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Hayabusa: The Falcon Flies

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From The Editor

At The Planetary Society, we don't like to leave a job unfinished. When that job is completing the initial reconnaissance of the solar system, we are particularly determined to see it through. In fact, we demanded that it be done, "it" being the launch of a spacecraft to Pluto, the last unexplored planet in our neighborhood. (If you want to debate whether Pluto deserves the title of planet, see our website, *planetary.org*.)

Now, *New Horizons* is on its way to explore Pluto and the icy worlds of the Kuiper belt beyond Neptune. This mission might never have launched without the dedicated and sustained efforts of Planetary Society members, who over and over again fought to keep this mission alive. At the prelaunch press conference, the mission's principal investigator, Alan Stern, publicly recognized our organization's unflagging support for *New Horizons*. That's unprecedented.

There is no more graphic demonstration of The Planetary Society's effectiveness than this. We can all be proud. Working together, our members truly made it happen.

So what next? Europa, Titan, even the Moon and Mars—think of all the unexplored territory out there. Will humanity reach out to these new worlds? You bet. The Planetary Society will make it happen.
—*Charlene M. Anderson*

On the Cover:

"If you build a high tower and climb it, you will see a new horizon," said Jun'ichiro Kawaguchi of the Japan Aerospace Exploration Agency's *Hayabusa* mission to asteroid Itokawa. *Hayabusa* (which means "falcon" in Japanese) has been beset with troubles in its mission to the near-Earth asteroid, but it has still returned remarkable images and has set the stage for future sample return missions. *Hayabusa* captured this image of Itokawa on October 22, 2005

Image: ISAS/JAXA

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Members' Dialogue

Our Names in Space

I agree fully with the "Members in Space" sidebar on page 9 of the November/ December 2005 issue of *The Planetary Report*. As a longtime member, I am proud of both the Society's active role in space exploration and my part in it. Not only am I proud, but I tell people about it regularly. No one I've talked to could say that they had their name on Mars as well as on other spacecraft doing important science throughout the solar system.

Having gone to school in the 1960s and watched all the *Mercury* and *Gemini* launches from the school cafeteria, I am incredibly disappointed in where we've gone—from a space-exploring nation landing men on the Moon, to almost 40 years later, being capable only of putting humans into low-Earth orbit in a very expensive and antique "taxi." After the Moon landings, I expected we'd have people on Mars in 10 to 20 years, but NASA failed me and many of my generation in shrinking back from its lofty achievements. With the exception of the Society and its programs, there has been little to be excited about for a very long time.

Keep up the good work, and I'll keep supporting it.

—ALEX COLE,
Nazareth, Pennsylvania

High Standards

I feel a comment is long overdue on the excellent standards of English used in *The Planetary Report*. Many of the other magazines, newspapers, and other publications that I read display an appalling grasp of spelling, grammar, and punctuation.

I have no time for those who insist that these things really don't matter, an attitude I often encountered while working for an organization deeply involved in the space industry. No wonder serious mistakes were made from time to time. *The Planetary Report* has always consistently used the highest standards in this respect, which seems to me to be so important for accurate communication, and essential in an engineering context. It reflects great credit on Charlene Anderson, as well as the complete editorial team, not to mention the contributors of the articles.

Well done, and thank you for the only publication I invariably read from cover to cover!

—ALAN TURK,
Swindon, Wiltshire,
United Kingdom

Articles on the Web

I am often tardy in reading my copies of *The Planetary Report* because I reserve my reading time to periods when I know that I will be solitary and uninterrupted.

I found the story by Rusty Schweickart on Asteroid 2004MN4 to be enthralling. [See the July/August 2005 issue of *The Planetary Report*.] I immediately began searching for opportunities to bring up this subject in my everyday conversations with friends and family.

Everyone I speak with about this topic has the same reaction: "There is an asteroid out there that will pass within the Moon's orbit of the Earth and I haven't heard about it? Are you sure about this? What if it had been destined to hit us, what would we have done?"

I am reluctant to loan my copy of *The Planetary Report* to too many people for fear that I may not have it returned. Is it likely that this article will eventually be published and available on your website for repeated future access?

Please keep publishing these sorts of everyday-science adventures. They are, in my view, very effective in relating how science in general is accomplished—one small step at a time, through the drudgery of attention to detail and checking and rechecking one's conclusions.

—PAUL WILSON,
Tallmadge, Ohio

Rusty Schweikart's article, "We Must Decide to Do It: The Saga of Asteroid 2004MN4," is now featured in the Near Earth Objects section of the Society's website at planetary.org/explore/topics/near_earth_objects. *Soon we will have past issues of* The Planetary Report *available in PDF format in our "For Members" section of the website.*
—Editor

Please send your letters to
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We Make It Happen!

by Bruce Betts

Gene Shoemaker Near-Earth Object Grants

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 near-Earth object (NEO) research. The purpose of the Shoemaker NEO Grant program is to increase follow-up and discovery of NEOs by providing seed funding to dedicated amateurs, observers in developing countries, and professional astronomers to greatly increase their programs.

Since founding the Shoemaker NEO Grant program, the Society has awarded grants to 22 recipients in countries around the globe. Our winners have 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: carefully measuring positions of recently discovered NEOs. It doesn't help to know a NEO is out there if you don't know whether or not it will hit the Earth.

The Envelope, Please

In 2005, we had 24 proposals from 12 countries. Here are the winners, in alphabetical order:

James W. Ashley of Minor Planet Research, Inc. (MPR) in Tucson, Arizona will receive a grant for equipment to be used as an integral part of MPR's Asteroid Discovery Station (ADS) education project. The ADS system uses both unreviewed and archival images from the Lowell Observatory Near-Earth Object Search program (LONEOS) to provide students with the unique opportunity to discover both main-belt and near-Earth asteroids.

Peter Birtwhistle will receive funding to enhance the ongoing NEO astrometric follow-up program at the Great Shefford Observatory in West Berkshire, England by upgrading an existing CCD camera. The upgrade will enable images from the camera to be transferred to its controlling PC at a rate about 20 times faster than currently possible. As a result, longer exposures will be achievable in a given elapsed time, permitting the detection of fainter NEOs.

David Higgins will receive funding to purchase a CCD camera and filter wheel. Higgins has a good observing site

What's Up?

In the Sky

Mars, orangish in the south after sunset, has faded and will continue to fade as Earth moves farther from it. Saturn is rising around sunset in the east below the bright stars Castor and Pollux. Jupiter is bright in the predawn sky in the south.

On March 29, there will be a total solar eclipse. The path of totality will begin in the Atlantic Ocean and move east through central Africa, Turkey, and central Asia, ending in central Russia. A partial eclipse will be visible throughout most of Africa, Europe, and Western Asia.

Random Space Fact

The *Stardust* Sample Return Capsule hit the atmosphere faster than any previous human-made object, going 28,860 miles per hour (12.9 kilometers per second). *Stardust* successfully landed in the Utah desert on January 15, 2006.

Trivia Contest

Our September/October contest winner is Dave Smith of Moline, Illinois. Congratulations!

The Question was: Who discovered Saturn's moon Titan?

The Answer: Dutch astronomer Christiaan Huygens.

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

What spacecraft left Earth at the highest speed?

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 April 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.*

north of Canberra, Australia, where he will concentrate on astrometric follow-up and light curve studies of NEOs.

Gianluca Masi will receive funding to repair and upgrade an 0.8-meter telescope that he uses for photometric observations of NEOs. Masi is a graduate student at the University of Rome working full-time on NEO observations.

Erich Meyer, Davidschlag, Austria, will receive funding to purchase a CCD camera with a large pixel array and extremely short readout time. The primary thrust of Meyer's observing program is to extend the observed orbital arcs of very faint newly discovered NEOs. The upgrade will extend his reach to even fainter objects.

A Look at Our Past Winners

Look what our past winners are accomplishing, in part due to their Shoemaker NEO Grants. As you'll see, their productivity is astounding.

John Broughton, eastern Australia: Following significant past discoveries, including a large NEO in 2004, the facility has been upgraded again, enabling much higher sky coverage per night. This has made possible various follow-up observations and a third NEO discovery during the last year.

David Dixon, New Mexico: According to a check of the Minor Planet Center list in 2005, only three professional observatories are credited with making a last observation more frequently than Dixon's Jornada Observatory, for NEOs discovered in 2003 or 2004.

Herman Mikuz, Slovenia: Using their 0.6-meter telescope, Mikuz and his colleagues at the Crni Vrh Observatory discovered an amazing five more NEOs since early 2004. They have made numerous upgrades of their system, including robotic use and all-sky observations that also capture many meteors and fireballs.

Jana Ticha, Czech Republic: From March 2002 to July 2005, the 1.06-meter KLENOT telescope at the Klet Observatory (finished in 2002 thanks to a Shoemaker NEO Grant) recorded a total of 9,750 astrometric positions of NEOs. Among them, more than 400 newly discovered near-Earth asteroids (NEAs) were confirmed using precise astrometric measurement, and 16 NEAs were recovered (found once again after being out of view or out of range for some period in their orbit).

Roy Tucker, Arizona: In 2004, he took more than 70,000 astrometric measurements of asteroids and discovered a comet. He also co-discovered what has now been named Apophis, an NEO that will have a flyby of Earth (closer than the Moon) in 2029.

For more information on past and present winners, including pictures and website links, go to *planetary.org/explore/topics/near_earth_objects*.

The Judges

Our proposal review committee consisted of some of the world's experts on NEOs, all of whom graciously volunteered their time! Thanks to Shoemaker NEO Grant Coordinator Daniel Durda, Southwest Research Institute; Alan Harris, Space Science Institute; Brian Marsden, Smithsonian Astrophysical Observatory; Petr Pravec, Ondrejov Observatory, Czech Republic; and Duncan Steel, Ball Aerospace-Australia. Thanks also to all of our members, who make this amazing program possible. The world gets enormous return on investment through this program.

Bruce Betts is director of projects at The Planetary Society.

HAYABUSA:

A DARING SAMPLE RETURN MISSION

by A.J.S. Rayl

Hayabusa (Japanese for "falcon") flies over its quarry, asteroid Itokawa, in this true-color illustration. Artwork: ISAS/JAXA

For less money than it took film director Peter Jackson to resurrect King Kong on the silver screen, the Japan Aerospace Exploration Agency (JAXA) has been staging a real Godzilla of a mission at a near-Earth asteroid with a spacecraft named *Hayabusa*.

Hayabusa—which means "falcon" in Japanese—is JAXA's ambitious mission to the near-Earth asteroid named Itokawa. It is the world's first spacecraft to attempt to land on an asteroid, collect samples, and return them to Earth, all on a budget the equivalent of about 170 million dollars.

Hayabusa is not a big mission. The spacecraft—which was developed at the Institute of Space and Astronautical Science (ISAS), now the space science research division of JAXA—weighed in at only 510 kilograms (1,124 pounds), far lighter than conventional spacecraft. Its onboard equipment, much of it miniaturized, was developed primarily from the collective technology of Japan.

ISAS/JAXA designed the mission to develop and test new technologies required for sample return missions, including a high-performance electric propulsion system, an autonomous navigation system that enables the spacecraft to approach a faraway asteroid without human guidance, a landing and sample-collecting system for a low-gravity environment, and a spacecraft/reentry capsule to return collected samples to Earth.

As the mission progressed, the small spacecraft with big goals suffered myriad problems, but the team's determination never swayed. "A determined, but relatively small, *Hayabusa* team has been working long hours to successfully adapt to some spacecraft anomalies, as well as an unexpectedly bizarre asteroid surface," said Donald K. Yeomans, senior research scientist at the Jet Propulsion Laboratory (JPL) and the US project scientist for the mission.

As *The Planetary Report* was going to press, *Hayabusa* was in trouble again. Unable to communicate with its robotic falcon, the project team redesigned the orbit to gain more time to save their bird, and on December 14, JAXA announced that the beginning of the return flight had been moved from December 2005 to spring 2007. The mission then shifted to a "rescue" phase, Jun'ichiro Kawaguchi, *Hayabusa* project manager, told *The Planetary Report*, with "the team still actively working to bring *Hayabusa* back to nominal operation in the near future." If *Hayabusa* can endure out there, some

180 million miles away, and if it does begin its return with the new exit strategy in 2007, it could arrive home in 2010.

Hayabusa's Evolution

Hayabusa began life as MUSES-C: for Mu Space Engineering Spacecraft, referring to the name of the Mu rocket, and C meaning it is the third in the MUSES series of spacecraft developed at ISAS to test new space technologies. The mission was first designed to target asteroid 4660 Nereus, with 10302 1989 ML as backup. It was to have carried a small NASA/JPL nanorover, with the planned sample return landing in Utah, but in late 2000, NASA backed out because of budget restrictions.

Japanese scientists and engineers on the project carried on and created a tiny hopping robot lander called MINERVA—short for MIcro/Nano Experimental Robot Vehicle for Asteroid—that would detach from *Hayabusa*, land on the asteroid, and survey it with miniature cameras and temperature gauges while leaping around the surface, using its own momentum by accelerating a weight inside itself.

The original launch date in July 2002 was delayed when an M-5 three-stage solid-fuel rocket, similar to that to be used for *Hayabusa*, failed to deliver Japan's Astro Ex-Ray Observatory into orbit. A new launch date meant that the original target (and backup target) would be beyond the mission's grasp. The team redesigned the mission and chose asteroid 1998 SF36 as its new destination. Later, the International Astronomical Union (IAU) bestowed that asteroid with its permanent name—Itokawa, after the late rocketeer Hideo Itokawa, father of Japan's space program.

On May 9, 2003, MUSES-C was launched by an M-V-5 rocket from what was then called the Kagoshima Space Center at Uchinoura (currently, Uchinoura Space Center) on Kyushu Island. Controllers described it as a picture-perfect launch. Once the spacecraft was successfully on its way, the Japanese christened it *Hayabusa*.

***Hayabusa*, which started out in life named MUSES-C, began its mission on May 9, 2003 with a perfect launch from Kagoshima Space Center (now called Uchinoura Space Center) at Uchinoura on Kyushu Island.** Photo: ISAS/JAXA

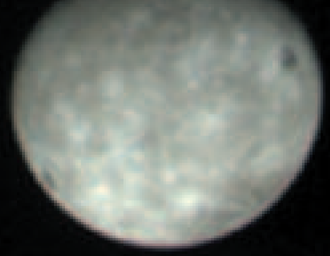
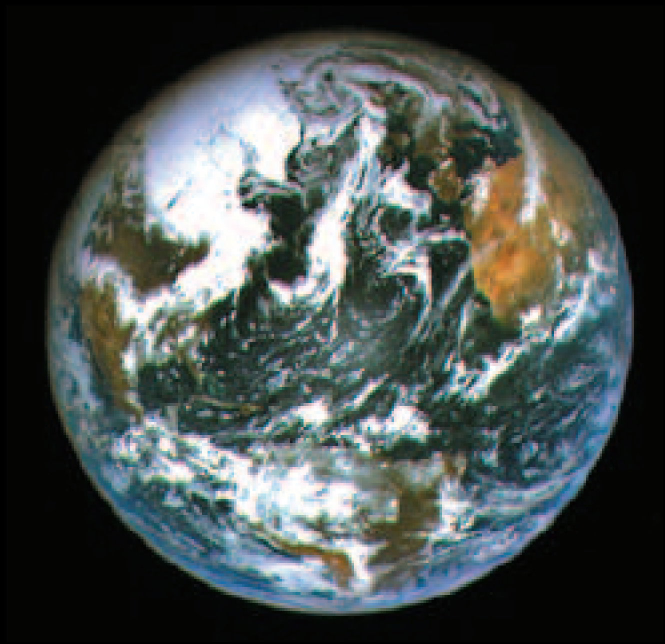
MINERVA (MIcro/Nano Experimental Robot Vehicle for Asteroid) is a tiny robot lander that was designed to hop around on Itokawa gathering data. Sadly, the Japanese cannot determine that MINERVA actually landed. Photo: ISAS/JAXA

Flight of the Falcon

Hayabusa's flight was smooth sailing in the beginning, but 6 months into the journey, in November 2003, the spacecraft encountered one of the biggest solar flares in recorded history. *Hayabusa* survived, though not unscathed. The spacecraft suffered some solar cell performance degradation that would delay its arrival at Itokawa. That would not be the last solar flare the mission would encounter.

Hayabusa flew by Earth for a gravity assist in May 2004, marking an important milestone for Japan and the world as it became the first spacecraft to perform a swingby maneuver using an ion engine as the main thruster. During the swingby, the spacecraft returned images of the Earth and Moon that seemed familiar from *Apollo*, and no less compelling.

On July 31, 2005, just 6 weeks or so before *Hayabusa*'s arrival at Itokawa, there was an incident on one of three reaction wheels that control the spacecraft's attitude and orientation. Project Manager Kawaguchi said the gyroscope had been experiencing increasing friction as it spun, to the point that it had to be shut down.

In May 2004, during *Hayabusa*'s unprecedented ion engine–thrusted swingby of the Earth/Moon system, it took pictures. The spacecraft captured these portraits of home on May 18, 2004 and the Moon on May 17, 2004. Images: ISAS/JAXA

Because the spacecraft was designed to function with the two remaining reaction wheels, it resumed attitude without a problem.

Finally, after traveling on a looping, one-billion-mile journey and surviving another solar flare on September 2, *Hayabusa* pulled up to Itokawa around 10:00 a.m. Japan Standard Time (JST; 1:00 a.m. Greenwich Mean Time) on September 12. The spacecraft promptly settled into a heliocentric "parking" orbit at about 20 kilometers (12 miles). Then, 3 days later, the spacecraft was jolted again by another solar flare. Again, it came through with no apparent significant damage.

Planning the Descent

Hayabusa's arrival at Itokawa was just the beginning of its mission. Following a short celebration, the team began testing and calibrating instruments to study Itokawa as equipment imaged it and to figure out where *Hayabusa* should land. The spacecraft is equipped with four scientific instruments to gather the topographical data needed: a visible imager with multiband filters called the Asteroid Multiband Imaging Camera (AMICA), a Near-Infrared Spectrometer (NIRS) to take spectral measurements, a Light Detection and Ranging (LIDAR), and an X-Ray Spectrometer (XRS). It also has high-performance navigation cameras.

The new "on-site" measurements showed Itokawa to measure 540 x 310 x 250 meters, and the team discovered that the asteroid is somewhat different from what they had assumed based on optical and radar data collected from the ground. Although it is ellipsoid, the asteroid appears "like two bodies united with each other," as if fused together, Kawaguchi explained. Moreover, he added, "there are very few craters on the surface and many boulders and rocks." Everyone expected more flat plains areas.

With these new data, the upcoming landing looked like it could be a very bumpy ride. The team homed in on the largest flat area on the asteroid, which lies near the midsection and was dubbed the MUSES Sea, and another area at the tip end of Itokawa where the terrain is broad and flat, which they called the Woomera Desert, after the place where the sample was slated to return to Earth.

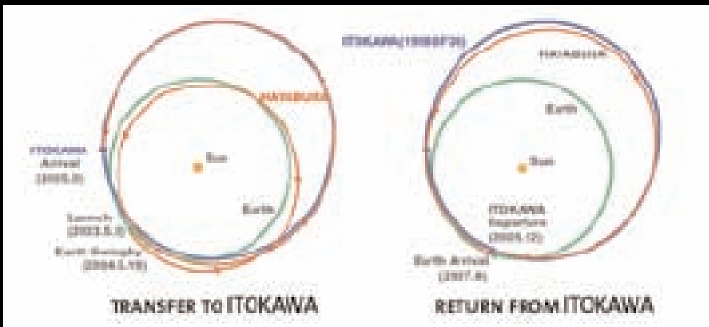
The surface gravity of the asteroid is estimated to be less than 1/100,000 of Earth's, so *Hayabusa*'s soft touch-downs would be more like dockings. "The descent to an asteroid is really a very sophisticated and challenging maneuver," noted Bruce Murray, cofounder of The Planetary Society and former director of JPL. "These kinds of landings must be very slow, highly controlled, and precisely aimed." The Japanese had to rely on autonomous guidance and navigation to get the job done because the delay from ground command to the spacecraft is about 17 minutes one way.

At the center of *Hayabusa*'s autonomy are the Optical Navigation Camera and four Laser Range Finder (LRF) instruments, which measure the distance to the asteroid and the shapes of the surface. Although the flight team at mission control in the Sagamihara Deep Space room could not maneuver the spacecraft in real time, they could send an order to stop a descent or a maneuver should that be deemed necessary.

Before *Hayabusa* went for the first rehearsal descent, the mission encountered more problems: the loss of the second of its three reaction wheels used to maintain attitude and orientation of the spacecraft. The mission control team in Sagamihara quickly verified that the malfunctioning of two attitude control wheels would not affect *Hayabusa*'s sampling activities. They would utilize the one reaction wheel left and rely on a system of hydrazine rockets (thrusters) to keep the spacecraft steady.

In early November, the team guided *Hayabusa* through two rehearsals for the touch-downs. The first, on November 3, was scrubbed when the flight team detected "an anomalous signal" at the critical go/no-go time point. The second, on November 12, was deemed a success, although it failed to deliver MINERVA to the surface.

Hayabusa had not received all the necessary information at the right time from its instruments, and as a



These orbital charts show the original mission plan, with arrival and departure dates, for *Hayabusa*. Because of mechanical problems and solar flares, the spacecraft would not arrive until September 2, 2005. Under JAXA's new schedule, *Hayabusa* will leave the asteroid in 2007 and return to Earth in 2010. Diagrams: ISAS/JAXA

In this view of the south pole, taken in late October 2005, Itokawa resembles a bumpy fortune cookie—a little different from the smoother-surfaced ellipsoid scientists predicted. Image: ISAS/JAXA

result, "MINERVA was released with the ascent velocity slightly higher than escape velocity," Kawaguchi explained, adding that the mission control team had no "definite evidence" that MINERVA hit the surface. Although MINERVA was errantly flying around and unable to carry out its duties on the asteroid, the team was able to communicate with the robot lander after its release. Moreover, "the MINERVA camera photographed *Hayabusa* as it separated," and the *Hayabusa* camera captured MINERVA flying away.

Sample Collection

Because no one really knows exactly what an asteroid is made of, there was no way of knowing just how difficult the collection of surface dust would be. The Japanese decided to employ a simple, direct strategy—breaking the surface by using a tiny pyrotechnic device to fire tantalum pellets or bullets into the asteroid. Yeomans explained, "the way it works is that *Hayabusa* descends to the surface very slowly, at about one-tenth of a meter per second, and as soon as the front end of the sample collection device—which looks like a stubby megaphone—touches the surface, a pyrotechnic discharge fires a tantalum pellet through the center of the device and into the surface at three hundred meters per second." The device then takes up the ejecta that should rise after the pellet penetrates the surface.

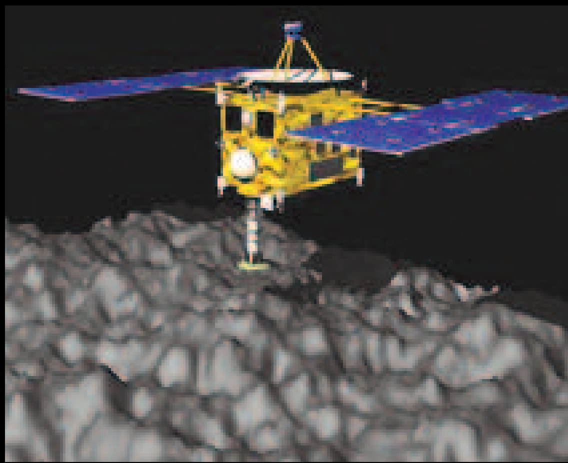
On November 19, *Hayabusa* headed in for the MUSES Sea area. As the spacecraft descended, its autonomous guidance and navigation system measured the relative position and attitude to the asteroid's surface, then used its rocket system to adjust its position.

As *Hayabusa* continued downward, the calendar flipped over to a new day. Prior to the touch-down maneuver that morning of November 20, the spacecraft shut down the rockets and entered into a free-fall descent so the jets wouldn't contaminate the asteroid surface. At about 40 meters altitude from the asteroid, the spacecraft released a target marker—a softball-sized ball—onto the asteroid. Tucked inside the target marker, now embedded in Itokawa, is an aluminum foil sheet engraved with 880,000 names of people from 149 countries gathered by The Planetary Society of Japan.

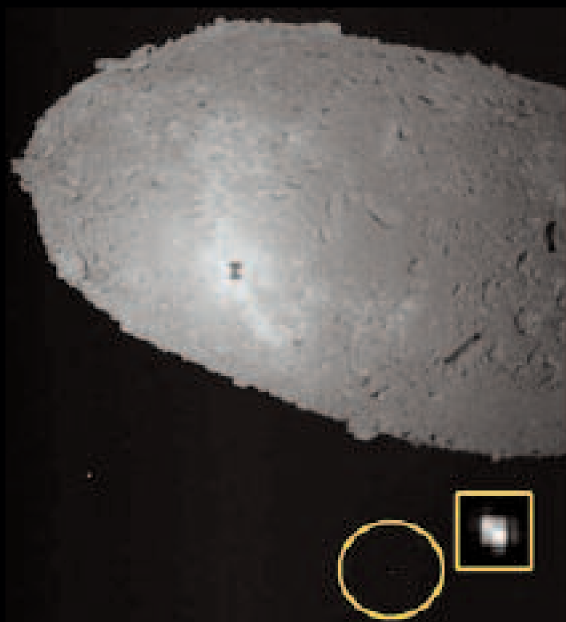
Once the *Hayabusa* team realized that landing on the rocky surface would be difficult, they set their sights on the MUSES Sea, the large, smooth area near Itokawa's midsection. They also looked at a broad, flat area near the asteroid's tip that they called the Woomera Desert, after the Australian landing site planned for *Hayabusa*'s return home. Image: ISAS/JAXA

Hayabusa transmitted a flash beam toward the target marker on the surface, and the target marker reflected as it was designed to do. Everything was going more or less like clockwork . . . when the ground team lost communication with the spacecraft.

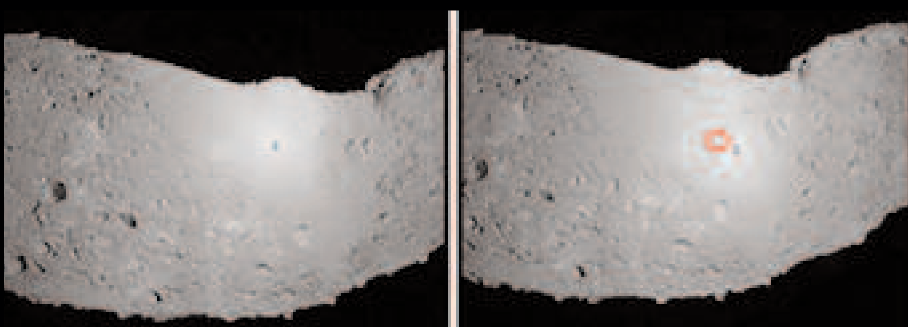
Some minutes later, sensors began displaying an increase in temperature, and the *Hayabusa* team commanded the spacecraft—which, unbeknown to them, was actually sitting on the surface of the asteroid—to abort the sample collection and fly away from the asteroid. It responded to the command and took off, flying out more than 100 kilometers (60 miles) and staying there until the team regained control and lured it back to its orbit. It had not collected a sample.



***Hayabusa*'s cone-shaped sample collection device is positioned on the outside of the spacecraft. It was designed so that when *Hayabusa* touched down and the cone encountered Itokawa's surface, a pellet would be fired into the surface at 300 meters per second, and the cone would capture and collect any ejecta thrown up by the impact.**
Illustration: Kazuya Yoshida, Space Robotics Laboratory, Tohoku University



On November 12, 2005, *Hayabusa* photographed the MINERVA lander (the white dot inside the yellow circle—which is blown up inside the yellow square) and asteroid Itokawa. MINERVA was deployed and activated successfully, but it failed to land on the asteroid. *Hayabusa* imaged its own hourglass-shaped shadow on Itokawa's surface.
Image: ISAS/JAXA



On November 20, 2005, *Hayabusa* dropped a softball-sized ball onto the surface of Itokawa. Embedded in the ball was a foil sheet engraved with the names of 880,000 people from 149 countries gathered by The Planetary Society of Japan. The region called MUSES Sea is shown at the center of the image at left, taken November 20. The view at right, taken 6 days later, shows the target marker as a white dot inside the red circle. Image: ISAS/JAXA

A Second Chance

The team spent the ensuing 6 days analyzing data and preparing to go for the second touch-down landing and sample collection. On November 25, *Hayabusa* started its last descent phase, with a command from Earth around 10:00 p.m. JST. By the wee hours of the following morning, Saturday, November 26, *Hayabusa* once more began the vertical descent to the MUSES Sea.

Just 35 meters above the asteroid, the spacecraft switched from its LIDAR instrument to the Laser Range Finders as programmed. Around 6:24 a.m., *Hayabusa* snapped some impressive images of the MUSES Sea that clearly showed a tiny glow that was the target marker containing the 880,000 names.

Hayabusa got to only 14 meters above the asteroid at about 7:00 a.m., and communication between the control room and *Hayabusa* switched from telemetry transmission to beacon mode. At 7:04 a.m., the LRF instrument showed that it had switched from range finding to sample control mode, and *Hayabusa* moved in for its prey. Early data returns indicated that the sample collection device fired as designed, and the mission control room erupted in cheers and shouts. The joy would not be sustained.

Minutes later, as *Hayabusa* was ascending from Itokawa, its redundant rocket system—on which it was relying for attitude—sprang a leak in one subsystem. The team scrambled to shut off the fuel valves, and the leak was stopped. Later, as team members were trying to restore the spacecraft, they discovered that the other subsystem had lost thrust—perhaps, they speculated, because the fuel lines had frozen.

The team managed to regain control and communication, but their efforts to get their falcon out of safe mode and to fire up its rockets did not go well. Early in December, the team initiated a new emergency strategy of replacing the rocket system by programming a new attitude control using a method of jetting out the xenon gas used for the ion engine operation and for conducting a test control for spin rate. It worked, and communication between the ground team and *Hayabusa* continued for another 3 days.

On December 8, when *Hayabusa* should have been preparing to head home, the spacecraft suffered a "torque disturbance" that the team believes was caused by the outgassing of fuel vapor generated by the evaporation of leaked propellant. Control capability using the xenon gas thruster control strategy was not strong enough for the spacecraft to withstand that disturbance, and thus

Hayabusa was thrown out of its attitude and out of position for any ground communication. With its departure window closing, the team went about redesigning the orbit—the only option if they wanted to get *Hayabusa* home.

At the same time, the team discovered from the latest data returns that it may not have gotten a sample after all: the pyrotechnics control device data show no evidence that the pellets or bullets fired. Team members are doing a detailed inspection of the sequence and command log.

Still a Success

If *Hayabusa* is restored, the plan calls for the spacecraft to send a small reentry capsule back to Earth in June 2010. Even if JAXA cannot restore the spacecraft, the mission still accomplished some of its primary objectives.

Hayabusa succeeded in demonstrating a high-performance electric or ion propulsion system. At the time of arrival at Itokawa, *Hayabusa* had driven its proprietary ion engines for 26,000 hours in interplanetary cruise, including the Earth flyby. Although NASA's *Deep Space 1* holds the distinction of being the first interplanetary spacecraft to use ion drive, *Hayabusa* is the first to use microwaves to ionize xenon fuel and the first Japanese craft to employ the technology.

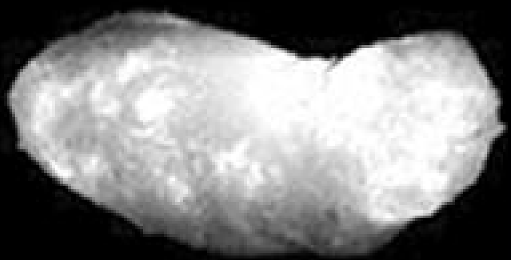
The mission also demonstrated its hybrid autonomous navigation and guidance system, and the team members gained hands-on experience with the landing and collection system for surface samples in an ultra-low-gravity environment. It remains to be seen if they will be able to test the spacecraft/reentry capsule system designed to return the sample.

Technology aside, "the mission has returned some valuable science data," said Yeomans. During the science phases at Itokawa, *Hayabusa*'s AMICA exposed 1,500 images, amounting to almost 1 gigabit of data; NIRS took some 109,000 measurements distributed globally over the asteroid; LIDAR accumulated 1.7 million measurements; and XRS received and integrated its signal for 700 hours.

"We attempted the first sample return in this world," Kawaguchi told reporters at the press conference last December. "Space development in the past was nervously carrying out projects with a solid chance of success under close watch [of] the mass media. But we think it is also necessary to take risks and go forward for space development to progress. If you build a high tower and climb it, you will see a new horizon. *Hayabusa* has inspired the morale toward building such a tower on our own," he said.

Meanwhile, *Hayabusa* is out there, somewhere. It is, as Kawaguchi put it, "full of wounds." He and his team know how difficult the prospects are for getting the robotic falcon home. "Yet, if there is any chance," Kawaguchi said, "we have a will to give it a try."

No matter what happens, the American and Australian scientists on the *Hayabusa* science team are looking forward to further cooperative missions with their Japanese colleagues, Yeomans said. "They showed just how far a determined, tight-knit group can go with a low-budget mission. They did it under the critical eye of the public and media that often expects complete success from even the most ambitious space explorations. But interplanetary space is an unforgiving environment, and Earth's neighbors in space will give up their secrets only to those who persist in the face of very long odds—to those explorers whose reach exceeds their grasp. Flying in formation and touching down upon one of Earth's closest neighbors is a first-rate space achievement and surely ushers Japan into the small cadre of premier spacefaring nations."



In late October, *Hayabusa*, passing directly between Itokawa and the Sun, photographed a phenomenon called the *opposition surge*, the extreme brightening of an object (in this case, on Itokawa) due to its direct alignment with the Sun. Image: ISAS/JAXA

This view of Itokawa (and *Hayabusa*'s shadow) was taken on November 12, 2005. Image: ISAS/JAXA

A.J.S. Rayl is a writer and editor for The Planetary Society's website, planetary.org. *You can read her continuing coverage of the* Hayabusa *mission at* planetary.org/explore/topics/hayabusa.

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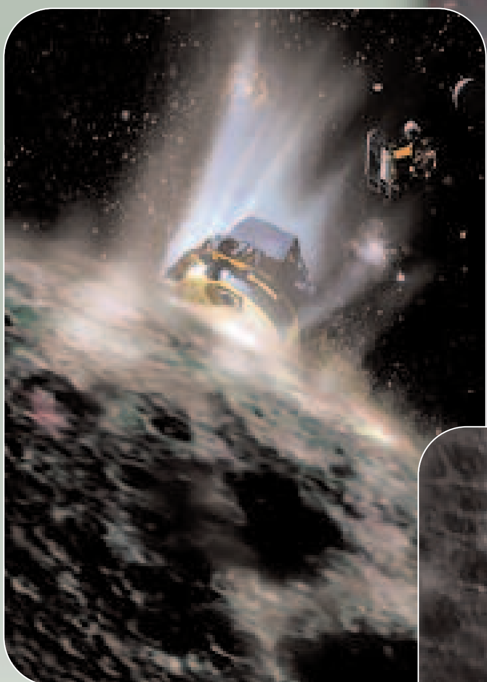

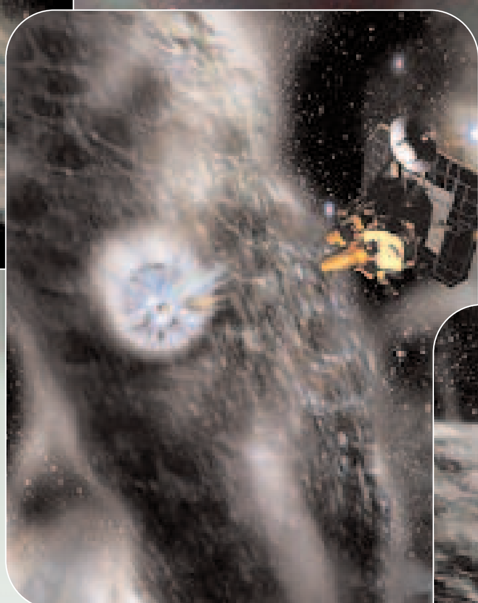

Above, top to bottom: Deep Impact*'s flyby spacecraft catches the action as the impactor strikes its target, cratering the surface and throwing up a plume of ejecta that will tell us about the oldest and coldest particles of our solar system. The flyby spacecraft had 13 minutes to record the event and its aftermath.* Illustrations: Ball Aerospace Corporation

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EEP IMPACT:

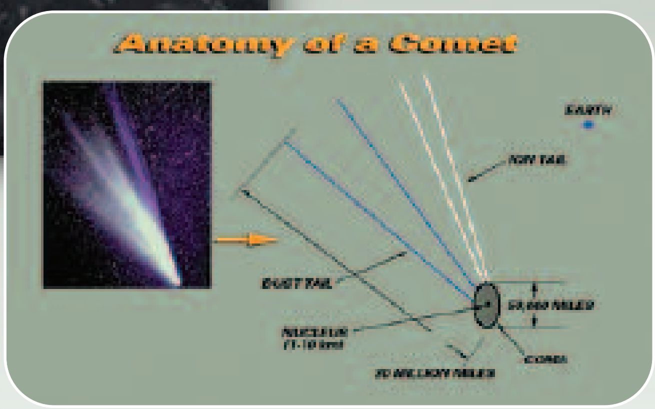
derstanding Comet Tempel 1

Left: It was the kind of thing many 10-year-old boys' fantasies are made of: on July 3, 2005, Deep Impact smashed an impactor spacecraft into the nucleus of comet Tempel 1. This unprecedented and flawlessly executed maneuver blasted a hole in the comet, revealing much about the composition of its nucleus and, scientists hope, our own origins.

Illustration: Ball Aerospace Corporation

Below: A comet has three major parts: a nucleus—the dark, dirty snowball composed of ice, dirt, rock and gas; a coma—the halo of gas, ice, and rock emanating from the nucleus; and a two-part tail—dust and ions that form the sweeping trails of particles sublimated off the nucleus. The diagram shows the scale of an average comet.

Diagram: Lucy McFadden; photo of comet West: Observatoire de Haute, Provence, France; redrawn by B.S. Smith

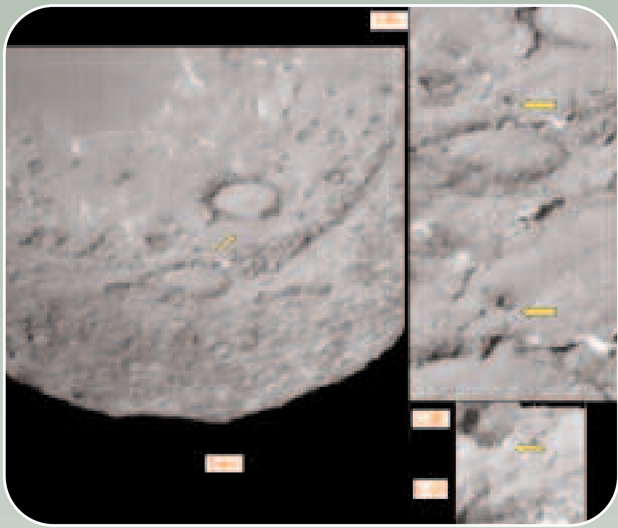


y McFadden and Ray Brown

omets are awesome sights to behold. Their dramatic tails attached to shining comas sometimes stretch across the entire sky. Although too far from Earth to be visible in ky, on July 3–4, 2005 comet Tempel 1 outshone scientists' ons. At 5:44:36 UTC (Universal Time, which is the same vich Mean Time), Tempel 1 collided with *Deep Impact*'s spacecraft, and a plume of dust and volatiles was ejected comet's interior. The ejecta gave us our first inside look est and coldest components of our solar system.

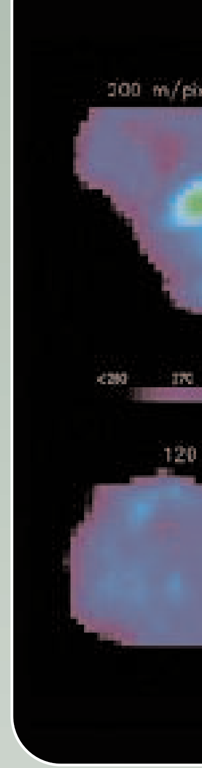
counter was the culmination of a project proposed to 1998. A team of scientists from the University of Mary-other institutions, along with engineers and managers at Ball Aerospace & Technologies Corp. and Jet Propulsion Laboratory (JPL), spent more than 6 years planning the mission and designing and building the two spacecraft and their instruments before the mated spacecraft could be sent on their 6-month journey to comet Tempel 1.

Deep Impact, a Discovery Program mission, had four primary science objectives: to improve knowledge of the physical and chem-



As Deep Impact *zoomed closer to Tempel 1's nucleus, the comet's circular features and scarp-like ridges came into view. As it neared the surface, the impactor was knocked about by particles driven off the surface by vaporizing gas and entrained dust.*
Image: NASA/JPL/University of Maryland (UMD)/AAAS-Science magazine

The best fireworks display of the Fourth of July weekend happened a day early at the Jet Propulsion Laboratory. After nearly 7 tense and quiet minutes of waiting once the impactor's signal went silent, the room lit up with this picture-perfect message of success.
Image: NASA/JPL/UMD



ical properties of a cometary nucleus; to determine properties of its surface layers, such as density, porosity, and strength; to study the relationship between the surface and interior; and to understand the evolution of cometary nuclei.

A Smashing Success

On January 12, 2005, a Delta II rocket lofted a pair of mated spacecraft, the impactor and a flyby spacecraft, on a direct route to Tempel 1. The impactor carried a copper ball designed to make a big impact. It also held the Impactor Targeting Sensor (ITS), an imaging telescope used to guide the impactor autonomously once the two vehicles had separated and to image the area around the target point until seconds before impact.

The flyby spacecraft observed the impact from a safe distance of 500 kilometers (300 miles) while traveling at slightly less than 10 kilometers per second (more than 22,000 miles per hour) relative to the comet. Tempel 1 was about to reach perihelion (its closest point to the Sun), when it would be moving with its highest orbital velocity. The flyby spacecraft carried two instruments, the Medium Resolution Imager (MRI), which is a copy of the ITS except with nine filters, and the High Resolution Instrument (HRI), which is a more powerful telescope coupled with an infrared spectrometer. The spectrometer is a key instrument used to analyze the composition of dust, gas, and the surface of Tempel 1.

Deep Impact had already collected valuable data beginning shortly after launch. Once safely beyond Earth's atmosphere and on its way to Tempel 1, the instruments had observed the Moon, Jupiter, and some stars. This was done not only to make sure the instruments had survived launch and were functioning but also to allow the science team to analyze their performance.

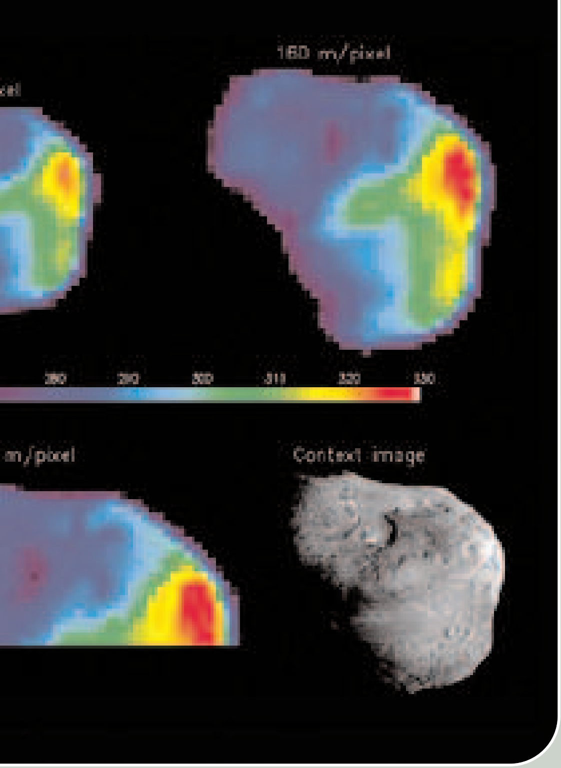
Excitement mounted at the end of April, when the instruments first spotted the comet. At that time, the spacecraft were almost 60 million kilometers (36 million miles) from their target and were able to capture faint images dominated by the comet's coma.

Daily observations continued through May and June, and well before the arrival of the impactor spacecraft, we observed outbursts of gas and dust emanating from Tempel 1's surface. On June 14, data from Spain's Calar Alto Observatory showed a new coma structure. Close examination of spacecraft data revealed a threefold increase in brightness in less than 10 minutes, followed by a gradual decay over about an hour. Prior to impact, we observed six such outbursts. Although jets of material have been observed before—from comet Wild 2—we have been able to correlate Tempel 1's outbursts with the arrival of sunrise. (A day on Tempel 1 is nearly 41 hours long.)

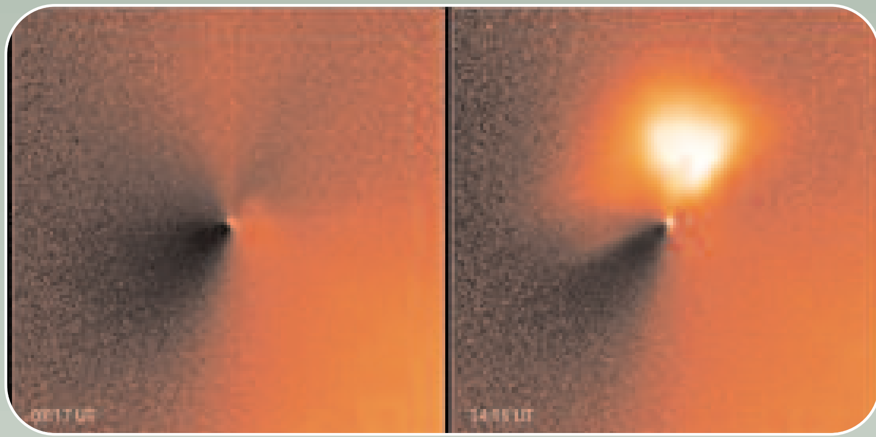
The encounter phase began on June 30, when observations shifted from 4-hour observing sequences to continuous observing. When the impactor spacecraft separated from the mother ship 24 hours before impact, the team was ecstatic. One of the mission's technical challenges had been carried out successfully.

When the spacecraft released the impactor, the comet was just a speck in the ITS camera. We watched the nucleus grow larger as the impactor approached. As the nucleus came into view, we could see its irregular shape, appearing brighter on the sunward side. A somewhat circular feature, partly bright and partly dark, appeared a bit offset from center. As the impactor drew closer, additional circular features came into view, as did ridge or scarp-like features, some dark and some bright. The impact site is shown above at left.

At JPL, the science team watched data displayed on a full-wall screen. We saw the last impactor images degrade, and we received word from mission control that the signal



This temperature map of Tempel 1's nucleus tells us that on the comet's surface, it is warm in the Sun and cold in the shadows. The Sun, which is off to the right in all these images, heats the surface closest to it (red) to 329 kelvins (56 degrees Celsius or 133 degrees Fahrenheit), which then cools quickly when not exposed. It's much cooler in the shadows at 260 kelvins (–13 degrees Celsius or 9 degrees Fahrenheit). The color bar shows temperatures in kelvins. Map: NASA/JPL/UMD



The Hubble Space Telescope took these pictures of Tempel 1 on June 14, 2005—about 2 weeks before Deep Impact*'s encounter with the comet. Taken 7 hours apart, the before-and-after images show an eruption of gas from the nucleus. The view at right shows that the jet (the bright, fan-shaped feature) extended about 2,200 kilometers (1,400 miles), which is roughly half the distance across the United States.* Images: NASA, ESA, P. Feldman, and H. Weaver, Johns Hopkins University

from the impactor had ceased. For nearly 7 minutes, as we waited for the flyby spacecraft to send back its images, we tried to be busy. When the wall lit up with the light from the impact, we all applauded, hooted, hugged, and jumped up and down. It was every bit the fireworks that we had hoped for, and more. The room exploded with excitement.

It will take some time to fully analyze the data collected from the *Deep Impact* mission. The science team recently published early results in *Science* magazine and is hard at work on a second batch. Here, we're excited to share what we've learned so far about comet Tempel 1.

Physical Properties of the Nucleus

Although the spacecraft directly observed only about half the entire comet, the cameras were able to measure the comet's dimensions. Its longest dimension is 7.6 kilometers (4.6 miles), and its shortest is 4.9 kilometers (2.9 miles). One measure that scientists use is the effective radius, which is what the radius would be if the volume were converted to a sphere. For Tempel 1, this is 3.0 kilometers (1.8 miles).

We monitored the brightness variations over time and determined that the rotation period (1 day) is 40.8 hours. We were also able to locate the rotational axis—information that is important for determining the surface temperature and the orientation of each surface element relative to incoming sunlight.

Deep Impact also acquired the first detailed temperature map of a comet nucleus. Tempel 1's temperature is highest near the subsolar point, where it is 329 kelvins (56 degrees Celsius, 133 degrees Fahrenheit). The shadows are cooler, at 260 kelvins (–13 degrees Celsius, 9 degrees Fahrenheit).

The temperature measurements show that the dusty surface does not retain heat well at all. The Sun heats the surface, which cools rapidly when not exposed to sunlight. It is also interesting to realize that most of the nucleus is above the temperature of water ice (273 kelvins, 0 degrees Celsius, or 32 degrees Fahrenheit) at 195 million kilometers (121 million miles) from the Sun. There are only a few areas shaded and cold enough for ice to exist on the surface, yet most of the vapor in the coma is derived from water ice.

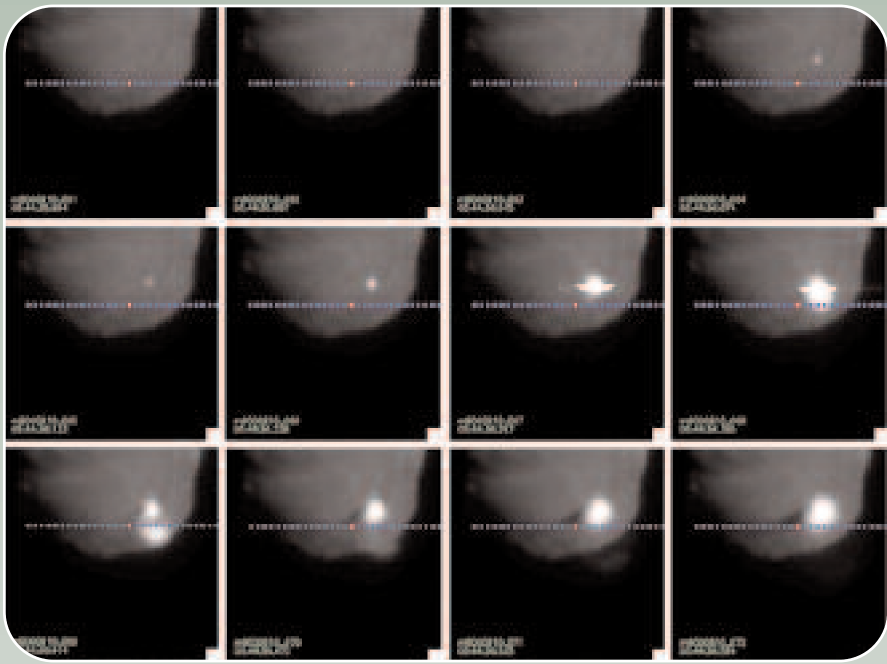
Impact

For 13 minutes after impact, the HRI and MRI returned images of the expanding ejecta cone and dust cloud. We expected the dust to clear within this time, but it didn't. The crater and its interior remained mostly obscured, possibly because of the large volume of small particles that were released from the interior.

The images at top left on page 16 show the progression of the impact. The first flash lasted less than 200 milliseconds. The second flash came from a different location and was so bright that it swamped both detectors for 120 milliseconds.

A plume of hot material shot out from the nucleus traveling at speeds greater than 5 kilometers per second (about 11,200 miles per hour) and dissipated quickly. The greater part of the ejecta traveled out from the crater at speeds closer to 3 kilometers per second (6,700 miles per hour). It cast a shadow on the nucleus, indicating that the particles rising in the plume made a dense column through which light couldn't penetrate.

After 13 minutes, the spacecraft went into shield mode, and 45 minutes later, it looked back (page 16, upper right). Those images, appearing on the screen in the science room late the night of impact, inspired another moment of awe. The dark side of the nucleus appeared in silhouette against a partly illuminated nucleus and the ejecta cone. This debris



Deep Impact's Medium Resolution Imager took this series of images showing the progression of the impact. A plume of hot material shot out of the nucleus at high speeds and dissipated quickly. The ejecta cast a shadow on the nucleus. Image: NASA/JPL/UMD

After 13 minutes of watching the aftermath of the impact, Deep Impact took a 45-minute break by switching into shield mode to protect the cameras from impacting dust. When it looked back at Tempel 1, 50 minutes after encounter, it saw the comet in silhouette against its bright ejecta cone. Image: NASA/JPL/UMD

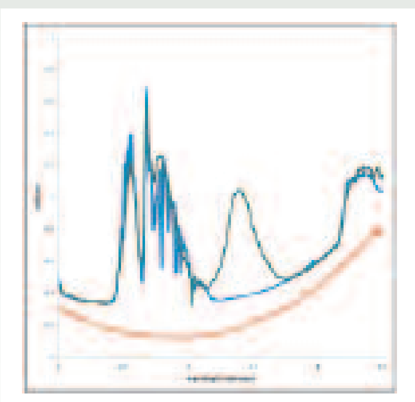
cone remained attached to the comet, indicating that the crater kept growing for many minutes after the impact and that the growth of the crater was controlled by gravity.

An impact into solid rock or even a material with the consistency of a terrestrial soil would have produced a small crater that would have stopped growing once the expanding shock wave from the impact had gotten too weak to disrupt the rock. The material on the surface of Tempel 1 was so weak that the crater stopped growing only after the shock wave had weakened to the point that the comet's tiny gravity could hang on to the particles on its surface.

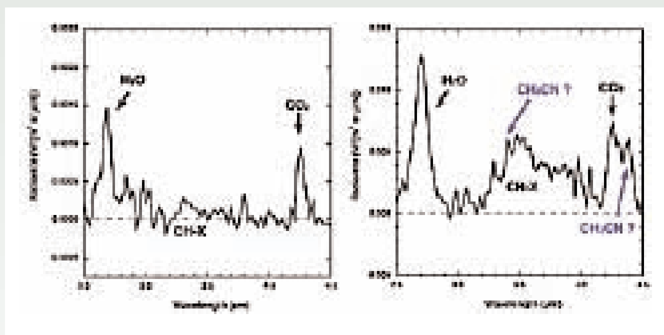
The strength of a material is equivalent to the amount of pressure that you have to put on it in order to deform it. Pressure is measured in a unit called a Pascal (a unit of force equivalent to Newtons per square meter). For comparison, a terrestrial soil is 1,000 Pascals. Assuming a maximum height of 750 meters at 1 hour after impact and material with the density of sand, the strength of the ejecta is estimated at about 65 Pascals. Nothing on Earth is as weak as Tempel 1.

By measuring the rate at which the base of the ejecta plume expanded, we determined that acceleration due to gravity on the comet is constrained to 50 milligals +34/–25 (or 500 micrometers per second per second, or 50 millionths of Earth's gravity). Knowing the force of gravity on the comet as well as the comet's size, we could figure out the comet's mass (which is 7.2×10^{13} kilograms).

From the mass and size, we determined the density to be less than 620 kilograms per cubic meter—significantly less than that of water, which is 1,000 kilograms per cubic meter. For a body that doesn't have much water ice on its surface but releases tons of water vapor into its coma, the



Left: To understand how much of Tempel 1's spectrum is attributed to vapors of water, carbon dioxide, and hydrogen cyanide (found in all comets) as well as hot dust, the Deep Impact team constructed a model comparing what it expected to find (blue) with what it actually found after the impact (green). The model spectrum matches the observed spectrum fairly closely. For comparison, the red line is a spectrum from the comet prior to impact.



Right: The team compared the components of the gas normally sublimated by Tempel 1 with those of the material blasted up from below the surface. It removed the heat factor from these data and then made 2 graphs comparing the gases' spectra. The graph at left shows the spectrum just off Tempel 1's limb 10 seconds before impact, and the one at right shows it 4 minutes after. By comparing the spectra before and after impact, the Deep Impact team found an excess of organic (carbon-bearing) material that was brought up from beneath Tempel 1's surface. Graphs: NASA/JPL/UMD/AAAS-Science magazine interior structure has to be very, very porous. Yet, Tempel 1 is structurally strong enough to support scarps and circular features on its surface. This is truly a new world to those of us bound to the Earth's surface.

Results from the Spectrometer

An important objective of the *Deep Impact* project is to compare the chemical composition of Tempel 1's surface with its internal composition. To do this, a spectrometer, part of the flyby spacecraft's High Resolution Instrument, recorded the intensity and wavelength of light coming from the comet. (When we plot intensity as a function of wavelength, the curve has many peaks in it. The wavelengths at which the peaks occur reveal the identity of the kinds of molecules that are emitting the light.) However, the light captured by the spectrometer also contained reflected sunlight and light emitted from the nucleus because of its heat.

The team analyzed a spectrum taken at the end of the first flash containing the hot vapor plume (page 16, lower left). The spectrum has three interesting emission features (regions in which there are many overlapping peaks). One, in the 2.5–3.0-micron interval, is associated with water vapor. A second, in the 3.2–3.5-micron interval, is associated with several organic molecules. The third, in the 4.2–4.5-micron range, is associated with carbon dioxide.

Peaks in Tempel 1's spectra indicate the presence of water, carbon dioxide, and hydrogen cyanide (a compound found in all comets). To find out how much of the spectrum can be accounted for by these molecules, the team constructed a model spectrum containing the vapors of water, carbon dioxide, and hydrogen cyanide as well as the preimpact spectrum and hot dust. The graph at lower left on page 16 shows the model spectrum plotted in blue and the observed spectrum plotted in green. The model spectrum matches the observed spectrum well except for the organic feature in the 3.2–3.5-micron range, which was not modeled.

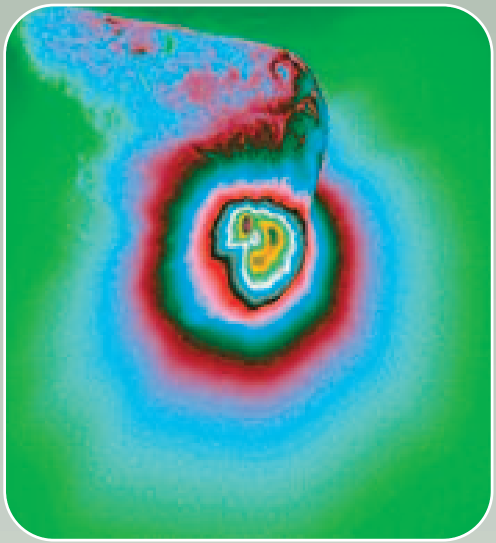
The organic feature has characteristics of molecules similar to formaldehyde and methanol. It is also present in preimpact, Earth-based observations, but it is not as prominent, suggesting that the impactor has excavated a greater abundance of materials than is normally vaporized in comets.

Subsequent spectra show that after the flash, water and carbon dioxide decreased by a factor of 20 but the organic feature decreased by a factor of only 6, indicating that newer ejecta are richer in organics. Reflected light decreased as the plume disappeared but later recovered as more ejecta appeared.

Analyzing Outgassing

The relationship between what is in a comet's coma and what is actually inside the comet is not well understood. The science team hoped that the impact with Tempel 1 would excavate material from deep inside Tempel 1 that differs from its usual outgassing.

After removing radiation due to dust, we compared the spectrum of normally sublimated gas with the spectrum of gas excavated from below the surface (page 16, lower right). The graph on the left shows the spectrum of normally sublimated gas. It was taken just off the limb of the nucleus 10 minutes before impact. The graph on the right shows the spectrum of the excavated gas. It was taken 4 minutes after impact. (Be careful when comparing values on one graph with values on the other. Although the graphs are the same size, their scales are different.)



This false-color map of Tempel 1 shows the various intensities of light that emanated from the impact. The nucleus of the comet is shown in blue and maroon, and the multiple colors that ring the impact site reflect a decrease in flash intensity as they move farther away from the point of the collision.
Map: Alan Delamere, Ball Aerospace Corporation

The graphs show that the intensity of the organic feature increased much more than the intensity of either water or carbon dioxide—in fact, it may have increased 20-fold. The intensity of water and carbon dioxide increased about 8-fold, carbon dioxide a bit less than water. Also, before impact, the ratio of organics to water was 1:5, and after impact, the ratio of organics to water had risen to 1:2.

A New View Emerges

Deep Impact was an unprecedented collaboration among astronomers the world over. Not only did *Deep Impact*'s flyby spacecraft observe the encounter with Tempel 1, but so did many major observatories on Earth as well as some in space. Now *Deep Impact* scientists are making new discoveries relating to the nature of comets and hence about how and of what the solar system was formed.

The *Deep Impact* mission revealed many surprises at Tempel 1. The comet looked very different close up from any of the comets that we have visited with spacecraft (Halley, Borelly, and Wild 2).

Tempel 1 also stands out from other comets because it has circular features similar to impact craters on other planetary bodies. Our inability to see the crater within the dusty ejecta thrown up from the impact was also a surprise.

We are just beginning to mine the information about Tempel 1's interior sent to us by *Deep Impact*. There are enough unanswered questions to keep astronomers busy for years to come.

Lucy McFadden is a coinvestigator of the Deep Impact *mission and managed the Education and Public Outreach program for the science team. Ray Brown is a retired software engineer-turned science writer and full-time grandfather of four.*

World Watch

by Louis D. Friedman

Washington, DC—Just before it adjourned in December, and following the passage of the NASA appropriations bill, Congress passed an authorization bill for the space agency. Although the authorization bill strongly supported NASA and called for a significant increase in funding, it is the appropriations bill that governs the NASA budget, and that was about 10 percent less than what was authorized.

The authorization bill put the US Congress on record in full support of the Vision for Space Exploration, the program to send humans back to the Moon and prepare for flights to Mars. Retiring the shuttle by the end of 2010 and developing the new Crew Exploration Vehicle to fly to the International Space Station are crucial parts of that plan.

As first steps back to the Moon, work has begun on the Robotic Lunar Exploration Program, which will send an orbiter in 2008, followed by a lander, possibly in 2010 but more likely in 2012. The bill also resolves two issues of concern to The Planetary Society: it restored funding for the *Voyager* mission and endorsed a shuttle mission to repair the Hubble Space Telescope, when and if the shuttle is determined to be safe.

The final bill also authorizes prizes of more than $1 million in the Centennial Challenges program designed to use prize money to lure private backing to space ventures.

With Congress' work wrapped up on the fiscal year 2006 budget (the federal government's fiscal year begins in October of the previous calendar year), attention is now turned to what the administration will propose for fiscal year 2007. NASA is seeking a considerable increase in its budget—as much as 9 percent—to fix shuttle problems and maintain funding for existing programs. If that increase is not granted, something will have to give—and we are on the alert to make sure the science and exploration programs get what they need.

NASA Administrator Mike Griffin fanned the flames of the "science versus shuttle" issue by sending a letter to the Bush administration budget office saying, in effect, that if a choice must be made between the two, then the priority will be full funding for the shuttle program, while science funding remains flat.

The Planetary Society will be watching this closely. We are particularly concerned about seeing a new mission to Europa. The National Academy of Sciences strongly endorsed a mission to this ocean-moon of Jupiter for what it can tell us about the chances for life on other worlds.

However, exploring Europa poses significant engineering challenges. To carry the fuel necessary to get to the Jupiter system and to put the spacecraft into orbit around the moon, a large rocket is required. Building a craft that can survive the dangerous radiation environment around Jupiter is a challenge (and expense) for spacecraft engineers. And then, after spending the time and money to get all the way to Europa, many in the science community (including me) feel we might as well add a lander that could tell us so much more about what lies beneath Europa's icy crust.

In fiscal year 2006, Congress did provide funds to study a Europa mission and directed NASA to prepare to start work on a new mission in 2007. (In an earlier budget-cutting move, NASA shelved the plan for a nuclear-propelled mission.) There is now concern that the Bush administration won't propose the new start and that NASA might try to reallocate the existing 2006 funds and delete Europa from the program planning.

The proposed budget will become public in the beginning of February, when the administration sends it to Congress.

The European Space Agency (ESA) is conducting advanced studies on exploring Europa, although it does not yet have approval to start work on a mission. Last year, ESA Science Chief David Southwood suggested that a Europa mission might be a natural follow-on to the successful NASA/ESA collaboration on *Cassini-Huygens*. Because of the expense and engineering challenges of exploring Europa, international cooperation probably is the best and easiest way such a mission could be accomplished.

The Planetary Society strongly advocates exploration of Europa—a tantalizing water world with much to tell us about the possibilities of extraterrestrial life. We may soon be calling on our members to take action and urge that NASA be directed to begin work on a mission to Europa. You can follow our Explore Europa campaign on our website at *planetary.org/programs/projects/explore_europa.*

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

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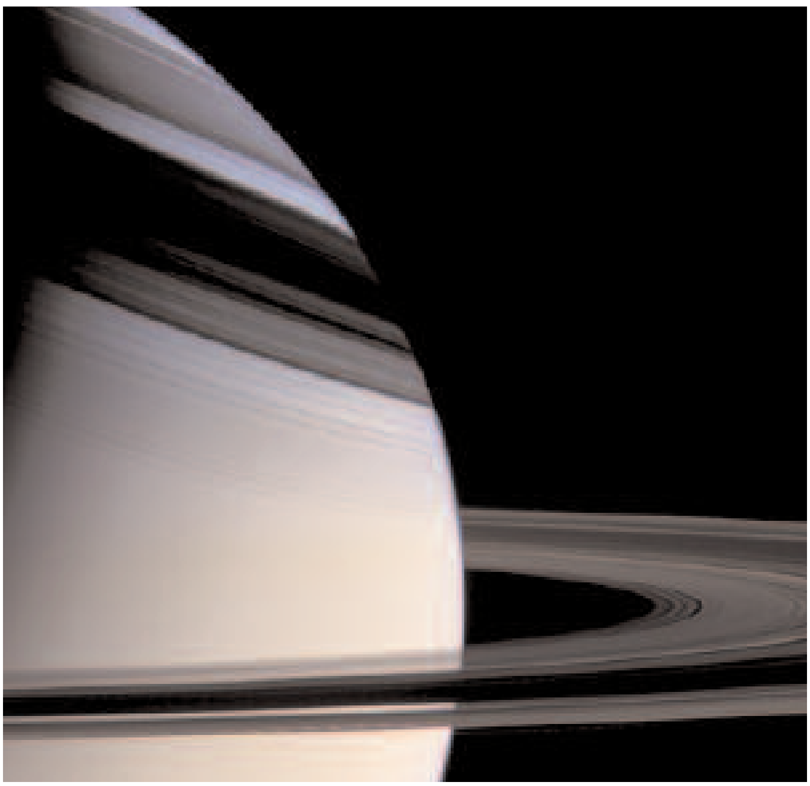
Questions and Answers

How does the* Cassini *team keep track of all the objects it studies for planning? How do they track all of Saturn's moons and rings relative to each other and to the spacecraft?
—Tom McDonald
Bedford, Massachusetts

Your question touches on a tough problem—one that I am responsible for and have to revisit often. We have to keep close track of both Saturn's satellites and its diverse ring system—not only to study them closely but also to monitor the hazards that they may pose.

We have no plans to fly *Cassini* through Saturn's main ring system. The main rings contain far too much dangerous material, and it is unlikely that the spacecraft would survive even one traversal through them. We can easily control *Cassini*'s trajectory to keep it far away from the main rings. Most of Saturn's satellites are outside the main ring system anyway, and our instruments are quite capable of studying every aspect of the planet's environment without flying that close to it.



Cassini ***took this picture of Saturn on May 4, 2005 as it cruised a few degrees above the planet's ring plane. Taken from a distance of 999,000 kilometers (621,000 miles) from Saturn, the images in this portrait were taken through blue, green, and red spectral filters to create a view similar to what the human eye would see. The*** **Cassini** ***imaging team works hard to keep the spacecraft safe from the danger of collisions while getting it as close as possible to Saturn, its rings, and its moons.*** *Image: NASA/JPL/Space Science Institute*

However, Saturn also has three other, faint rings that are beyond the main ring system. The F ring—a twisted, tortured spiral that is shepherded by the small satellites Prometheus and Pandora—is just beyond the main rings, and it is easy to avoid as well. The G ring is much fainter—barely visible in just the right lighting conditions—and it lies between the main rings and Saturn's closest major satellite, Mimas. Though it is dim, the G ring still poses a hazard to the spacecraft, and we have specifically controlled the trajectory to avoid it, or to barely pierce a far edge.

Then there is the E ring, a very broad and faint ring that extends from Mimas all the way out to Titan—a radial distance of more than 2 million kilometers (more than 1.2 million miles) end to end. We believe the E ring is composed almost exclusively of particles about one micron (one millionth of a meter) in size. These particles are far too small to pose any hazard to the spacecraft. We have crossed through this ring safely many times already, and studying the ring at close range has told us much about its origins and composition.

We fly as close as we safely can to a number of Saturn's moons to study them up close. For every targeted flyby of this kind, there are a handful of nontargeted encounters. These encounters tend to move around somewhat as we update the positions of the satellites and the spacecraft, and each time, we update the trajectory to improve science or to accommodate a change in strategy. We are constantly recalculating the nontargeted encounters' geometries, and we do monitor them closely to make sure that we remain a safe distance away from any hazardous bodies—be they pebbles in the faint F or G rings, perhaps a millimeter in diameter, or instead moons that might be100 kilometers (62 miles) across.

We don't employ sexy 3-D software packages to determine how close we come to Saturn's faint rings and moons. Most of the time we merely look at dry reams of data. However, there are some 2-D graphics tools that we use often. Sometimes you really do have to see it to solve it.

Cassini was specifically designed to study Saturn's moons and ring systems, and some interesting observations can be made only when it is very close to these objects (or within the faint rings). We can't gamble the survival of the whole mission just to take one set of measurements, but we need to

take some small risks because studying the many wonders of Saturn's environment is why we are there in the first place. Striking the right balance is an art, and that is the tough part.
—DAVID SEAL,
Jet Propulsion Laboratory

Because radio telescopes are used to image asteroids in our solar system, would it be possible to use the same method to detect planets in nearby solar systems?
—David Robertson
Maldon, Essex, England

No, because the returned radio signal would be much too weak to be detected with current radio telescopes, even huge ones like Puerto Rico's Arecibo telescope. The problem is that the closest stars are at least 400,000 times farther away from Earth than an asteroid in our solar system. The radio beam sent out to bounce off the extrasolar planet would be diluted by the inverse square of the distance to the extrasolar planet—that is, by a factor of $400{,}000^2$ or 160 billion. Once the radio waves bounced off the extrasolar planet and traveled back toward Earth, they would again be diluted by this same factor, for a total dilution of a factor of 26,000 billion billion for a comparable asteroidal-size target.

Of course, an Earth-like planet would have a cross-sectional area perhaps 100 to 10,000 times larger than an asteroid, increasing the returned signal by the same factor, but this is not nearly enough to overcome the losses due to the much greater distances involved. Even if the initial radio beam could be focused exactly on the extrasolar planet, so that the outgoing beam losses were less than a decrease by a factor of 160 billion, the reflected beam would still suffer the loss by the other factor of 160 billion, which is still enough to make the detection impossible.
—ALAN BOSS,
Carnegie Institution of Washington

Factinos

Uranus has another pair of rings! In late December 2005, scientists using the Hubble Space Telescope (HST) reported that they'd imaged a pair of rings so far from the planet that they are being called Uranus' "second ring system." In addition, HST found two small satellites—one sharing its orbit with one of the newly discovered rings. On top of that, precise analysis of the data reveals that the orbits of Uranus' inner moons have changed significantly in the last 10 years.

"The new discoveries dramatically demonstrate that Uranus has a youthful and dynamic system of rings and moons," says Mark Showalter of the SETI Institute. "Until now, nobody had a clue the rings were there—we had no right to expect them."

Because the newly discovered rings are nearly transparent, they will be easier to see when they are edge-on. They will increase in brightness as Uranus approaches its 2007 equinox (when the Sun shines directly over Uranus' equator). When that happens, all the rings will be tilted edge-on to Earth, making the new rings much easier to study.
—from the Space Telescope Science Institute

For the first time, some of life's most basic ingredients have been detected in the dust swirling around a young star. NASA's Spitzer Space Telescope discovered these building blocks—gaseous precursors to DNA and protein—in the star's terrestrial planet zone, a region where scientists believe rocky planets like Earth are born.

Fred Lahuis of the Netherlands' Leiden Observatory and the Dutch space research institute SRON, along with his colleagues, spotted the organic (carbon-containing) gases around a star called IRS 46 that resides in the Ophiuchus constellation about 375 light-years from Earth. This constellation harbors a huge cloud of dust and gas in the throes of a stellar baby boom. Like most young stars, IRS 46 is circled by a disk of spinning gas and dust that might eventually form into planets.

When the researchers probed this star's disk with Spitzer's powerful infrared spectrometer instrument, they were surprised to find the molecular "bar codes" of large amounts of acetylene and hydrogen cyanide gases, as well as carbon dioxide gas. The team observed 100 similar young stars, but only one, IRS 46, showed unambiguous signs of the organic mix. The Spitzer data also revealed that the organic gases are so hot that they are most likely located near the star, about the same distance away as Earth is from our Sun.
—from NASA/JPL/Caltech

Scientists have found that Pluto is colder than it should be. They think the planet's lower temperature is the result of interactions between its icy surface and thin nitrogen atmosphere. The researchers used the Submillimeter (SMA) network of radio telescopes in Hawaii to confirm that Pluto's average surface temperature was about 43 kelvins (–230 degrees Celsius or –382 degrees Fahrenheit), which is also the temperature of Pluto's largest moon, Charon.

Scientists had suspected for years that Pluto is colder than it should be, but they were unable to confirm their suspicions until recently because it was difficult to separate its heat emissions from those of nearby Charon.

"We're the first to have the combination of resolution and sensitivity to be able to do this experiment," said Mark Gurwell, a scientist from the Harvard-Smithsonian Center for Astrophysics. Other large telescopes have higher resolution than the SMA but are less sensitive to cold objects. Gurwell is one of the researchers on the report, which was presented in early January 2006 at the American Astronomical Society's annual meeting in Washington, DC.
—from *Space.com*

Society News

The Society Website Gets a New Look!

As part of our 25th Anniversary celebration, we unveiled our redesigned website. We invite you to come and check out *planetary.org*, where you will find the same great space exploration news and daily weblog you have come to rely on, plus lots of new features, including a new area exclusively for members.

To access our special "For Members" area, send an e-mail with your membership number to *formembers@planetary.org*, and we will send you the login information. Please make the subject "For Members." (Your membership number can be found on the address label of *The Planetary Report*.)

We extend special thanks to our Planetary Society members around the world who told us what they wanted to see on the new site; our special donor who funded the redesign; Zoomwerks for its long-standing technical support and hosting of our website; and Pop Multimedia, Inc., whose hard work and donation of time and expertise are hidden from view but form the foundation of our new site.

—Monica Lopez, Marketing Manager

Supporting the Society Is Easier than Ever!

Hooray! The Society's new website is up and running. Your comments helped us redesign our membership and giving areas. Thank you!

As we enter a new year of exploration, we hope you will consider a gift to the Society. Check out our new website, find the project that piques your interest, and make a donation. Or, give a gift membership or a donation to celebrate a special occasion or to honor a special person in your life.

You can also help the Society as a volunteer, consider donating your appreciated stock, participate in a workplace giving program, join the Discovery Team or our New Millennium Committee, or make a planned gift that will provide a legacy of exploration.

Let us know what you think—we love to hear from you. E-mail me at *andrea.carroll@planetary.org* or call me at (626) 793-5100, extension 214.

—Andrea Carroll,
Director of Development

Annual Audit Completed

The firm of Hensiek & Caron has completed its yearly audit of The Planetary Society. The firm determined that the Society's 2005 financial statement was in conformity with generally accepted accounting principles.

Copies of the financial statement are available upon request.

—Lu Coffing, Financial Manager

Be Part of Our Digital Time Capsule!

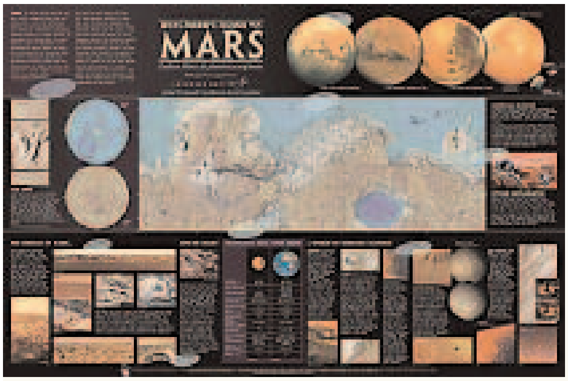
From *New Horizons'* January 2006 launch to its Pluto flyby in July 2015, the spacecraft will cruise through the emptiness of interplanetary space, biding its time until the exciting weeks of its Pluto encounter. But the Earth that *New Horizons* leaves behind will not be the same as the Earth that watches for those Pluto images 9 years later.

The Planetary Society invites children and adults everywhere to take a photo of something that may change in 9 years and submit it to our digital time capsule—a snapshot of Earth in 2006.

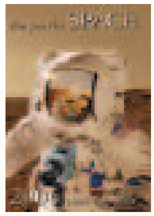
The completed time capsule will be placed on DVD and kept securely at Planetary Society Headquarters in Pasadena, California. When *New Horizons* approaches Pluto in 2015, the spacecraft will send a command across the billions of kilometers separating Pluto from Earth to open the time capsule. At that time, the time capsule will be reopened and the contents shown to the Earth of 2015.

For rules and complete information on how to enter, visit *planetary.org/pluto_time_capsule.*

—Emily Stewart Lakdawalla,
Science and Technology Coordinator



A New Year of Exploration!



Last Chance on 2006 Calendars

Deep Space Mysteries: 2006 Wall Calendar
Each month, enjoy awe-inspiring full-color images from deep space. 2 lbs. **#520 $12.00**

The Year in Space: 2006 Desk Calendar
This planner includes 52 weekly calendars, 12 monthly calendars, a full-year planning calendar, and a four-year, long-range calendar. 1 lb. **#523 $12.00**

NEW! An Explorer's Guide to Mars
Explore Mars! Our recently updated Explorer's Guide to Mars features images from the *Mars Odyssey*, *Mars Express*, *Mars Global Surveyor*, and *Viking* orbiters as well as images of Mars' surface from the *Spirit* and *Opportunity*, *Pathfinder*, and *Viking* spacecraft. Informative captions and charts enhance a detailed US Geological Survey map produced from data returned from *Mars Global Surveyor*'s Mars Orbiter Laser Altimeter. On the reverse side, find even more detailed information about Mars. 24" x 37" 1 lb. **#505 $15.25**

Solar System in Pictures
Recently updated: all nine planets are featured on full-color, 8" x 10" mini-posters. Each includes detailed information and a scientific description of the planet.
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22" x 34" 1 lb. **#571 $13.50**

"Is Anybody Out There?" Poster
39" x 16" 1 lb. **#320 $13.50**

Pale Blue Dot Poster
12" x 30" 1 lb. **#326 $10.00**

***Spirit*'s View at Bonneville Crater Poster**
10" x 39" 1 lb. **#350 $13.50**

Nebula Poster
49. 22" x 34" 1 lb. **#315 $13.50**

Mars in 3-D Poster
12" x 39" 1 lb. **#306 $13.50**

***Pathfinder* Images of Mars**
20 slides. 1 lb. **#215 $7.50**

Surf Titan T-Shirt
Adult sizes: S, M, L, XL, XXL 1 lb. **#593 $20.00**

"Is Anyone Out There?" T-Shirt
Adult sizes: S, M, L, XL, XXL 1 lb. **#586 $19.95**

Future Martian T-Shirt
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1 lb. **#695 $3.00**

The Planetary Society License Plate Holder
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