meanwhile, we still have a full roster of other projects. In this issue, we cover the threat to Earth from errant asteroids and what can be done about it—work we are sponsoring. We also have a report on *Huygens*' discoveries on Titan by longtime Society friend Toby Owen.

Exploration goes on, as does the dream of new worlds to explore, and we are still part of it.

—Charlene M. Anderson

On the Cover:

On July 3, 2005, 67 seconds after its impactor smashed into the nucleus of comet Temple 1, *Deep Impact*'s flyby spacecraft took this picture. Scattered light from the collision saturated the high-resolution camera's light detector on the flyby craft, creating the bright splash and rays seen here. It's reflected sunlight, however, that illuminates the comet's nucleus.

Image: NASA/JPL-Caltech/University of Maryland

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Members' **Dialogue**

On *Cosmos 1*

I am writing to pass on the sentiments of the members and the board of the National Space Society (NSS): Thank you for daring, thank you for dreaming, and thank you for inspiring our planet.

The flight of *Cosmos 1* captured the attention of the world. In so doing, it did more in a week to advance public knowledge of solar sailing and interstellar travel than had ever been done before.

Everyone at NSS was fervently wishing for success, and for the chance to go outside in the early evening and to spot the bright moving star.

But the great effort to explore and open space is just beginning, and we hold out the hope that *Cosmos 1* may yet yield a child, whether she is named *Cosmos 2* or something else. You have so much to be proud of.

—GEORGE WHITESIDES,
Executive Director,
National Space Society

Here is a selection of comments from* planetary.org*:

Whether you find the craft or you don't, you guys still rock. I haven't had this much interest in a mission in a long time. Thanks for all the hard work. And especially for making us a part of it.

—DEVON E. BOWEN

Thank you for doing your cool job. It is nice to sit down with a cup of coffee and read what is happening now—good, bad or uncertain—from someone that has firsthand knowledge. You make me feel like I am a part of the team.

I wish more space missions would have a weblog like yours. The Planetary Society may be unique in that your transparency and desire to communicate may be your biggest selling point.

—WILLIAM H. DEPEW

Keep the faith, you guys; no complex feat of engineering ever goes smoothly! Even if the worst occurs, be proud of the fact that you were audacious enough to try; I have never been prouder to be a member of the Society than today.

—NICHOLAS PREVISICH

Note to Emily Lakdawalla for her* Cosmos 1 *weblog:

I've been sticking with you from the excitement of prelaunch all the way to where we are now. Your updates are outstanding and very informative. I feel like I'm a member of the team.

—MARK LOPA

Clarification

I enjoyed "Eavesdropping on *Huygens*" in the March/April 2005 issue of The Planetary Report. However, I was struck by the strangeness of the sidebar, "Elements of a Link Budget."

It is signal strength, not attenuation, that is inversely proportional to the square of the distance. The "space loss" would have diminished the signal by a very large factor, such as 10 to the 30th power, not the tiny factor indicated by the negative exponent. Alternatively, the signal would have been diminished to (not by) a very small value.

It's probably beside the point to mention this, but the inverse-square law applies without regard to frequency and power level of the transmitted signal. Thus, those numbers (2 GHz and 10 watts) are informative (if they are correct) as to the actual parameters of the project, but they have nothing to do with the concept of signal loss due to distance.

—NORMAN K. MOSHER,
Corinth, New York

My intent was to say that the transmitted signal power has to be multiplied by this very small number (10 to the power –30) to compute the received signal when accounting for space loss, which is, indeed, a function of the frequency. Even at the same distance, signals at different wavelengths experience different space losses.
—SAMI ASMIR,
The Jet Propulsion Laboratory

Erratum

On page 21 of the May/June 2005 issue, there is an error in the distance between the star GQ Lupi and its companion GQ Lupi b. The correct distance is 100 astronomical units (100 times the distance between Earth and the Sun). This is about 2.5 times the distance between the Sun and Pluto. *—Editor*

Please send your letters to
Members' Dialogue
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or e-mail:
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We Make It Happen!

by Bruce Betts

Cosmos 1 Solar Sail

On June 21, The Planetary Society tried to fly the world's first solar sail spacecraft, a vehicle to be pushed along by light from the Sun. Failure of the Russian Volna launch vehicle meant that the *Cosmos 1* spacecraft never had a chance to fulfill its technical mission. It did, however, accomplish many of its goals.

The Society sought to inspire the world's public, and we succeeded. We were deeply touched by the outpouring of interest and support from all corners of the globe. Our web traffic measured in the tens of millions of hits; more than 1,500 stories appeared in the worldwide press concerning the mission; and we received thousands of e-mails and other correspondence from the public and from you, our members, expressing interest, support, and condolences. More than condolences, the threads we saw through all the correspondence were how important this project was to the public and the feeling that we should try again. This boosted our spirits in what could have been a dark time, causing us to cast our gaze to the future while not losing sight of learning from the present.

Below is an update from our Executive Director, Louis Friedman, who is also the *Cosmos 1* Project Director, on what happened to *Cosmos 1*. — *BB*

The Story of *Cosmos 1* Is Not Over

by Louis D. Friedman

The word *failure* is sticking in my craw. Certainly, we failed to achieve the objective of *Cosmos 1*: we did not achieve solar sail flight. With all we have done, however, I don't believe that I can call *Cosmos 1* a failure.

What's so excruciatingly frustrating is that we were done in by a launch vehicle failure. Our spacecraft never got a chance even to try. But we chose to launch on the Volna, and we take responsibility for that.

People keep asking me how I feel. Because I first became involved with solar sailing 30 years ago, they think that some dream of mine has now been destroyed. But I am not about dreams, nor technologies, no matter how sweet. Rather, I want to make space missions happen, to shape the future—so you might think that I should be extremely "bummed out." After all, solar sailing is in our future, and the *Cosmos 1* mission is now in our past.

Surprisingly, I am not bummed out. I expected to be. Secretly, not sharing with anyone, I thought that if this mission failed, I would come back devastated and in a mood to give it up. So, at about 20:25 GMT on June 21, when it became evident that something had gone gravely wrong with the mission, I waited for the depression to set in. Instead, I got caught up in the immediacy of the situation, and now, I feel focused on what we did, what we still are doing, and what we might do in the future, rather than feeling any regret about what might have been.

I've now been involved with three missions that ended in Russian launch failures: *Mars 96* was failed by a Proton, and our solar sail project suffered two Volna failures. But this was the first launch failure that was evident in real time. After the 20-minute launch phase went by with just a single-sentence report, when we were expecting nearly minute-by-minute updates, we knew something must have gone wrong. The one sentence, coming two minutes after launch, was "Confirm first-stage separation." That report is now significant because a half hour or so later, Evgeniy Kulagin, the flight control manager, came over and said it was an error—first-stage separation never occurred. Later yet, we learned that the Russian space agency (RKA), acting on information from the Makeev Rocket Design Bureau (the Volna's manufacturer), had issued a statement saying that no stages separated and that the whole launch vehicle, plus spacecraft, flew on a much-shortened trajectory into the Barents Sea.

The issue of whether or not the Volna's stages separated is the critical one for resolving the differing reports about what happened to our spacecraft.

***The Volna is launched from the submarine* Borisoglebsk.**
Photo: ©The Planetary Society

At first, we were also told that the portable tracking stations in Petropavlosk, Kamchatka, and Majuro in the Marshall Islands received no signals. That seemed to be the end of it. Jim Cantrell reported from Project Operations Pasadena (POP) that the US Strategic Command also saw nothing. But soon my colleague, Slava Linkin of the Space Research Institute, the payload and electronics leader of the project, reported that Oleg Andreyev (a member of his group, who was in charge of the portable station in Kamchatka) said that Doppler data (tracking information about the speed and position of the spacecraft) were recorded in Kamchatka. Then, as we were driving home at 4 a.m. Moscow time, Jim Cantrell called me on my cell phone from our POP room and said that Viktor Kerzhanovich had indeed received a signal in Majuro—a very weak one that was not noticed on the frequency meter but was contained within the data recorded. When we called the team at the Tarusa station, who were in charge of orbit tracking, they told us that the Czechs at the Panska Ves station also had |received a signal.

The mystery of the signals received from a spacecraft reported to be at the bottom of the sea has occupied us since then. The Russian military and space agency are firm that the entire rocket and spacecraft went down together. But what, then, were those signals in the data recorders? They are now being analyzed by Dr. Linkin's group, the Czech tracking group, and The Planetary Society project operations group. There seems to be some indication that the spacecraft was injected into a low orbit, one that would quickly decay and cause the spacecraft to fall back to Earth and burn up in the atmosphere. We hope to have more to say about that soon.

As we were planning our mission, we spent a lot of time thinking about the value of creating an extra portable ground station and taking it to Majuro in the South Pacific for only seven minutes of work during the first orbit. Working out the logistics of a quick trip to the Marshall Islands was not easy. Later, we added the Panska Ves tracking station in the Czech Republic to the project. Those decisions turned out to be correct and valuable. So, too, was the effort made by Jim Cantrell and his POP team, and Vladimir Nazarov and his MOM (Mission Operations Moscow) team, to facilitate and enable rapid data handling in the mission. I would not feel so comfortable with any conclusion we make if it weren't both coordinated and independently reviewed by these two teams.

Right now, I am not thinking about what might have been. What we did is not bad. We built the first solar sail spacecraft. There is even a chance it got to orbit in working condition and ready for its mission. We created an international partnership with very limited resources. We conducted the first space mission by a privately funded space interest group. We tested the notion of private funding for space ventures based on the idea that they have exciting stories to tell. We built a private partnership with a science-based entertainment company, Cosmos

What's **Up?**

In the Sky

Bright Jupiter and the even brighter Venus are in the west after sunset. The two will appear closer until they are only one degree apart on September 1. Mars, glowing orange, is high in the southeast at dawn, brightening and growing higher with time, leading up to its very bright opposition (when it is on the opposite side of Earth from the Sun) in early November. By late August, it can also be seen rising in the east before midnight. The Perseid meteor shower peaks the night of August 12, with an average of one meteor per minute from a dark site.

Random Space Fact

Comet tails always point approximately away from the Sun. So, when a comet is headed away from the Sun, its tail is in front of it.

Trivia Contest

Our May/June contest winner, from Palmetto, Florida, wishes to remain anonymous. Congratulations!

The Question was: Hydrogen makes up most of the giant planets (Jupiter, Saturn, Uranus, and Neptune). What gas is the second most common material in the atmospheres of all the giant planets?

The Answer: Helium

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

STS-3 was the only space shuttle landing at a site other than Kennedy Space Center or Edwards Air Force Base. Where did it land?

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, 2005. 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.*

Studios—a partnership based on a shared vision of the value of exploration. We engaged national space agencies, won their respect, and spurred on their programs in solar sailing. More than a simple "prize" adventure, this may be a segue to private-public partnerships in pursuit of popular goals. We certainly captured the public's attention, both satisfying and creating interest in exploring space. The public attention to this project was overwhelming—almost. The Planetary Society staff is doing a great job of coping with it.

There simply is no way I can be depressed with all these achievements on our slate.

Cosmos 1 boasts a host of specific technical accomplishments. The spacecraft design offers great promise as a platform for future missions, including, perhaps, even missions to Mars. The low-cost system we put together for mission operations, tracking, data handling, and international coordination of a satellite is a model for the future.

One other achievement is noteworthy: we did this mission entirely with private funds. Ann Druyan representing Cosmos Studios was an incredibly loyal sponsor, and philanthropist Peter Lewis and the members of The Planetary Society were very generous donors.

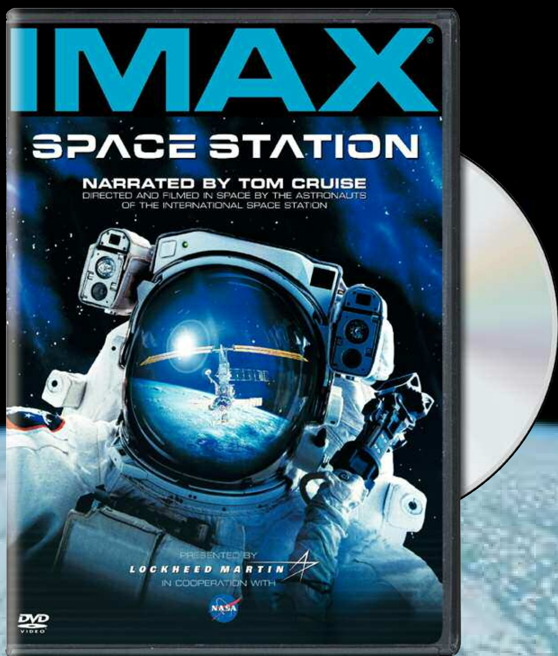
In its 25 years, The Planetary Society has been part of both failed and successful space missions. Two examples come immediately to mind: *Mars Polar Lander* crashed carrying our Mars Microphone, and the hugely successful *Mars Exploration Rovers* carried our calibration target and hosted our Red Rover Goes to Mars students. We know well the highs and lows of space exploration.

We deeply appreciate and are buoyed by the determination and spirit of Planetary Society members and by the public who wish us well, congratulate us for our efforts, and are telling us even now, "Keep going." We will keep going. Although right now I don't know exactly how, I do know that we are committed to trying again, for The Planetary Society exists to make space exploration happen. Join us on this continuing adventure. ❑

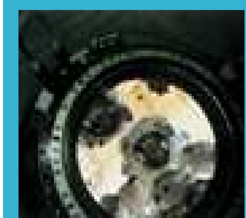
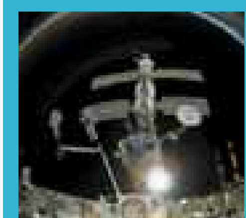
We Challenge You to Help The Planetary Society Grow

and receive a special gift for yourself!

Give a year's membership in The Planetary Society to a fellow space enthusiast . . . and we will send you—FREE—the just-released *Space Station* DVD (a value of $19.98).



As astonishingly beautiful as it is technically dazzling, the *Space Station* DVD is the story of challenges, setbacks, and triumphs—and ultimately, the shared international victory of men and women whose dreams exceed the limits of life on this Earth.





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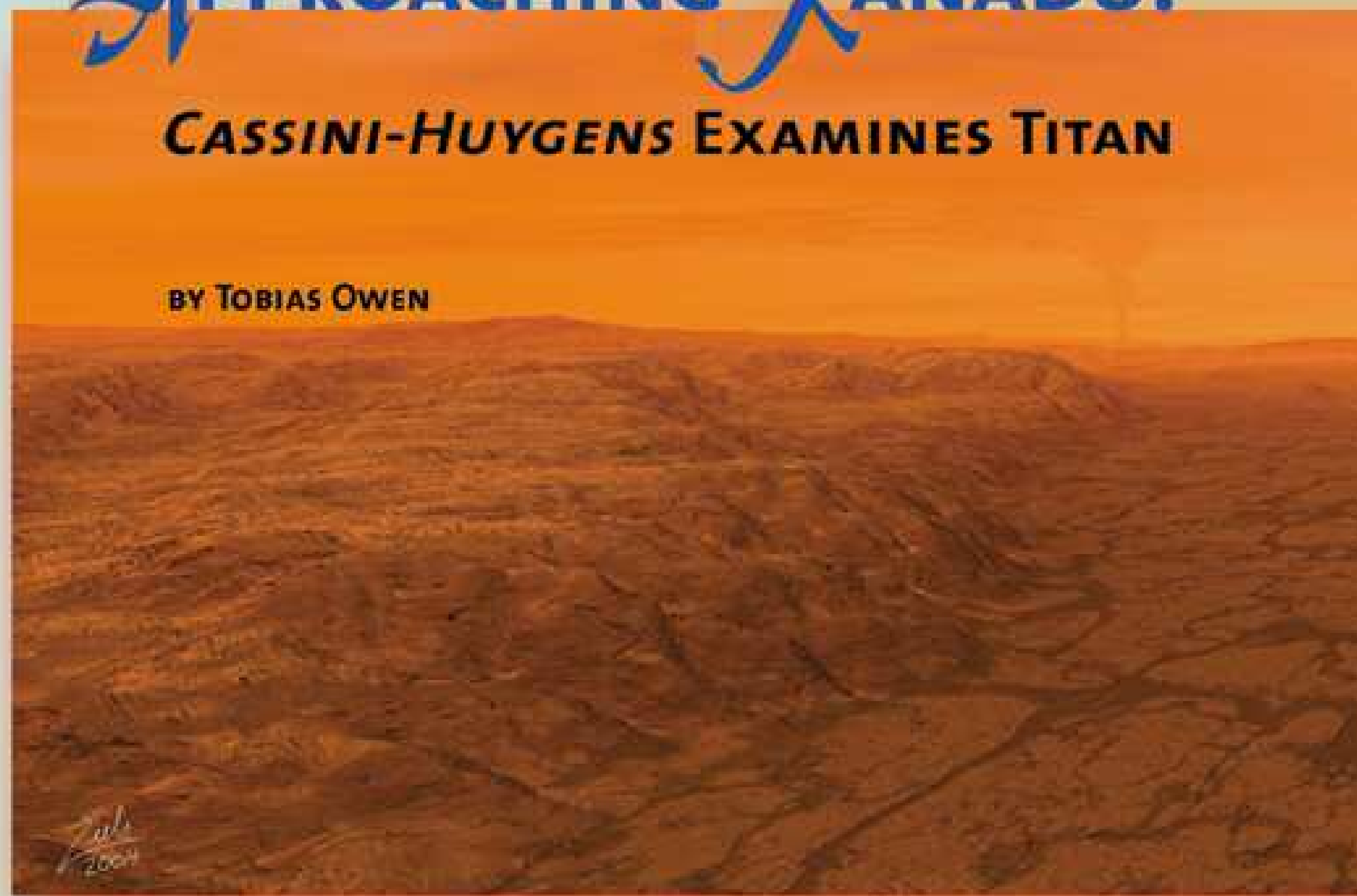
APPROACHING XANADU:

CASSINI-HUYGENS EXAMINES TITAN

BY TOBIAS OWEN



Like a frozen echo of the early Earth, Titan calls us to admire its marvels and decipher its secrets. The urge to answer this call and explore this mysterious moon was perhaps the strongest driving force behind the inception and development of the *Cassini-Huygens* mission. In our solar system, Titan is the only world besides our own with a thick atmosphere that is primarily nitrogen. It has the largest unexplored surface in the solar system and a vigorous, sunlight-driven atmospheric chemistry that is producing compounds that on Earth were the very early forerunners of life.

As a tourist destination, Titan offers the prospect of liquid methane raining from its skies and pooling on its surface. The extremely low temperature of that surface, 95 degrees Kelvin or minus 178 degrees Celsius, ensures that water must be frozen out so completely that there is no bountiful source of oxygen available to oxidize the methane or the plentiful hydrocarbons and nitriles in aerosols that must be drifting down from the upper atmosphere like manna from heaven. Rivers of methane might race through a landscape of solid ice that is overlain in places by drifts of accumulated aerosols. Thus, Titan is held in an ultra-deep freeze, allowing us a kind of cosmic time travel to a world forever trapped in the primitive stages of its evolution. Clearly we need to explore this fascinating place to find out exactly what was going on, and what it could teach us about the early days of our own planet.

Before we get carried away by a possible association with terrestrial biology, however, some important caveats are in order. Both the lack of liquid water and the concomitant inaccessibility of oxygen will prevent the origin of life as we know it at Titan's surface. But was there an early, warm epoch when liquid water was available? Could there, even now, be warmer regions, where the ice might melt deep below the crust? Some models for Titan's interior suggest there may be a global, subcrustal ocean of water mixed with ammonia (NH_3). Even without this, however, Titan offers us a giant natural laboratory in which we can test our ideas about the origin and early evolution of our own atmosphere and about some of the chemical reaction pathways that lead from simple molecules such as methane (CH_4) and nitrogen (N_2) to more complex species.

Probing for Answers

Exploring all these different aspects on Titan is obviously an enormous challenge, one that *Cassini-Huygens* was designed to meet. The orbiter, *Cassini*, carries several

The arrival of the Huygens *probe at Saturn's moon Titan in January 2005 was a major milestone in solving one of the solar system's great mysteries. Before* Huygens *landed, The Planetary Society held a contest, "Imagining Titan: Artists Peer Beneath the Veil," challenging artists to depict what sort of world* Huygens *would see beneath Titan's thick atmospheric cloak.* Cassini *scientists declared this illustration, submitted by David Ziels (adult category), to be the entry that most closely resembled what* Huygens *actually saw on the surface.*

instruments that can analyze both the atmosphere and surface, and the *Huygens* probe was specially designed to enter Titan's atmosphere, carry out experiments during its descent, and then—if luck was with us—return data from the satellite's surface.

We had been told by the project team not to plan on a soft landing for *Huygens*. That would have driven the cost too high. Instead, we were simply to take advantage of whatever opportunities the impact with the surface would provide, then hope for 3 minutes of data transmission. With this very much in mind, we included a package of instruments known as *landing science* in the probe's payload.

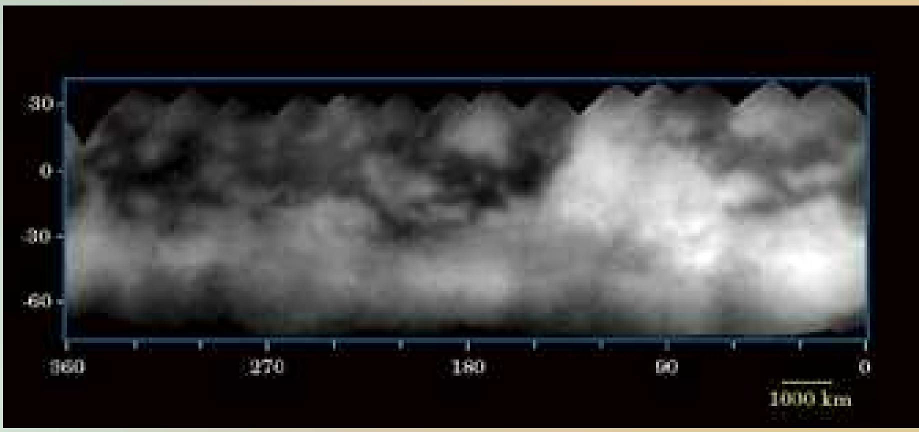
But would all these beautiful instruments get to Saturn safely and work when they got there? There is a saying in space exploration: "There are hundreds of ways for things to go wrong but only one way for everything to go right." For *Cassini-Huygens*, fortunately, everything went right. The launch was perfect, and injection into orbit around Saturn posed no problems, nor were there difficulties with the release of the probe, the probe entry, or its descent through the atmosphere. As the icing on the cake, *Huygens* transmitted data from Titan's surface for more than an hour!

The Results Come In

The eagerly awaited results came flowing in. Before *Huygens* reached it, Titan had been almost as baffling to the *Cassini* orbiter as it had been to ground-based telescopes. Working at infrared wavelengths with adaptive optics from the ground and using the infrared camera on the Hubble Space Telescope, Earth-based observers had been able to make out dark and light patches on Titan's surface vaguely reminiscent of the light and dark areas on our own Moon but without their underlying circularity. Knowing that methane and ethane (C_2H_6) could condense on Titan, several astronomers had suggested that the darker features might be seas of liquid hydrocarbons, following the logic of Galileo's assumption that the dark areas on the Moon were seas of water like those on Earth.

A large bright area that was bright at all wavelengths, including ground-based radar, was named "Xanadu," after the pleasure dome in Samuel Taylor Coleridge's poem "Kubla Khan." It was selected as a reference point for other features (see image on page 10).

The first images from *Cassini* didn't add much to this picture. Again we saw black-and-white regions, but they were not overprinted with the rich tapestry of impact craters found on other icy bodies in the outer solar system.



Murky scenes such as this, from Earth-based observations, were until recently our best views of Titan's mysterious features. This map of Titan's surface is composed of images taken by the 10-meter Keck II telescope on Hawaii's Mauna Kea. Bright, fascinating Xanadu is the whitish area to the right of the map. The contrast between dark and light areas has been enhanced.

Map: Courtesy M. E. Brown, California Institute of Technology

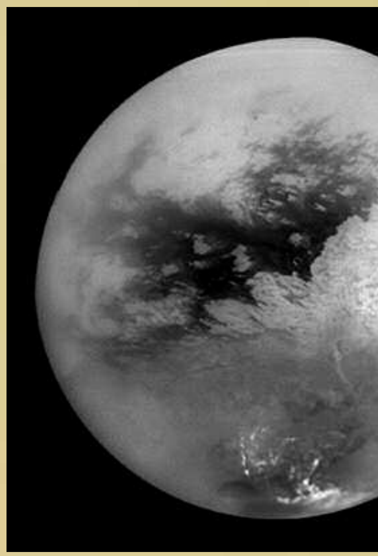
We could see one or two circular features but not the countless numbers found on Saturn's moon Rhea, Jupiter's Callisto, or the highlands on our own Moon. Evidently, some process on Titan is erasing the craters that are a normal feature of any small, airless, solid body's surface by covering them up and/or by tectonic and erosional processes.

Titan's Atmosphere

We also had some basic knowledge about Titan's atmosphere, thanks mainly to the *Voyager 1* flyby in 1980. We knew it was mostly nitrogen, with methane present at a few percent. White clouds appeared in some ground-based images, concentrated near the south pole.

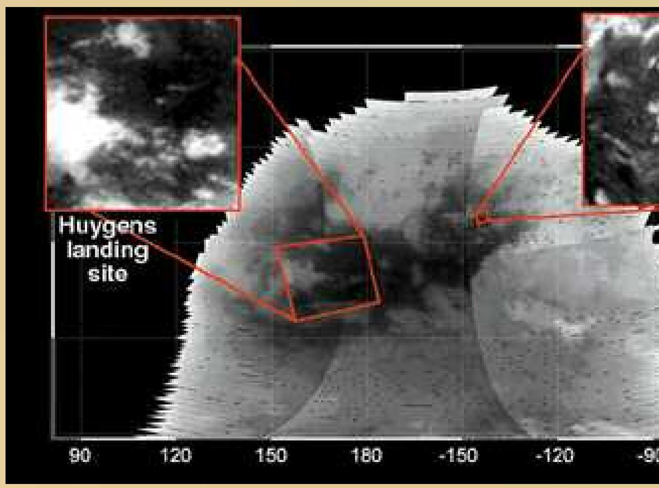
Cassini verified those clouds in its first close pass, but we are still puzzling over their origin. Presumably made of frozen methane, they may be concentrated over the pole right now because of maximum solar heating of the surface at this season. The heating would drive vertical convection in the atmosphere, leading to methane condensation that produces the clouds. Or they may be associated with surface features we have not yet identified, such as volcanoes, vents, or geysers gushing methane into the atmosphere. Further observations will help us here by revealing whether or not the clouds move northward as the seasons progress on Titan, following the track of maximum heating from the Sun. At the site of the probe's descent trajectory, methane is not supersaturated in Titan's atmosphere as some had thought, but it does become saturated (i.e., the local humidity becomes 100 percent) about 10 kilometers (6 miles) above the surface. The hazy clouds produced there add to the high-level hazes we'd already identified and increase the difficulty of getting a clear view of Titan's surface using remote sensing observations.

Perhaps the most interesting question about Titan's methane is its origin. The Sun-driven photochemistry that is producing all those fascinating compounds in the satellite's upper atmosphere is gradually destroying the methane. The present atmospheric complement will be gone in 10–20 million years—the blink of an eye, cosmically speaking. Either we happened to come along just as some huge, original supply of methane is about to disappear (which seems very unlikely), or there must



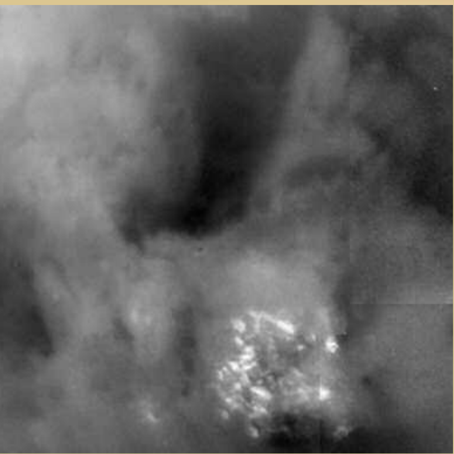
Early* Cassini *images of Titan revealed the moon's dark and light areas in somewhat better detail than ground-based observations but were still limited in the details—such as craters—that we are used to seeing on other icy worlds in the outer solar system. This view (taken in October 2004) is centered at approximately 160 degrees longitude in the map above.

Image: NASA/JPL/Space Science Institute

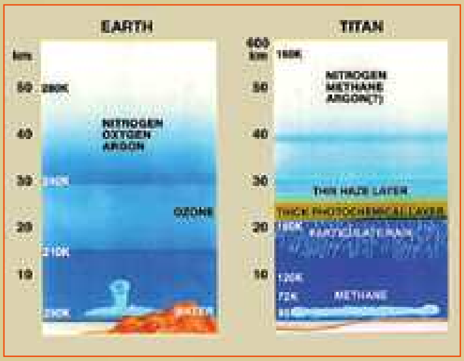


be a source to replenish it.

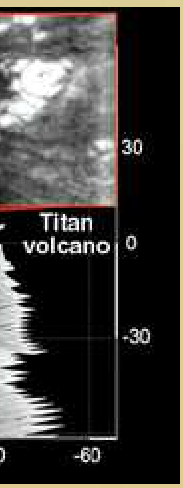
The *Huygens* mass spectrometer showed that the second alternative must be correct. Nitrogen and carbon atoms come in two stable forms, called *isotopes*, that have different atomic weights. Whereas the lighter nitrogen is depleted on Titan, indicating it has escaped from the atmosphere, this is not true of carbon, which shows only a small loss of the original amount of its lighter



This bright, rapidly changing cluster of methane storm clouds at Titan's south pole is about the size of Arizona. A year after Cassini *took this image (July 2, 2004), scientists are still trying to fathom the clouds' origin.* *Image: NASA/JPL/Space Science Institute*



Titan data gathered by Voyager 1 *made it possible to compare the atmospheric chemistry of Earth with what scientists believed to be present on Titan. We now know that Titan's atmosphere does indeed contain radiogenic argon and that its surface has been sculpted by flows of liquid methane.*
Illustration: NASA



No one is certain about what processes are responsible for replenishing Titan's methane atmosphere, but vulcanism is one possible answer. The right inset in the image shows a circular feature that scientists think is an ice volcano. The visual and infrared mapping spectrometer (VIMS) images in this montage of Titan's far side were taken during Cassini*'s October 26, 2004 flyby.*
Images: NASA/JPL/Space Science Institute

isotope. This means that the methane has not been in the atmosphere as long as the nitrogen has. Evidently, Titan's methane is being resupplied from the interior through some type of outgassing process.

The Source of Titan's Methane

We have independent evidence that outgassing has been going on from the detection of the argon isotope ^{40}Ar in Titan's atmosphere. About 1 percent of Earth's atmosphere consists of this isotope, which is a product of the decay of radioactive potassium in Earth's crust. In the case of Titan, we think that most of its rocky bits are deep inside the satellite, but some rocky material may have escaped being sequestered in the interior to be mixed with the icy mantle. In any event, ^{40}Ar must come from inside Titan and thus must find a way out. Methane could follow that same path.

Methane has gained considerable notoriety lately because it has been detected in tiny amounts on Mars, where it might indicate signs of life. Alternatively, the methane on Mars could be produced abiogenically through an entirely geologic process such as the following. First, hydrogen forms from the reaction of certain rocks with water through a process called *serpentinization*, and then this hydrogen can react with carbon dioxide (CO_2), or carbon monoxide (CO) or other carbon carriers, to make CH_4. This same process is an interesting contender for the source of methane on Titan.

Another idea is that the methane was originally captured by the accreting satellite in the form of clathrate hydrates, and clathrates are now floating at the top of an ocean beneath the crust, episodically releasing their methane to the atmosphere. These clathrate hydrates consist of cages of frozen water molecules that can contain guest molecules—in this case methane. Methane hydrates are familiar on Earth, where they appear in natural gas pipelines and at the bottom of Earth's oceans; the methane they contain is produced by bacteria.

Could Titan's methane be biogenic, produced by huge colonies of busy bacteria far below the satellite's surface? We think not. On Earth, biogenic methane is distinctly different from methane produced inorganically; the light isotope of carbon is enriched. This is a common feature of complex, multistep chemical reactions involving carbon, so we expect the same isotopic fractionation to occur in other carbon-dependent living systems. As already mentioned, there is no evidence of such an enrichment in Titan's methane. Of course, we can't rule out totally new forms of life that don't even depend on carbon. All we can say is we have no evidence for life, and given the ferociously low temperatures on Titan, we don't really expect any.

Atmospheric Surprises

But we did expect to find and study the heavy primordial noble gases—argon, krypton, and xenon—and here, Titan gave us a big surprise. In addition to ^{40}Ar, argon has two other stable isotopes, ^{36}Ar and ^{38}Ar. You are breathing tiny amounts of these right now, together with the stable isotopes of krypton and xenon. All these gases are primordial, in the sense that they were made in stars, released into the interstellar medium, and ultimately incorporated into meteorites and planets. They were not made on the planets, as is ^{40}Ar. Along the way to establishing their present concentrations, these gases, in their abundances, can be changed and their isotopic abundances can be rearranged. Interpreting the results of these changes can tell us about the histories of the atmospheres that contain these gases, so we were eager to investigate them on Titan.

Unfortunately, they just aren't there, or are present at less than 10 parts per billion. We have detected and studied these gases in the atmospheres of Venus, Earth, Mars, Jupiter, and the meteorites, so this was a major surprise. There are at least three possible explanations, proposed by different scientists, and they are not mutually exclusive. Perhaps the gases are there, but they are sequestered as clathrates at the bottom of the ammonia-water ocean. Or they are there, but they have been "scrubbed" out of the atmosphere by the downward-drifting aerosols. Or they were simply never captured in detectable amounts by the icy planetesimals that made Titan.

This last option also requires the methane to be formed on Titan, rather than delivered, because the planetesimals would not have captured this highly volatile gas either. If this scenario is correct, it has obvious implications for the Jupiter system: the Jovian subnebula would have been even warmer than the Saturn subnebula. Depending where the satellites actually formed, perhaps even ammonia was not captured. This is an arrestingly simple explanation for the absence of thick nitrogen atmospheres on Ganymede and Callisto, which have nearly the same mass and density as Titan.

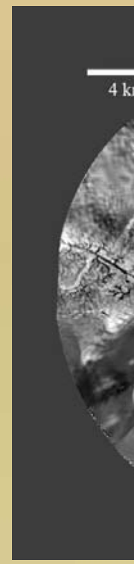
Titan's Landscape

Although our hopes of finding noble gases in Titan's atmosphere were not realized, the expectation that liquid hydrocarbons flow on the surface was richly fulfilled. *Huygens'* descent imager gave us irrefutable evidence that rivers of liquid methane course across Titan's icy surface. These pictures are probably the most exciting results from the mission so far.

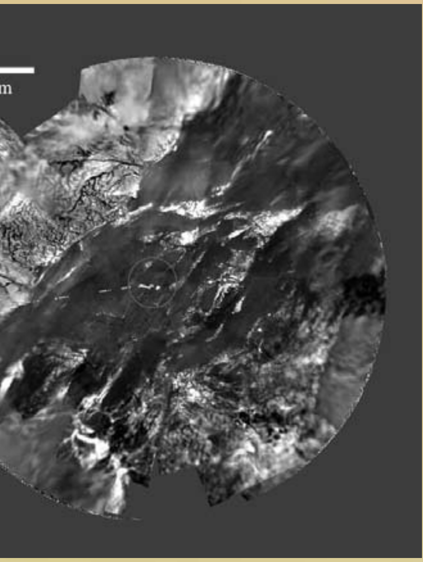
What many of us had thought might be a strange, alien landscape turns out to be surprisingly familiar. As the images came in, jokes circulated about whether we had actually landed in Southern California or maybe on Mars. On this particular part of Titan's surface, there was no evidence for the kind of highly eroded landscape much loved by space artists that provides the spectacular vistas of the American Southwest or the grandeur of the Himalayas. What that means, in turn, is that on this tiny fraction of Titan's surface, we've seen no evidence for plate tectonics, the forces that would cause the crust to buckle, creating the conditions for spectacular mountain ranges.

What we found is exciting enough. These familiar-looking streambeds are totally different from anything we have seen before. At a temperature near 95 degrees Kelvin, the bedrock is solid ice, and the stream itself is liquid natural gas—methane that is participating in a "hydrocarbiological" cycle of evaporation, precipitation, and runoff. This conclusion is not based solely on the thermal properties of these substances. After

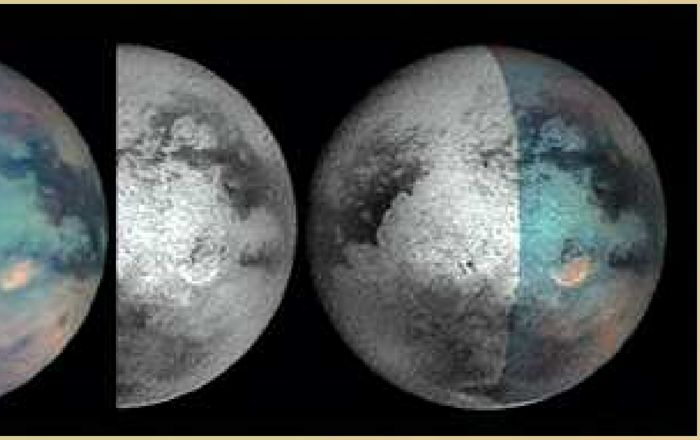
Did **Huygens** *make a pit stop at Mars on its way to Titan? No, but this view of Titan's surface has been colorized to look the way it would to our eyes if we were on Titan where the lander is positioned. Those "rocks" littering the landscape are actually blocks of fiercely cold water ice.*
Image: ESA/NASA/University of Arizona



This dark, footprint-shaped feature, about 234 by 73 kilometers (145 by 45 miles), might be a lake of liquid hydrocarbons—the condensation of methane and ethane expected to be on Titan's surface. Although scientists are not sure of this dark object's nature, the shorelike smoothness of its perimeter and its closeness to the south pole's methane storm clouds make it the best candidate so far for an open body of liquid on Titan. Image: NASA/JPL/Space Science Institute



This new mosaic, a product of the Descent Imager-Spectral Radiometer (DISR) on board Huygens, *shows the boundary between the light and dark terrain on Titan. The bright terrain has what appear to be many darker drainage channels that lead to the dark, flat lakebed in the center of the field. The dotted line marks* Huygens*' path as it descended toward the surface. Martin Tomasko, principal investigator of the DISR, was kind enough to let us use this brand-new mosaic. It will appear, with several others, in an article on Titan in an upcoming issue of* Nature.
Mosaic: ESA/NASA/University of Arizona



A fine example of Titan's many unsolved mysteries is an enigmatic bright spot to the southeast of Xanadu. This montage shows three views of the spot. At left, Cassini*'s VIMS shows it in red. The picture at center is from the spacecraft's imaging science subsystem (ISS), and a combination of both appears at right. The VIMS team detected the bright area after* Cassini*'s March 31, 2004 encounter. The bright, curved feature to the southeast of Xanadu in the center image was informally dubbed "The Smile" by* Cassini *scientists in December 2004. When placed together, these pictures show that The Smile cradles the southeastern edge of the infrared "Bright, Red Spot."*
Images: NASA/JPL/Space Science Institute

the *Huygens* probe landed, the mass spectrometer found that the local abundance of methane in the atmosphere at the ground suddenly increased by about 40 percent and held almost steady, declining slightly toward the end of the period of data transmission. It looks as if *Huygens* settled on or just above a wet region on Titan's surface, and the wetness was contributed by liquid methane.

What would it be like to stroll across the landscape near the probe on Titan? Unfortunately, there would be no gorgeous view of Saturn floating majestically in Titan's sky; it wouldn't even be possible to see the Sun through all that smog! Near where *Huygens* landed, the surface probably resembles a giant slab of ice with a thin layer of something like runny, highly diluted chocolate sauce on top. In some places, you'd see patches of methane "dew"; in others, you'd have to scramble over scattered boulders of ice. Where did those ice boulders come from? We can turn back to Coleridge's poem for inspiration:

And from this chasm . . .
A mighty fountain momently was forced . . .
Huge fragments vaulted like rebounding hail, . . .
And 'mid these dancing rocks at once and ever
It flung up momently the sacred river.

Perhaps the icy blocks were produced by the same, as yet unidentified process that renews the atmospheric methane. Could there be geysers of liquid natural gas? Or are these blocks the erosional products of the rivers, swept across the landscape by massive methane floods?

The surface near the *Huygens* landing site appears to consist of the dark material that is so obvious in remote views of Titan. It probably consists of accumulated drifts of aerosols that have rained down from the atmosphere—not chocolate sauce after all! Some of the white features seen in these dark surroundings appear to be accumulations of ice blocks that were moved to their present positions by flowing methane. These large dark areas probably are more like snowdrifts than hard rock. We are eager to see if we can detect changes in the outlines of the dark and light areas during the course of *Cassini*'s mission that are analogous to the wind-driven changes in surface markings observed on Mars.

This is just one of many fascinating observations that *Cassini* will carry out during the next four years (possibly six, if the mission is extended). In this short survey, I have said nothing about the radar images that will gradually build up a picture of Titan's surface through a series of dedicated passes. Even after four years, the radar will have sampled less than one third of the surface—so this by itself will be a great reason to keep *Cassini* operating: just to extend the radar coverage. We are still in the very early stages of the nominal mission, so even the cameras have showed us only a small fraction of what Titan has to offer. As we go to press, the Imaging Team has just reported a dark feature on the surface with a crisp, well-defined outline, approximately the same size and shape as Lake Ontario in the United States. It looks more like an actual lake of liquid methane than anything seen so far. Are there more lakes like this one? Even seas? Giant river systems? Mountains? Volcanoes? What is going on in bright, mysterious Xanadu? Stay tuned!

With Wing Ip and Daniel Gautier, Tobias Owen is one of the major architects of the Cassini-Huygens *mission. He is an interdisciplinary scientist and a member of the* Huygens *GCMS and ACP teams, as well as the* Cassini *CIRS team. He participated in the* Viking, Voyager, *and* Galileo *missions and also studies planets, satellites, and comets with the telescopes on Mauna Kea.*

We MUST Decide to Do It!

The Saga of Asteroid 2004MN4

by Rusty Schweickart

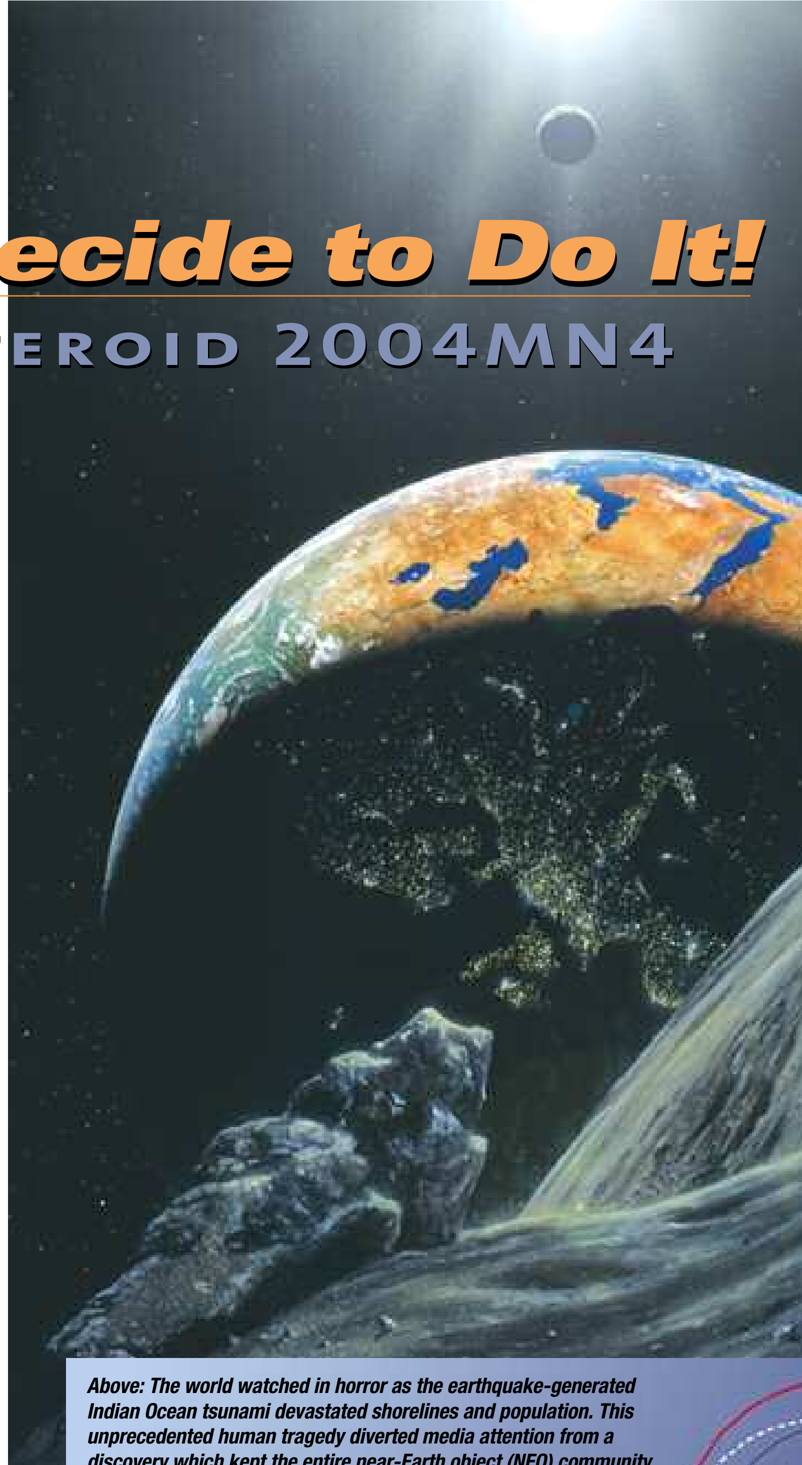
The year 2004 ended in an awful week. Most folks were involved in and looking forward to the holiday season, when suddenly it seemed that the world went out of kilter.

The main event occurred about 8 a.m. local time on December 26 (Boxing Day), as the India tectonic plate lurched farther under the Burma plate and Earth's crust off the northwest coast of Sumatra broke along a northwest-southeast line. The Burma plate jumped upward by about 10 meters. The magnitude 9.0 earthquake created a massive tsunami that ultimately killed more than 250,000 people, some as far as 8,500 kilometers (5,000 miles) away in South Africa. For the next 2 months, this huge human tragedy dominated the news.

But the coincidence of the holiday season and the Indian Ocean tsunami allowed another rare and potentially devastating event, developing at the same time, to go virtually unnoticed. This is the still-unfolding saga of near-Earth asteroid (NEA) 2004MN4.

In June 2004, using the Bok telescope at Kitt Peak, Arizona, Roy Tucker, David Tholen, and Fabrizio Bernardi discovered the asteroid, but weather and other circumstances made it impossible for others to confirm its existence. On December 19, Gordon Garradd of the Siding Spring Survey in Australia rediscovered the asteroid, which was designated 2004MN4. MN4, as it came to be called, made a particular splash within the scientific community even upon its initial acknowledgment as a potential Earth impactor, entering the list of potentially risky asteroids at a Torino level of 2, the highest risk rating ever assigned to an asteroid. (See JPL's Sentry impact risk table at *neo.jpl.nasa.gov/risks* and Torino scale explanation at *neo.jpl.nasa.gov/torino_scale.html*.)

The asteroid, initially thought to be about 500 meters in diameter (subsequently downsized to 400 and then 320 meters), was headed for the vicinity of Earth with an ominous encounter date of Friday, April 13, 2029. Based on observations up through December 23, 2004, it appeared that MN4 would most likely pass outside the orbit of the Moon, but the uncertainty about its orbit also included about a 1 in 300 possibility of an Earth impact.



Above: The world watched in horror as the earthquake-generated Indian Ocean tsunami devastated shorelines and population. This unprecedented human tragedy diverted media attention from a discovery which kept the entire near-Earth object (NEO) community abuzz. It appeared that a recently detected asteroid, designated 2004MN4, had a 1 in 37 probability of a collision with Earth in April 2029. In this painting, 2004MN4 speeds toward Earth.
Painting: Michael Carroll

Right: The orbital path and positions of asteroid 2004MN4 (dotted white line) and Earth (red line) on December 23, 2004. The asteroid is 14 million kilometers (9 million miles) away from Earth in this view. For several days the probability of an impact in 2029 continued to escalate. *Illustration: NASA, redrawn by B. S. Smith*

Increasing Risk, But Little Attention

By December 24, the entire NEO (near-Earth object) community was watching intently as additional tracking

information narrowed the uncertainty further. MN4 was determined to be coming even closer to Earth than previously thought. Indeed, the error ellipse (a range of predictions for the asteroid's orbit) had shrunk, and the probability of impact with the Earth had risen to 1 chance in 60, warranting a Torino scale rating of 4. Although the probability of MN4's missing Earth was more than 98 percent, this was nevertheless the most threatening potential impact situation that the NEO astronomers had ever seen—by far.

Those involved in the tracking and calculations were amazed that almost nothing about MN4 appeared in the press. This lack of publicity had its good side: in many prior cases, actual situations had been mischaracterized by much of the press, usually in the alarmist direction.

With excitement substituting for sleep, most of us NEO watchers attended closely to new calculations, watching on Christmas Day as the probability of Earth impact rose again, to 1 in 47. On the morning of Boxing Day, it rose yet again, to 1 in 37—about the same probability as rolling snake-eyes or boxcars (double 1s or double 6s) in dice. Still, very few in the general public were aware of this unusual risk, and the certain disaster of the Indian Ocean earthquake/tsunami drew attention even further from the possible disaster of an asteroid impact.

The probability of MN4 impacting Earth had risen to unprecedented levels, levels that most of us in the NEO community believed we would never see in our lifetimes. The combination of events that day gave a surreal sense that Mother Nature was bent on reminding us of just who is boss.

With a great sense of relief, tempered by a touch of disbelief, we NEO observers finally relaxed when JPL announced that Jeff Larsen and Anne Descour of the Spacewatch Observatory near Tucson, Arizona had discovered faint traces of MN4 on photographic plates taken in March 2004. Integrating these data with the more recent observations yielded a still smaller error ellipse, but in this case one that excluded Earth. Although it would come close to Earth, MN4 definitely would not hit us—at least not on April 13, 2029.

The Story Behind MN4

MN4 is a somewhat unusual NEA in that it spends most of its time inside Earth's orbit. This characteristic puts it in the class of Atens (as opposed to Apollos and Amors), which constitute only about 8 percent of the NEAs discovered. Furthermore, MN4 has an orbit quite similar to Earth's, moving from just outside Earth's orbit to just inside that of Venus, and taking 323 days to circle the Sun. One result of this somewhat Earth-like orbit is that for extended periods, due to glare from the Sun, Earth-based observers can see MN4 only near twilight and sometimes not at all, even though it is relatively close by.

Another, more subtle result of this situation is that for several years at a time, MN4 and Earth orbit the Sun relatively close to each other, but then for extended periods (6–7 years), the two are far enough apart that regardless of MN4's position with respect to the Sun, it's too far away to see with our telescopes. We are now about a year from beginning one of those extended periods when we will get little new information to further refine the orbit of MN4.

But we already know that it will miss us in 2029, so do we really care about its orbit? As a matter of fact, yes, we do.

Our best information indicates that in the fading twilight on April 13, 2029, Londoners will be able to see MN4 with their naked eyes. They will have to look just to the west of due south, about 45 degrees above the horizon, to catch this magnitude 3 object (about the same as a medium-brightness star) as it passes behind Earth, headed toward the just-set Sun. It will dim slightly over the next 40 minutes as it moves almost horizontally to the west, passing closest to Earth in the west-southwest at 21:40 local time. The asteroid will pass over London at less than one tenth the distance to the Moon and 4,000 miles inside the geostationary satellite orbit. There will doubtless be evening parties all across northern Europe celebrating this unique cosmic event.

What will be invisible to all of us on that evening is the 28-degree turn that MN4 will take as it whizzes past us. MN4 will end up in quite a different orbit on April 14 from what it had on April 12, shifting from an orbit 323 days long to one of about 428 days. Exactly what its new orbital period will be depends on precisely how far behind Earth it passes on April 13, and the result could, although it is highly unlikely, make all of the 2029 parties in Europe seem highly inappropriate.

If, by chance, MN4 passes by Earth so that its new orbit has a period of about 426.125 days, the asteroid and Earth will come back to the identical orbital positions in exactly seven years. MN4, however, will have taken precisely six orbits of the Sun to do so, while Earth took seven. In this situation, called a *resonance orbit*, two bodies orbit the

On December 27, 2004, NEO observers breathed a collective sigh of relief. Jeff Larsen and Anne Descour of the Spacewatch Observatory near Tucson, Arizona had found and measured very faint images of the asteroid on archival data dating back from March 2004. These observations enabled scientists to better understand 2004MN4's orbit and, thus, to rule out an impact for 2029. This diagram shows the most likely path (blue line) of 2004MN4 on April 13, 2029. Should the asteroid actually pass through a very small segment of the white line (Earth) just slightly farther out than the path shown here, it could return to hit Earth on April 13, 2036. The probability of this happening is currently about 1 chance in 12,000. Illustration: NASA, redrawn by B. S. Smith

Left: An earthquake isn't the only way to start a tsunami—an impact in the ocean would have a similar effect. This frame was captured from an animated simulation of an asteroid 400 meters in diameter striking in the Pacific Ocean at a velocity of 12.6 kilometers (almost 8 miles) per second. About 4 hours later, the California coastline would experience a series of tsunami waves up to about 17 meters (56 miles) high.

Animation still: Steven Ward, courtesy of the author

Sun in periods that are exact multiples (with low values) of each other.

That's all well and good, you may say—so let's plan some more parties. The big "if" in all this is the very low probability that the orbit of MN4 will end up not at 426.1250 days but, in fact, about 30 seconds shorter than that, or 426.1246 days. In that very specific and improbable instance, Earth and MN4 will do their 7/6 dance around the Sun, but instead of an exact repeat of the April 2029 party time, in this case, Earth and MN4 will come together on April 13, 2036 in a cosmic collision the likes of which happen here on Earth about once every 50,000 years. This narrow "window" through which MN4 could pass to bring about such a collision is called a *keyhole*—in this instance, the 7/6 keyhole. The likelihood that MN4 will pass through this keyhole is extremely low (about 1 chance in 12,000 at this writing), but it could happen, and the reason we have a program to discover and track near-Earth asteroids is to convert such statistical possibilities into measured certainties.

Is an event with a probability of occurrence of 1 in 12,000 worth spending any time or money on? Certainly not, if the consequence of the impact's occurring were negligible. However, in this instance, we're dealing with a substantial 320-meter object, and the most likely consequence of an impact, should one occur, is a tsunami following an impact in the Pacific Ocean. Based on models by Ward and Chesley, the economic cost of an impact tsunami such as would result from an MN4 impact would be about $400 billion, for infrastructure losses alone! Given this cost-probability ratio, it is well worth spending time and money to ensure that we don't suffer such an avoidable calamity.

What's Ahead for MN4?

So will MN4 pass through this keyhole, or won't it? The answer is that we don't know yet. Although we have been tracking this asteroid since early 2004 and we have more data on it than on most NEAs we've discovered, the data are not accurate enough yet to answer this question. Normally, with the optical tracking that we have on this asteroid, we could predict what will happen to it about 31 years in advance. But in this particular case, the very close pass by Earth in 2029 will dramatically amplify the small unknowns that currently exist in its orbit.

An obvious question is "When will we know what's going to happen?" Less obvious but more important questions are "When do we need to know, and will we know by that time?" We don't simply want to know if the asteroid is scheduled to hit us; we want to know far enough in advance that we can do something about it. More specifically, we will want to deflect it to prevent it from hitting us!

It may be news to most people that such an audacious thing is possible, but in fact we are just at the point of having technology that will allow us to deflect an asteroid heading toward a collision with Earth. To deflect an incoming asteroid, we need to know early enough that a deflection is needed, and we need a high-efficiency, low-thrust propulsion system to push on the asteroid and slightly modify its orbit. Specifically, we need a couple of decades of warning that an asteroid has our name on it, and we need a spacecraft that can dock with the asteroid and push on it with a couple of pounds of force, continuously, for a year or two.

The first requirement, in this instance, is partially met. We know that there is a possibility of impact with

The Planetary Society is sponsoring a B612 Foundation project to better communicate near-Earth object threats to the public. B612 is developing software that would automatically create maps and other visual information for possible Earth impacts, based upon the latest data available on potentially threatening objects. More information will be available on our website, planetary.org, *later this year.*

Unlike other natural disasters, we can predict an asteroid's collision with Earth decades ahead of time. One way to prevent this would be to dock a spacecraft, or space tug, with the asteroid and to apply gentle, continuous pressure for months—which would slightly alter its orbit. For such a process to work, we would need accurate warning of an impact a couple of decades ahead of time, as well as one to two years for the spacecraft to dock and do its work.

Illustration: Pat Rawlings, Science Applications International Corporation

2004MN4 in 2036, more than three decades away. In fact, we know, via the Spaceguard Survey (*impact.arc.nasa.gov*), that of the 3,400 near-Earth objects we've discovered so far, only 71 have any chance of hitting Earth in the next 100 years. More important still, we know that the probability of any one of those hitting us is extremely small, and we are tracking them and will have excellent early warning if additional data change those odds. Unfortunately, there are another 300,000 NEOs out there that we don't know anything about yet, and we need to increase our search capabilities so that we have a fighting chance to protect the planet.

Regarding the second requirement to protect Earth from asteroid impacts, we're not quite there yet, but we're getting close. The B612 Foundation (see *www.B612Foundation.org*) has been working on the challenge of deflecting asteroids from impact with Earth since 2001. We worked through what would be required, recommended a goal of demonstrating such a capability by 2015, and designed a preliminary mission to get the job done. (The demonstration mission that B612 proposes was introduced publicly in "The Asteroid Tugboat," published in *Scientific American* in November 2003.)

From 2002 through early 2005, NASA was developing exactly the propulsion and power technologies that would be required. These key technologies will be needed in any event to enable cost-effective access to deep space. Unfortunately, the Prometheus program, which was developing the key technology of nuclear electric propulsion (NEP), has recently been put on hold in order to focus on nuclear surface power for use on the lunar surface. This is regrettable because NEP appears to be the most effective technology, in most cases, for NEO deflection.

Returning to 2004MN4, the questions resolve to the following: "Will we know enough about MN4 early enough and accurately enough to deflect it using our best technology, if we need to?" The only way to answer this question is to make the assumption that MN4 will hit us in 2036 unless we do something about it, then figure out what we need to know and when, in order to prevent this calamity.

Unlike most natural disasters, asteroid impacts come in "sizes" up to and including extinction of some forms of life on Earth, as with the dinosaurs 65 million years ago. What's different here is that unlike virtually all other major natural disasters, we can predict asteroid impacts decades ahead, and we can prevent them. We're not talking about providing a bit of warning so folks can head for their cellars or the high ground, or about making low-interest loans available for reconstruction after the disaster—we're talking about prevention of the disaster itself.

We're just about there, but we need to keep our eye on the ball—or NEO, in this case. We should continue the development of NEP and use it to demonstrate to ourselves that we can deflect an asteroid. Without question, such a demonstration will teach us a great deal about the process and provide the public with confidence that life can indeed be protected from this natural cosmic hazard.

Good News and Bad News

If we assume that MN4 has our address and, without intervention, will deliver in 2036, will we be able to make this the first successful exercise in impact prevention? There's no question that very shortly after the 2029 parties are over, we'll know how close our return visitor will come in 2036, but unfortunately, we'll have much too little time left to do anything about it. Furthermore, the amount of energy that it would take to successfully deflect MN4 between 2029 and 2036 would exceed our capability by quite a large margin.

The good news, however, is that if we were to deflect MN4 prior to 2029, it would require very little energy to get the job done. In fact, deflecting MN4 (from a 2036 impact) prior to 2029 would require less than 0.01 percent (1 ten-thousandth) of the energy that it would take after 2029. This should (if we do our homework) be well within not only our NEP/tugboat capability but within the reach of some alternative deflection techniques as well.

There is no good news, however, without bad news . . . or so it seems. The reason that deflection would require so much less energy prior to 2029 than after is the amplification effect of swinging by Earth so closely at that time. The corollary of this is that, in order to know prior to 2029 that the asteroid will in fact collide with Earth in 2036, we have to have more accurate knowledge of its orbit than we normally would have—in fact, thousands of times greater accuracy.

Where does this leave us? Let's guess that we'll need to get to MN4 something like 4 or 5 years before 2029 to accomplish the deflection and that it could take us as much as 3 years to get there. Thus, we'll need to launch our tugboat deflection mission by about 2021. The space industry likely would need another 6 or 7 years to plan and put the mission together, so we're talking about committing to the mission by about 2014. Our big question has then worked its way to: "Will we know by 2014 whether or not MN4 will collide with Earth in 2036?"

At the moment, our best guess is that unless we do something special in terms of gathering and refining data, the answer to that is probably "no." It looks as though we'll have to determine the specific distance that MN4 will pass behind Earth in 2029 within an accuracy of about 600 meters to know for certain what our situation will be in 2036. But, one may ask, do we really have to know for certain? Well, no. A probability of impact of 1 chance in 10 or higher is likely adequate to justify a deflection decision.

However, in this instance, we know that using the best telescopes existing now, and allowing for inevitable uncertainties, we will be able to predict the probability of impact with MN4 to be no higher than about 1 in 150 by 2014, even if we're headed for a direct impact! Radar data that we hope to get in 2012 may help, but probably not enough to allow a clear choice. Would we launch a deflection mission if the chances were 149 out of 150 that the asteroid would miss us? Or even 39 out of 40? Not likely. So what do we do should this unlikely circumstance arise?

The unfortunate reality is that there is no one designated within our government to analyze this, or any similar situation. While we are just short of having the technology and knowledge available to protect Earth from this natural hazard, no is charged with the responsibility to provide such protection. In the current situation with MN4, there are critical decisions to be made, options to be evaluated, and actions to be taken. One of those choices is to gather much better information about where the asteroid is going soon enough to do something about it, if necessary. By launching a scientific mission to 2004MN4, we can do excellent and valuable science, and in addition, we can know whether or not we'll have to deflect the asteroid.

How's that? It turns out that if you want to know the orbit (trajectory) of something in space, the most accurate way to do so is to install a radio transponder on it. That's what we do with our spacecraft; it's what enables us to fly cheaply out to Saturn (or wherever) by doing the same orbit-altering trick that MN4 will do using Earth in 2029. We can make these very clever orbit-changing maneuvers, swinging by Venus and/or Earth on the way out to deep space, because we know precisely where the spacecraft is. The trick, then, is to place a radio transponder onto 2004MN4 in order to know with certainty, by 2014, whether the asteroid is going to be a pest in 2036.

Well, that's easy, right? Perhaps it would be if someone were in charge. And on that score there is now hope. The US House of Representatives has included language in NASA's 2006 appropriations bill requiring that it report back within 120 days after the president signs it into law with an assessment of what actions would be necessary to address the potential threat from asteroid and comet impacts. It is hoped that in response to this congressional request, NASA will, for the first time, look not only at discovering NEOs but also at what will be required in order to protect the planet from impacts. In that process, 2004MN4 should be addressed specifically. How will we deflect it if we need to? By when must the deflection decision be made? Will we have adequate information to make such a decision by that time? Is a scientific mission to 2004MN4 needed? Is such a mission prudent given the additional knowledge to be gained by the science and exploration equipment aboard? Finally, there is a federal agency charged to look at these questions. We hope this will be done with wide participation and input from interested parties who have been wrestling with these issues.

After all this, then, we come to the strange reality that the saga of 2004MN4 leads right back to today. There's not a thing in the world we could have done on December 26, 2004 to prevent the Indian Ocean tsunami from inundating the coastlines and communities around the Indian Ocean, even if we had known about it ahead of time. Similarly, we have no way of knowing about such earthquakes and tsunamis that lie ahead.

We *can* know, however, whether there is a far worse tragedy headed our way on April 13, 2036. Even more important, there is something we can do about it in the unlikely event that asteroid 2004MN4 has our name on it: we can prevent the collision. Not only can we do this in the instance of the saga of 2004MN4, but we also can, and should, do it for all near-Earth asteroids and for all time. The ball (finally) is now in NASA's court. We simply have to decide to do it.

Rusty Schweickart is a founder and chairman of the board of the B612 Foundation. He was a NASA astronaut from 1963 through 1987 and flew as lunar module pilot on the Apollo 9 *mission in 1963. Schweickart was also the assistant for science and technology to California Governor Jerry Brown in the late 1970s and later served as chairman of the California Energy Commission.*

World Watch

by Louis D. Friedman

Walk into a NASA meeting. Say "ITAR." Watch people dive under their chairs.

ITAR is the acronym for International Traffic in Arms Regulations. These regulations arise from US laws designed to prevent the export of American technology to potential enemies. Sometimes, those laws are interpreted narrowly and specifically; sometimes, they are enforced very broadly.

The Planetary Society is no stranger to ITAR: our organization is registered with the US State Department as an arms trafficker. That may surprise you. It sure surprises me; I have never held a gun in my life. But registering (at a pretty hefty annual cost) is a prerequisite to engaging in international cooperation in space.

A technical assistance agreement (TAA) is required for any substantive discussion of international space cooperation, and you can get a TAA only if you are a registered arms trafficker. Anything that is part of a space mission is considered "arms," no matter what its level of technology. If you want to discuss cooperating on solar sails, you need a TAA. If you want to provide solar sail material to the Russians (or even to the British), you need an export control license. These agreements and licenses take months or even a year to get, and they are reviewed by the Departments of State, Defense, and Commerce, as well as NASA and possibly other federal agencies—all of which ask questions.

This is why people dive under chairs: they are afraid of the process. It inhibits them from even considering international cooperation—which, to some politicians, is the whole point.

The Planetary Society is not inhibited. We have applied for and received about a dozen export control licenses and have a current TAA for our solar sail work. But when you work inside a bureaucracy, such as NASA or one of its contractors, the layers of management further inhibit you, because managers all must review and approve the mere act of considering applying for one of these licenses or agreements.

Thus, the European Space Agency is cooperating with Russia on Kliper, the planned human-piloted orbital transfer vehicle. Satellite manufacturers are paying more than they should for launches because they cannot take advantage of an international market. In fact, because US regulations may limit US participation, Russian space officials have suggested they take over prime responsibility and control of the International Space Station.

In the United States, future Mars missions and other new space ventures are being planned unilaterally. Today, because of ITAR, *Cassini-Huygens* probably would not be possible. Major robotic missions, such as a Europa orbiter/probe or a Mars sample return, may be thwarted by ITAR. With great fanfare, last year the NASA Exploration Office held a meeting with more than a dozen potential international partners. The current US exploration projects—the Crew Exploration Vehicle, lunar orbiter and landers, and Mars missions— are being pursued alone. All because of ITAR.

There is another law inhibiting space exploration, the Iran Non-Proliferation Act (INA). The goal is to punish those engaging in nuclear arms proliferation by not doing business with them. It is interpreted so broadly that, for example, if any aerospace industry in Russia is even suspected of proliferation, then specific injunctions are made against the Russian space agency, even if it is not suspected of such actions. Thus, US industry is prevented from using Russian rockets. Of course, this drives up the cost to US industry for launching, and, in the case of the International Space Station, it may leave the US at home while other countries occupy and use the station.

Since the loss of *Columbia*, Russian rockets have been the only way to reach the space station. It's not as well known that Russia has the only "lifeboat" or escape vehicle that astronauts and cosmonauts can use to leave the space station in the event of emergency. Such a lifeboat is a requirement for crews to occupy the station. So far, Russia has supplied these lifeboats as part of the original agreement establishing the International Space Station partnership. That agreement is about to expire, and now the US will have to purchase transportation services from the Russians. There is nothing wrong with that—it's cheaper than creating a US-only capability, and it has proved reliable over many years. The problem is that the INA prevents such purchases, which may limit US access to the International Space Station.

Although nonproliferation is a nonarguable goal, broadly interpreting the INA to endeavors that have nothing do with Iran or proliferation is considered by many to be a tool of US politicians wanting to restrict space to domestic industries.

The future of the International Space Station may hang on ITAR and INA. In fact, without international cooperation, the space station never would have been built. Now, NASA's new Vision for Space Exploration is suffering from tepid public support. Without international cooperation, there will not be enough support for new exploration ventures beyond Earth orbit.

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

Questions and Answers

There has been a flood of crater pictures—from Mars and [the moons of] Saturn—released lately, and I'm struck by the huge variation in the number of craters displaying central peaks. In some places there are almost none, and in others it seems that every crater has one. Because the impactors are likely similar, it must be differences in the targets that make the big difference.

What's the latest thinking on the factors influencing central peak formation?

—Dave Boyle,
Fox River Grove, Illinois

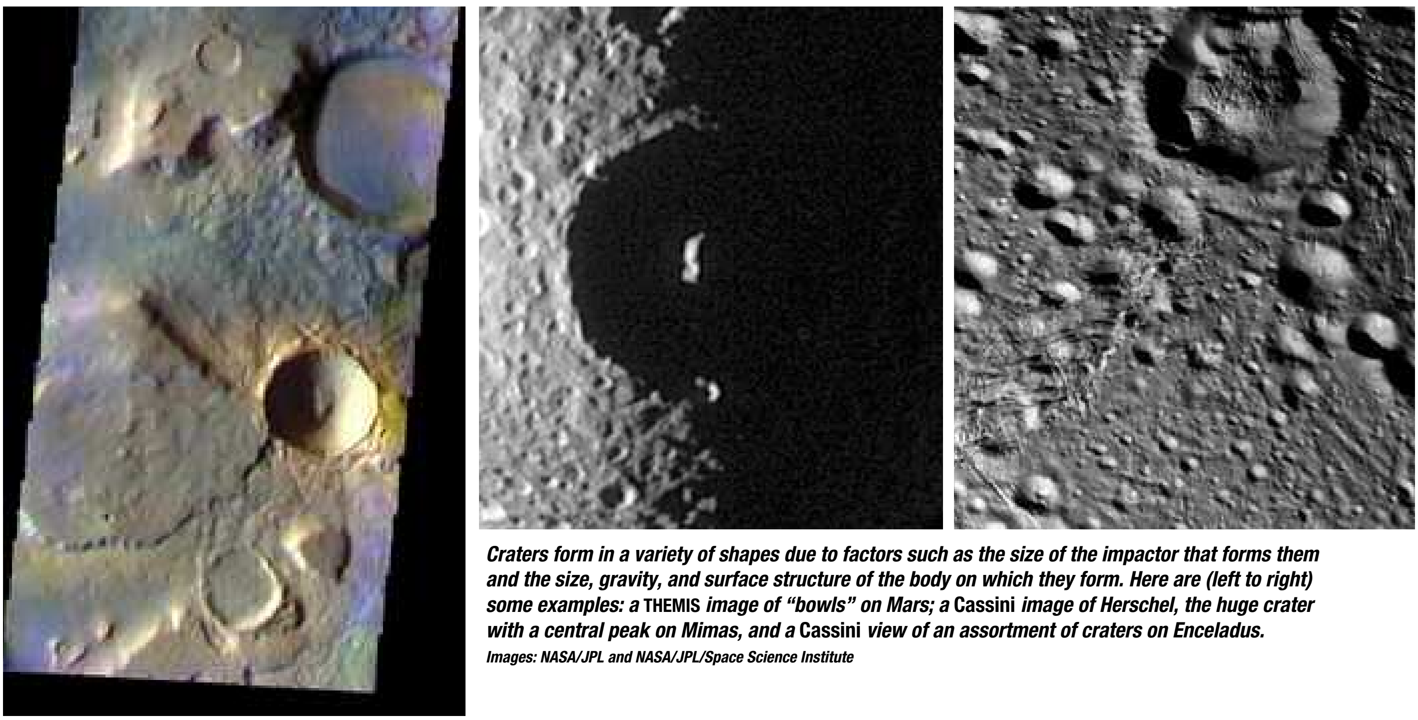
This is a good observation on your part. Perhaps the main influence, as we move from one target planet to another, is gravity. As a crater forms, a large transient cavity forms momentarily, which is bigger than the final crater. The walls of this cavity then slump back down and inward, and material wells up from the floor of the cavity to form the final crater. The walls of the cavity (weakened by impact stresses) can support only so much weight. For example, a 10-meter crater in a farmer's field can support the weight of the walls and does not slump or collapse very much. However, a crater 100 kilometers (60 miles) wide will undergo enormous modification as the transient cavity fills in.

As a result of these effects, on any single planet, there can be a variety of crater forms—from small to larger, simple bowl-shaped craters, craters with central peaks, craters in which the central peak broadens out into a ring of peaks, and finally, giant multiring basins (like Orientale on the Moon).

In answer to your question, the transition between crater forms occurs at larger sizes as the gravity of the body they are on decreases. On Earth, where gravity is strong, a crater only a few kilometers across may undergo wall collapse and floor uplift, then form a central peak. On the Moon, the crater's size would have to be more like 10 to 20 kilometers across for transition to occur. Most lunar craters below that size are bowls, and above that size they have peaks. On the small satellites of Saturn, the transition size is even larger—a striking example is the prominent crater on Mimas with its large central peak. On the smaller asteroids or Phobos, we see no central peaks at all—an impact large enough to create a crater with a central peak would smash the whole body!

Additional factors at play include, as you mentioned, target properties. For example, in the Moon's lava plains, there is a layer of gravelly regolith over solid basalt. Lunar craters about 100 meters across that tap into this solid layer often show a rubbly mound of debris in the centers of their floors, somewhat resembling a central peak (but not created in quite the same way).

—WILLIAM HARTMANN,
Planetary Science Institute



Craters form in a variety of shapes due to factors such as the size of the impactor that forms them and the size, gravity, and surface structure of the body on which they form. Here are (left to right) some examples: a* THEMIS *image of "bowls" on Mars; a* Cassini *image of Herschel, the huge crater with a central peak on Mimas, and a* Cassini *view of an assortment of craters on Enceladus.

Images: NASA/JPL and NASA/JPL/Space Science Institute

Factino

***As we went to press, the long-awaited encounter—and collision—of* Deep Impact *with comet Tempel 1 happened, in a spectacular way. We've devoted this page to a synopsis of the breaking story as it appeared on* planetary.org.**

After 172 days and 431 million kilometers (268 million miles) of deep space stalking, *Deep Impact* successfully reached out and touched comet Tempel 1. The collision between the coffee table–sized impactor and city-sized comet occurred on July 3, 2005 at 10:52 p.m. Pacific Daylight Time.

"Our cratering experiment went very, very well," reported impact scientist Peter Schultz of Brown University. A first look at early science results from the mission suggests that although some events unfolded according to scientists' predictions, Tempel 1 provided many enticing surprises as well.

The mission did not end with the demolition of the impactor spacecraft. Days after it slammed into the comet, the flyby spacecraft was still capturing so-called lookback images as it receded from Tempel 1.

At a press conference the next day, *Deep Impact* Project Manager Rick Grammier reported, "The team is very tired; however, they are very excited and feeling very proud at this moment. The flyby spacecraft is in good shape—all subsystems are green. Every iota of memory storage is totally full. It's still performing like a champ. We are working as fast as we can to get all the data downlinked and sent to the science team."

Two exhausted members of the science team, Michael A'Hearn of the University of Maryland and Peter Schultz, attempted to explain some of their preliminary impressions of the images and data. The most obvious conclusion that could be drawn from a first look at the returns is that the nucleus of the comet did not look like they expected it to, an elongated body similar to Comet Borelly. "You look at that nucleus, and obviously it does not look like a pickle or a cucumber. It looks closer to a muffin," said A'Hearn.

Schultz was clearly thrilled to have caught, in the moment after the impact, an incandescent flare. "At the moment of impact, you heat materials to extremely high temperatures. Some of that is heated vapor. Some of that is 'melt' droplets from within the crater itself. It is like a flashbulb—material that is glowing so brightly that it illuminates its own picture."

Following the flare, Schultz said, there was a delay before a plume of material could be seen exiting the impact point. The plume actually cast a shadow across the surface of the comet, a shadow that eventually will help the science team pin down the precise location of the impact crater.

Knowing the crater's size is important, of course, and both the science team and the public had a game going to guess how large the crater actually would be. "I think it's big," Schultz said. "I don't think it's house sized, I think it's bigger than that."

Deep Impact produced, and continues to produce, a rich trove of science data. Interpretation of that data will develop slowly over the next few weeks and months.

—Emily Lakdawalla, from *planetary.org*

This image shows comet Tempel 1's "muffin-shaped" nucleus. The impact took place near the bottom of the comet between two circular craterlike features.

Each portion of this eight-frame sequence of the impact is separated from the last by 50 milliseconds. The upper right frame shows the incandescent flare. The lower frames show the expanding ejecta curtain. The shadow of the narrow plume described by Peter Schultz appears as a gash crossing the left side of the comet's nucleus.

Images: NASA/JPL/Caltech/University of Maryland

Society News

Save the Date! "Our Next Age of Exploration"

The Planetary Society is turning 25. Please help us celebrate! Our gala Awards Dinner will usher in "Our Next Age of Exploration." Plan to join us in Los Angeles, California on Saturday, November 12, 2005 for an evening of fun, great food, and fascinating people.

We'll announce the winner of the Thomas Paine Award for the Advancement of Human Exploration of Mars, which has been awarded in years past to some of Earth's greatest explorers. This year, you'll witness the inauguration of a new award: the Cosmos Award for Public Presentation of Science.

Over the past 25 years, The Planetary Society has grown into Earth's largest space interest organization. Our international membership is a force in shaping space exploration.

This is what we'll celebrate at "Our Next Age of Exploration" Awards Dinner. As the date approaches, we'll be posting information on our website at *planetary.org* and also in *The Planetary Report*.

If you'd like to know about sponsorship opportunities, please contact Andrea Carroll at 626-793-5100, extension 214 or via e-mail at *andrea.carroll@planetary.org*.
—Andrea Carroll,
Director of Development

25 for Our 25th!

It's hard to believe we're more than halfway through our 25th anniversary year. What a year it has been! You've rushed to save crucial planetary missions, jumped in to help solve an intriguing mystery, and ridden the highs and lows of our own solar sail mission.

With a few short months to go as we head into our next age of exploration, I've asked Members for their ideas about how to make our anniversary year even more special. Here is what we came up with—25 for our 25th:

- Tell us, in 25 to 250 words, why you're a Member of The Planetary Society
- Give 25 gift memberships (or just one!)
- Introduce 25 people to The Planetary Society—send them to our website, give a presentation at a school or senior center, throw a planet party
- Volunteer at a Planetary Society event and sign up 25 people interested in receiving our electronic newsletter
- Give a gift—of $25, $250, $2,500, or $25,000—for a special project or Society "wish"
- Journey to Pasadena for The Planetary Society's 25th Anniversary Awards Dinner, "Our Next Age of Exploration," on Saturday, November 12, 2005.

Call me at 626-793-5100, extension 214, or e-mail me at *andrea.carroll@planetary.org* if you have questions about how to make any of these ideas happen. Please let me know, too, if you have another way you would like to mark this 25th anniversary year and help launch us into our next age of exploration. *—AC*

New Look for Our Website This Fall

As part of our 25th anniversary celebration, our website, *planetary.org*, is undergoing a complete redesign. For those who know and love our website, don't worry, all our great content will remain, but soon it will be easier to access and we'll have new features to show off.

Look for the new website this fall. If you haven't already checked out *planetary.org*, please do, then come back and explore more.
—Jennifer Vaughn,
Director of Publications

Marketplace

Show Off Your PLANETARY SOCIETY Spirit!

Nebula Poster
This awe-inspiring image from NASA's orbital Spitzer Space Telescope shows a false-color infrared view of nebula RCW 49—a birth-place 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*. 12" x 30" 1 lb.
#326 $10.00

We're Saving Space for You! Bumper Sticker
1 lb. **#695 $3.00**

Planetary Society Key Ring Medallion
This elegant key ring medallion features our Planetary Society logo—planet, rings, and sailing ship—etched in black on solid brass. 1 lb. **#677 $16.00**

Planetary Society Cap
The royal blue cap features our logo on the front and *planetary.org* on the back. 1 lb.
#673 $13.50

The Planetary Society License Plate Holder
Let your Planetary Society spirit travel with you on our members-only license plate holder.
1 lb. **#675 $5.25**

Planetary Society Lapel Pin
This striking pin is approximately 1 1/4 inches long, with a vibrant blue background and gold lettering. 1 lb. **#680 $3.00**

Explore the Planets
This poster is full of fascinating facts about our planetary neighbors. 34" x 22" 1 lb. **#310 $11.50**

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