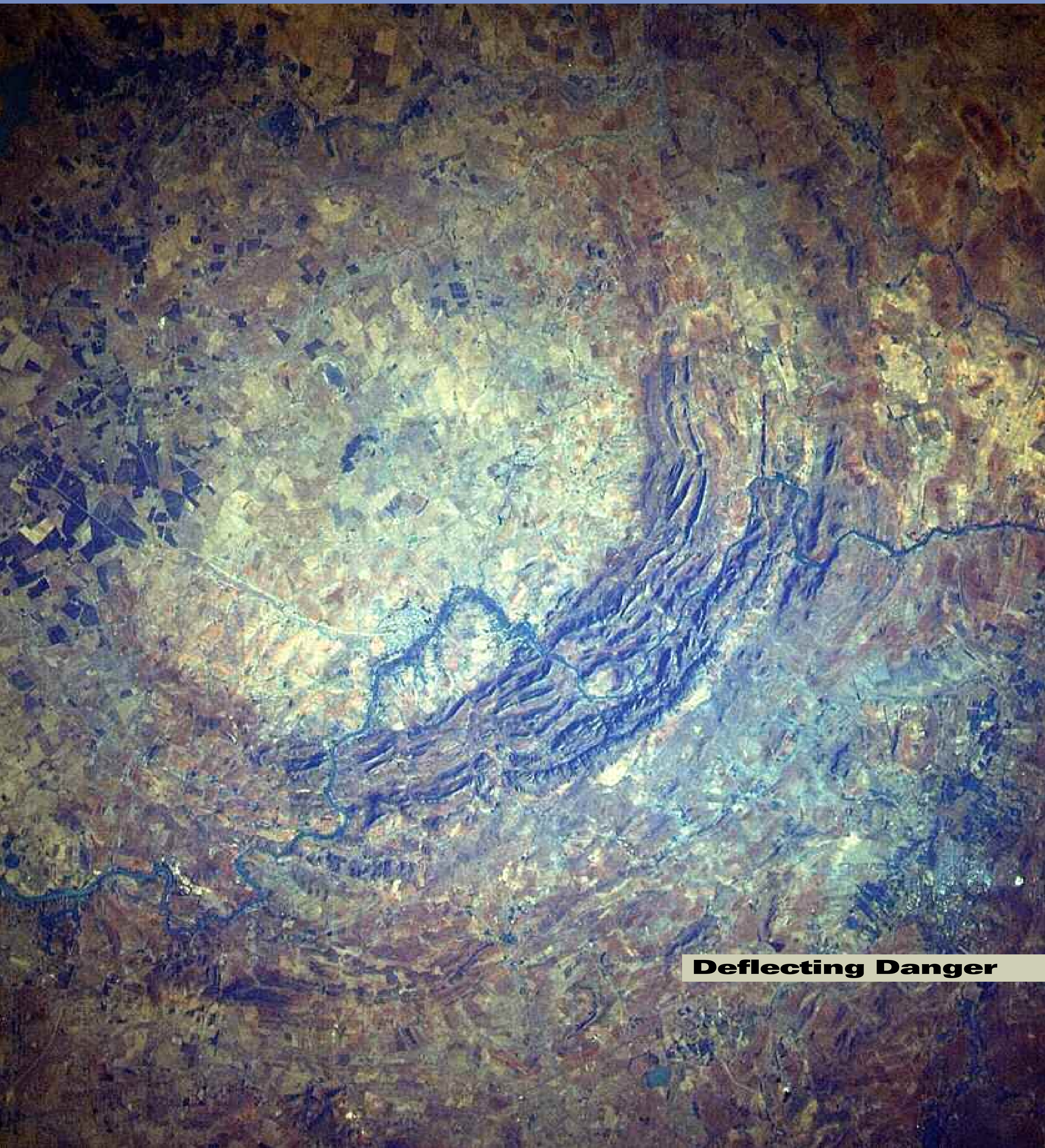
The PLANETARY REPORT

Volume XXIX Number 2 March/April 2009



Deflecting Danger

From The Editor

Jim Bell, the new president of The Planetary Society, really hit the ground running with the Members' Survey that you received in the mail a few weeks ago. Even as I write this, we are receiving responses and tabulating and analyzing the results.

We will report to you soon on the final tallies (send our membership department your e-mail address if you haven't already), but we've already seen some results come booming through, loud and clear.

For example, we asked "Which of these Planetary Society projects and activities do you support?" The choice of "Monitoring potentially dangerous near-Earth asteroids and comets" is an overwhelming favorite so far.

There's obviously some sort of confluence of energy about this topic, because we've been planning to increase our efforts in this area, beginning with the article "The Quest to Find the Next Killer Asteroid—Before It Finds Us" in this issue of *The Planetary Report*. In a few months, you'll receive a special issue of *The Planetary Report* on near-Earth objects and the threat they pose to our civilization.

Meanwhile, we're getting ready to announce the winners of our most recent round of Gene Shoemaker Near Earth Object Grants, and two of our previous winners have been in the news lately: Quanzhi Ye, who co-discovered comet Lulin, and Jean-Claude Pelle, who helped track asteroid 2009 DD45 as it passed only 40,000 kilometers from Earth on March 2.

Thank you for your survey responses—we're already acting on your directions. Together, we will fulfill the mission of The Planetary Society to explore other worlds, protect this one, and seek other life.

—Charlene M. Anderson

On the Cover:

Vredefort is the oldest and largest visible meteor impact crater on Earth. With a diameter of roughly 300 kilometers (about 190 miles), it is twice the size of the Chicxulub crater associated with the extinction of the dinosaurs. Named after the town of Vredefort, which is situated near its center, this crater is located in the Free State Province of South Africa. Vredefort is one of Earth's few multi-ringed impact craters; they are more common elsewhere in the solar system. This image was taken on August 29, 1985 by an astronaut on board the space shuttle. Image: NASA

Background:

A startling sight greeted the faithful in the Nubian desert of northern Sudan as they emerged from morning prayers on October 7, 2008. White smoky streaks hovered in the air above them, forming ghostly patterns in the morning skies. Faced with this strange phenomenon, the Sudanese villagers did what any citizens of the 21st century would do in such circumstances—they took pictures with their cell phones. And that is how the impact of asteroid 2008 TC3—the only asteroid to be tracked in space before striking the Earth—was recorded for posterity. Photo: Mauwai Shaddad

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A PUBLICATION OF THE PLANETARY SOCIETY

We Make It Happen!

Can living beings survive a journey of years through interplanetary space? The Planetary Society is addressing this question with our Living Interplanetary Flight Experiment (LIFE), which is set to fly to Phobos and back on board the Russian Phobos-Grunt *sample return mission, scheduled to launch this October. Using a simulated meteoroid inside the Russian spacecraft, LIFE will be a unique test of one aspect of transpermia: the hypothesis that life can travel between the planets. Below, Planetary Society Writer-Editor Amir Alexander gives us a rundown of the fascinating and varied organisms that the LIFE science team selected to fly.* **—Bruce Betts, Director of Projects**

Who Will Survive?

Ten Hardy Organisms Selected for the LIFE Project

by Amir Alexander

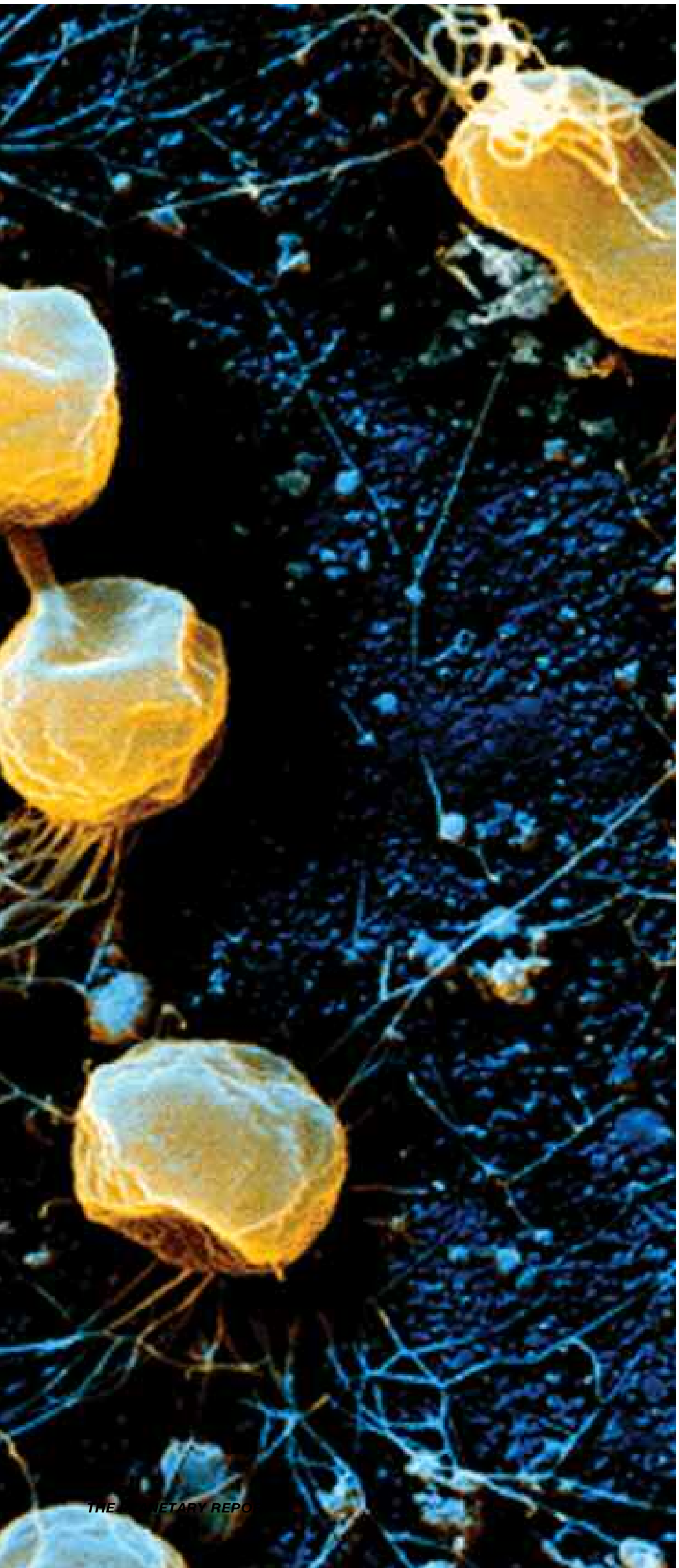
For life to be able to travel between the planets, certain organisms must be able to survive years of exposure to the punishing environment of space and still thrive when they reach their destination. Not only would an organism need to endure micro-gravity and the near-vacuum conditions of space at extremely cold temperatures, but it also would have to overcome exposure to extreme levels of galactic and solar particle radiation far from the shelter of Earth's magnetic field. It would need to do so not for a few days or weeks but for years or decades. No living being has ever shown the ability to survive such brutal treatment in space—at least, not yet.

Putting Transpermia to the Test

Many Earthly organisms have flown in space in the past and survived the experience relatively unharmed. The space shuttle has carried dozens of experiments into space

Selected for its ability to thrive in very high temperatures, the extremophile Pyrococcus furiosus *may serve as LIFE's temperature control. If it is the only organism to survive the journey, this will indicate that the cause of the others' demise was not conditions of interplanetary space but, rather, overheating. The cells shown in this photomicrograph adhere to sand grains (yellow) from their natural habitat, the coast of Vulcano Island, Italy.*

Image: © 2006, American Society for Microbiology, reprinted by permission over the years containing a wide variety of organisms. Among these was The Planetary Society's own GOBBSS experiment, which flew on the shuttle *Columbia*'s tragic last mission in 2003. Many other experiments containing living beings are housed even now on board the International Space Station. All of these, however, have remained well within our planet's protective magnetic field—a far friendlier environment than interplanetary space.



On only two occasions have organisms been sent on voyages beyond low Earth orbit. European experiments designated Biostack 1 and Biostack 2 were included in the payload of *Apollo 16* and *17* in 1972. Each Biostack contained an assortment of living organisms, and each traveled to the Moon and back on board the *Apollo* command modules.

Although the Biostack organisms did travel far from Earth, their exposure to the harsh interplanetary environment was of short duration. Each *Apollo* mission lasted well under two weeks, and the experiments' sojourn beyond Earth's protective magnetosphere was even shorter than that. With that said, the ability of Earthly organisms to survive for a prolonged period in interplanetary space has not yet been tested.

All this, however, will change once The Planetary Society's LIFE module takes to the skies and embarks on its three-year voyage in deep space. Sealed inside the experiment's titanium-shell capsule will be individually sealed triplicate samples of ten organisms that will, for the first time, put transpermia to the test. If, upon the capsule's return, no organism is found to have survived, scientists will be much more skeptical of the notion of life as we know it making the journey between the planets. If any of the LIFE organisms survives, however, it will show that travel between the planets is not an insurmountable barrier for living beings. It will be a crucial piece of evidence in the transpermia puzzle.

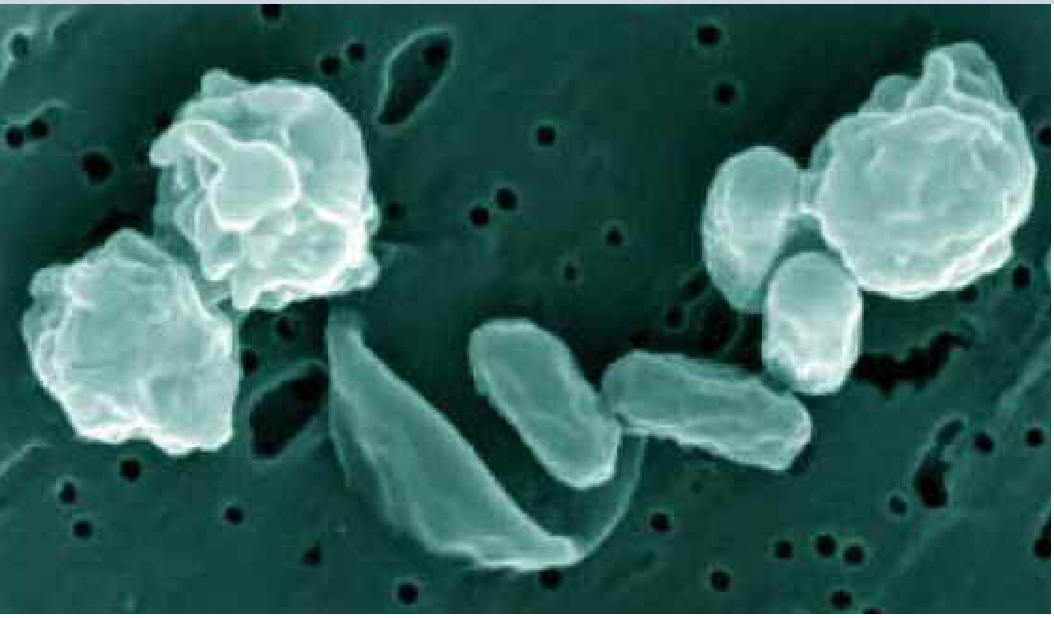
The Final List of Ten

Because only ten organisms could be selected for the trip, the stakes in choosing the right ones were high. Three fundamental guidelines governed the selection of the organisms for the trip to Mars. First, the organisms selected would represent the three domains of life—eukaryotea, bacteria, and archaea. Second, the organisms should be very well studied (e.g., having their genome sequenced and studied in many other experiments) to make it possible to accurately assess the effects of the long exposure to space. Finally, a strong preference would be given to organisms that appear to stand the best chance of surviving the journey—extremophiles, or organisms that thrive in harsh conditions.

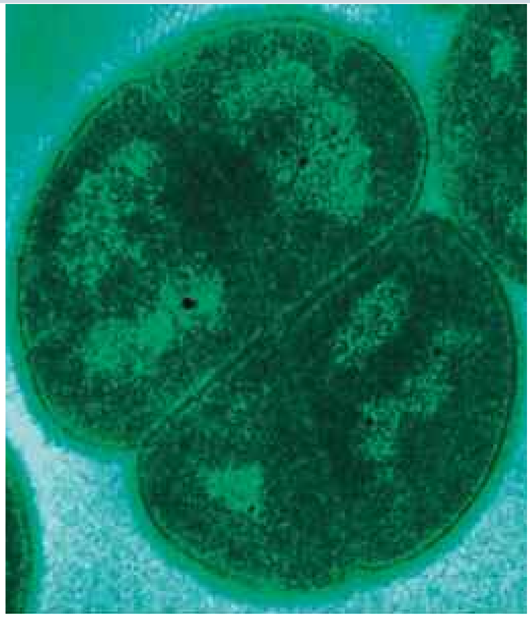
Here, we present the final list of organisms.

• *Bacteria*

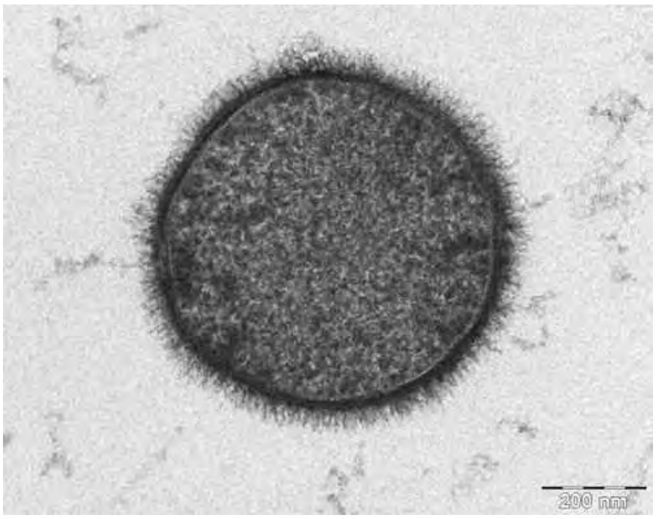
Bacillus safensis—This bacterium was discovered only a few years ago and in an unlikely location: the Spacecraft Assembly Facility (SAF) at the Jet Propulsion Laboratory. At the time of the discovery, the *Mars Odyssey* spacecraft was being assembled in a clean room at SAF, to make sure that the orbiter would not carry any Earthly organisms to the Red Planet. Despite the thorough cleansing of the assembly area, and despite elaborate procedures to avoid contamination from the scientists and engineers, colonies of bacteria still were



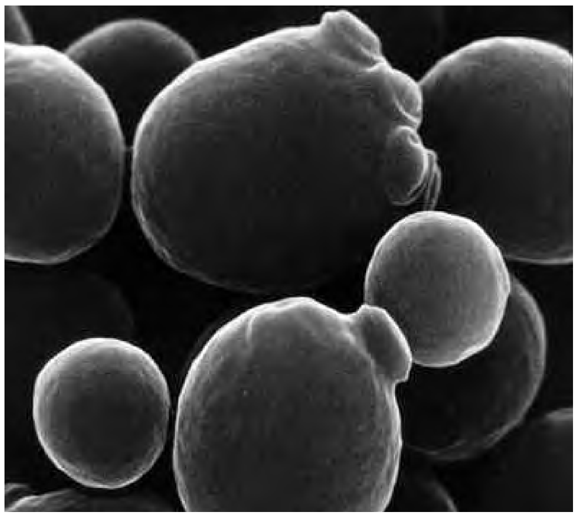
Despite scientists' and engineers' extreme efforts to keep the Jet Propulsion Laboratory's Spacecraft Assembly Facility (SAF) germ free, these rod-shaped bacteria survived and even thrived. The new type of bacillus was found on the surface of **Mars Odyssey** *during assembly. The bugs were named* **Bacillus safensis**, *meaning "bacillus of SAF."* Image: NASA/JPL



Its seeming imperviousness to radiation damage allowed **Deinococcus radiodurans** *to join this exclusive group. With its sophisticated DNA repair system, this organism can be exposed to levels of radiation that blow its genome to bits, only to repair itself and be back in business 12 to 24 hours later.* Image: Oak Ridge National Laboratory



Like **B. safensis, Bacillus subtilis** *is a very tough, spore-producing bacterium capable of surviving the stresses of high heat, acidity, and salinity. It was chosen to fly on the LIFE module because it is considered to be a "model organism" and is used in a wide variety of biological experiments. This is a cross section of a rod-shaped* **B. subtilis** *cell. The scale bar is 200 nanometers wide.* Image: Allon Weiner, The Weizmann Institute of Science, Rehovot, Israel



Saccharomyces cerevisiae *is the only fungus that has been chosen to make the trip to Phobos. We are more familiar with its other names: brewer's, baker's, or ale yeast. This well-studied eukaryote has something in common with* **B. subtilis**, *in that it is also considered a model organism for biological research.*
Image: Courtesy of Alan Wheals, University of Bath, United Kingdom

found on surfaces of the spacecraft, the floor, and other locations in the clean room. This bacterium, which had survived and even thrived in the hostile clean room environment, was found to be a new type of bacillus, and it was christened *Bacillus safensis*, Latin for "bacillus of SAF."

Deinococcus radiodurans—The Latin name for this bacterium means "terrifying berry that survives radiation." As its name suggests, this bacterium is round and extraordinarily resistant to radiation. To get an idea of just how resistant it is, consider that a dose of 10 Gy (Grays) of radiation is sufficient to kill a human, whereas a culture of *Deinococcus radiodurans* will fully survive a dose of 5,000 Gy, and more than a third of the cells will survive a dose of 15,000 Gy! It is this startling capacity to emerge intact from the most trying ordeals that earned *Deinococcus radiodurans* its popular nickname,"Conan the Bacterium."

Bacillus subtilis—If *B. safensis* and *D. radiodurans* were selected for the LIFE project thanks to their ability

The one plant to be included in the LIFE module is, not surprisingly, a weed. Arabidopsis thaliana *is commonly known as thale cress or mouse ear cress. Its five chromosomes and short genome make this relative of mustard the lab rat of the plant world.* A. thaliana *also flew to the Moon as part of the Biostack experiment on* Apollos 16 *and* 17*, and scientists will use data from Biostack to compare the effects of shorter- and longer-term space travel.* Photo: Carl Farmer

This tiny beast, called a tardigrade *or, more appealingly, a "water bear," is the one true animal that will take an interplanetary trip inside the LIFE module. These little extremophiles are found everywhere on Earth and are able to withstand high radiation, pressure, heat, and cold as well as long periods in a vacuum. They do this by entering a state of* cryptobiosis*, or suspended animation, when the going gets tough. When environmental conditions improve (even after nearly a decade), tardigrades can return to life as viable animals.* Image: © Dennis Kunkel, Microscopy, Inc.

to survive under extraordinary circumstances, another bacterium, *Bacillus subtilis*, was picked for a different reason: it is a "model organism," a standard bacterium used over and over again in all kinds of biological experiments. Two distinct strains of *B. subtilis* will fly in the LIFE canister: one designated "168" and the other, "MW01." Both are radiation resistant, although MW01 is far more resistant than its cousin, 168. Most important, *B. subtilis* was included in the two Biostack experiments that flew on board *Apollo 16* and *17* and in a variety of subsequent experiments in low Earth orbit. This means that the effects on the bacterium of LIFE's 34-month sojourn in interplanetary space can be compared with effects of the much shorter journeys to the Moon and back in the early 1970s and to multi-year exposure in low Earth orbit.

• *Archaea*

Along with the bacteria samples, LIFE will carry three species of archaea. This domain of life was discovered and defined in the 1970s (in part by LIFE science team member George Fox), when new organisms were detected in places where no life was thought to exist. Like bacteria, archaeons (as archaea organisms are called) are single-celled organisms, and, like bacteria, they are prokaryotes—meaning that the cells do not contain well-defined organelles such as a nucleus or mitochondria. They are sufficiently different from bacteria to be considered a separate branch of life.

Haloarcula marismortui—Many archaeons are extremophiles that thrive under conditions that would destroy other organisms. One of these archaeons, known as *Haloarcula marismortui*, is halophilic, meaning that

What's **Up?**

In the Sky— April and May 2009

Mercury looks like a bright star low in the west after sunset from mid-April to early May, but it dims rapidly during this period as it changes phases. Look for it near and below the thin crescent Moon on April 26. Saturn is up in the east in Leo after sunset and visible high in the sky in the evening. In the predawn sky, bright Jupiter is high in the east and reddish Mars is low in the east. Extremely bright Venus becomes visible low in the east in April, then is close to Mars during May, and both are near the crescent Moon on May 21. As seen from western North America, the Moon will pass in front of Venus before dawn on April 22. The Lyrids, an average meteor shower, peak on April 21, with increased meteor activity a few days before and after.

Random Space Fact

In microgravity (e.g., on the International Space Station), candle flames are nearly spherical in shape.

Trivia Contest

Our September/October contest winner is Virginia Gallenberger of Ocala, Florida. Congratulations!

The Question was: What is Mars' obliquity (axial tilt) at present? *The Answer is:* 25.2 degrees, similar to Earth's 23.5 degrees. However, Mars' obliquity varies over tens of thousands to millions of years, changing by tens of degrees, radically affecting climate.

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

Since what date has the International Space Station been continuously staffed (had people on board constantly)?

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 July 1, 2009. 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.*

it thrives in extremely salty environments. Why are we testing an organism that seems to enjoy high salinity? The reason has little to do with conditions the organisms will encounter in space but much to do with conditions that prevailed on ancient Mars. If Mars had water on its surface at some point in the past, it was in all likelihood very salty and briny. If life did exist on Mars, then it is likely that it would have populated these same Martian seas and therefore would have been halophilic.

Methanothermobacter wolfeii—This member of the archaea, designated *Methanothermobacter wolfeii*, belongs to a family of methanogens—archaeons that produce methane gas and are common in animal and human intestines as well as in raw sewage. Recent observations from Earth and by the *Mars Express* orbiter have detected trace amounts of methane in the Martian atmosphere. This is surprising, because methane is an unstable gas that would not survive for long. Its presence strongly suggests that something on Mars is pro ducing methane, and one possibility is that this "something" could be methane-producing organisms similar to *Methanothermobacter wolfeii*.

Pyrococcus furiosus—The third type of archaea included among the LIFE specimens is another extremophile known for its great fondness for heat. *Pyrococcus furiosus* was discovered in 1986 in volcanically heated marine sediments off the coast of Italy, and it thrives in temperatures between 70 and more than 100 degrees Celsius (160 and 210 degrees Fahrenheit). Overheating is not really a problem in interstellar space, nor is it likely to be a concern on the surface of Mars or Phobos. There is, however, a certain risk that a malfunction will cause the LIFE biomodule to overheat when it reenters Earth's atmosphere at the end of the journey. In that case, *Pyrococcus furiosus* will serve as a kind of temperature control. If it is the only organism to survive, this will indicate that the cause of the others' demise was not conditions in interplanetary space but simply overheating.

• *Eukaryotea*

The last three organisms to be selected for our round-trip voyage to Phobos are eukaryotea—organisms whose cells contain a nucleus and other organelles. Like bacteria and archaea, many eukaryote species are single celled, but some are complex, multicelled organisms. In fact, most of the creatures we normally think of as living beings—everything from amoebas to elephants—are eukaryotea.

Saccharomyces cerevisiae—This eukaryote is more popularly known by its nicknames: brewer's yeast, baker's yeast, ale yeast, and so on. It is the very same fungus that has been used for millennia for baking bread and fermenting beer. Because of its central role in food production, *Saccharomyces cerevisiae* is one of the most-studied organisms and one of the best known to scientists. It is a "model organism," used in a wide array of biological experiments, just as *Bacillus subtilis* is a model bacterium for researchers.

Arabidopsis thaliana—The only plant included in the LIFE capsule is known scientifically as *Arabidopsis thaliana* and more commonly as the thale cress or mouse-ear cress. Thanks to its relatively small genome, its short life cycle, and the ease with which it can be genetically manipulated, *Arabidopsis thaliana* has become a favorite of scientists and is now used as a benchmark in plant research. Furthermore, *Arabidopsis thaliana* already has been to interplanetary space as part of the Biostack experiment that flew to the Moon. By comparing the results of the short trip to the Moon with the effects of the long trip to Phobos, scientists can gain exceptional insights into plants' ability to adapt to conditions of interplanetary space.

Tardigrades—These organisms are members of the animal kingdom and are popularly known by the more endearing name "water bears." Tardigrades are huge compared with the other LIFE travelers, except the seeds, but tiny by human standards: the largest adults reach a length of 1.5 millimeters, and the smallest are less than one tenth of that. Their bodies are composed of four segments, each with two legs punctuated by claws at the end. Tardigrades are extremophiles, capable of surviving in extraordinarily hostile conditions: they can tolerate being heated to more than 150 degrees Celsius (300 degrees Fahrenheit) for several minutes or being chilled to just a few degrees above absolute zero; they can withstand both the pressure of 6,000 atmospheres and a vacuum; they have survived exposure to space in low Earth orbit; and they are radiation resistant. The secret to tardigrades' mind-boggling survivability is their ability to enter a state of *cryptobiosis*, or suspended animation. In this condition, their water content is drained to 1.0 percent of normal, and their metabolism is reduced to 0.01 percent of its normal rate.

• Permafrost

The final passengers to Phobos in the LIFE module are the microbial residents of permafrost grains from the Siberian arctic, provided by Russian scientists. The rationale behind including them is that a living colony of interdependent organisms has been shown to be hardier and more resistant to hostile environmental conditions than a single organism on its own. When the grains return from their long sojourn in space, scientists will be able to compare any surviving organisms with identical control samples that were left on Earth.

Ten Earthly organisms and a few grains of permafrost will soon be launched on an epic journey between worlds. Will any of them live long enough to thrive on Earth once again? Both scientists and laypeople around the world can't wait to find out.

Amir Alexander is a writer-editor for The Planetary Society's website, planetary.org.

Below: This is a full-scale mock-up of the* Phobos-Grunt *spacecraft, slated for launch in October this year. The sample return mission will land on Mars' moon Phobos in August 2010, gather samples, and return them to Earth in 2012. As* Phobos-Grunt *swoops back past Earth, the LIFE biomodule will be released to land on Earth, very much like a meteorite does. *Photo: CNES*

Above: The rugged, well-sealed titanium LIFE module is just 57 millimeters in diameter and fits comfortably in the palm of one hand. Hitching a ride on board the* Phobos-Grunt *mission, this tiny space capsule will carry LIFE's 30 sample tubes and 1 colony sample. When the organisms inside this module return from their three-year journey in interplanetary space, they will help to shed light on one crucial riddle of the transpermia hypothesis: whether life can survive space travel if protected inside rocks blasted by impact off one planet to land on another. *Photo: Bruce Betts*

THE QUEST TO FIND THE NEXT KILLER ASTEROID—BEFORE IT FINDS US!

BY STEVE CHESLEY

As has happened many times in Earth's history, a piece of the solar system has struck our planet. Impact Imminent *depicts an asteroid on a collision course with Earth. The result of such an impact can be no more than an interesting rock in an open field, or it can involve planetwide devastation and the extinction of life. The people of Earth are becoming more aware of this danger, and we're lucky that some of them are working hard to make sure that scenes like this do not happen again.* *Illustration: Mark Garlick*

Some clear, cold, dark night this spring, a dome on Maui's Haleakala peak will open, and the telescope inside will start imaging the sky in minute detail. The 1.8-meter Pan-STARRS 1 telescope and its 1.4-gigapixel camera, after more than six years in development, finally are ready for action, probing the heavens and cataloging billions of the celestial objects that grace our skies.

PS1, as it is called, will pull back the virtual curtains on the skies for scientists involved in nearly every aspect of astronomy, from cosmology to galaxies, quasars, supernovae, and, yes, even plain, ordinary stars. It will also yield the most thorough inventory of the solar system ever made:

ALPHABET SOUP

Asteroid experts use an array of abbreviations and acronyms to refer to different types of objects in the inner solar system. Among them are the following:

- **NEO**: Near-Earth Object. Any asteroid or comet that passes within 1.3 AU of the Sun. Earth revolves around the Sun at 1 AU (about 93 million miles, or 150 million kilometers), so many—in fact, most—NEOs do not pose a risk of impact with Earth. Long-period comets (those whose full orbit takes more than 200 years) are excluded.
- **NEA**: Near-Earth Asteroid. The subset of NEOs that are asteroids rather than comets.
- **PHA**: Potentially Hazardous Asteroid. Any NEA whose orbit passes within 0.05 AU of Earth's orbit, meaning that approaches closer than this distance are at least possible. (Some astronomers further restrict the set of PHAs by requiring that they have an estimated diameter of at least 140 meters, but that convention is not used here.)
- Other categories, such as PHO and NEC, are used less frequently but follow the simple descriptions above.

NEA classes

- **Amor class**: NEAs that orbit the Sun entirely exterior to Earth's orbit
- **Apollo class**: Earth orbit crossing asteroids with orbital periods longer than one year
- **Aten class**: Earth orbit crossers with orbital periods less than one year
- **Atira class**: NEAs that orbit the Sun entirely interior to Earth's orbit. These are the hardest to discover, with only about ten found to date.

in just three years it will more than double the number of cataloged objects in all classes, including near-Earth objects, main belt asteroids, icy dwarf planets at the outer reaches of the solar system, and more. Among the several scientific goals for this telescope is one with a purely practical application: to warn of a catastrophic asteroid impact with Earth.

THE ASTEROID HAZARD

Until only about 30 years ago, scientists did not recognize that the demise of the dinosaurs 65 million years ago probably was caused by a huge impact of an asteroid several kilometers across into what is now Mexico's Yucatán Peninsula. That impact was a global catastrophe of immense scale. The collision involved millions of times more energy than the largest nuclear weapons and caused global earthquakes and huge tsunamis. Material ejected into space rained down around Earth, superheated by atmospheric reentry, to cause a planet-wide firestorm. The dust and soot that were lofted into the upper atmosphere blocked solar radiation, and that brought photosynthesis—and indeed the entire food chain—to a virtual standstill. It was a very bad day indeed.

The Pan-STARRS 1 (PS1) telescope, visible inside its dome on top of Maui's Haleakala peak, will use its 1.4-gigapixel camera to find distant asteroids headed for Earth.
Photo: Brett Simison, © Institute for Astronomy, University of Hawaii

To our good fortune, and thanks in large part to the asteroid searches conducted so far, we can now say with confidence that no asteroids large enough to cause such a global calamity are headed our way. Indeed, searches to date have been so successful that no more than a handful of multikilometer potentially hazardous asteroids (PHAs) remain to be discovered, and the majority of the asteroid hazard now stems from much smaller objects. Although there are likely still a few undiscovered PHAs out there with the potential to cause a global climatic disruption, these will be found in due course as we direct our attention to finding threatening asteroids that are much smaller but still pack a terrific punch.

Impactors as small as 50 meters, and some even smaller, have the capability to cause tremendous damage over areas tens of kilometers across. These "city-buster" asteroids strike Earth every thousand years or so, but most of them have landed, and are expected to land, in uninhabited regions. Population centers should be affected far less frequently, about once in 20,000 years. Larger asteroids, in the range of several hundred meters in diameter, collide much less frequently, on intervals of hundreds of thousands of years. Yet one of them could ruin an average-sized state or European country or create a tsunami that would ravage the coastlines of an entire ocean basin. It's the magnitude of the destruction, not its frequency, that is most concerning.

RECENT HISTORY

The public at large is coming to acknowledge, more and more, the risk posed by celestial objects impacting Earth. At the same time, policymakers are recognizing not only that this threat is serious but also that this one—unlike other natural catastrophes—is wholly preventable, because we have the technology to deflect an incoming asteroid if we have sufficient warning.

Of course, if we don't find the next impactor before it finds us, all the deflection technology at our disposal will be useless. This is why the asteroid search programs are vital to making Earth a safer place to live. If we find an object on a collision course, then we have the opportunity to deflect it, which surely beats the alternative. Even if the surveys do not turn up something on a collision course, we still will be safer for the effort, because the statistical threat posed by undiscovered asteroids will be reduced. It is, after all, the ones that we don't know about that pose the greatest concern, which is why simply discovering asteroids actually reduces the risk that we face.

ASTEROID DEFLECTION

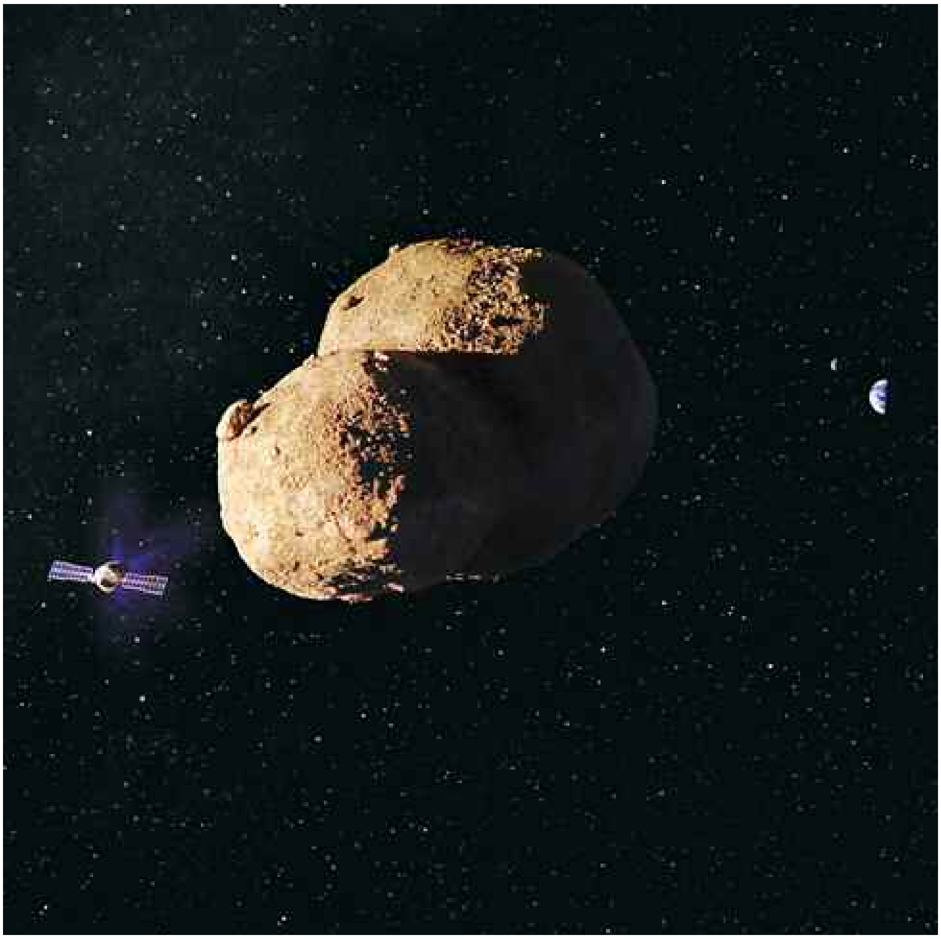
Various techniques have been proposed to prevent an asteroid from striking Earth. Some are already doable with current technology, whereas others can only be considered futuristic.

Current technology

- **Smack it**—use a high-speed spacecraft collision to knock it out of the way
- **Tractor it**—hover a spacecraft close by and use the mutual tug of gravity to tow it to a safe orbit
- **Nuke it**—best reserved for situations in which more controlled techniques are not powerful enough

Not ready for action

- **Paint it**—change the way heat radiates from the surface to subtly alter the orbit
- **Broil it**—use a solar concentrator or laser to boil away material
- **Tug it**—send a tugboat spacecraft with really big grappling arms

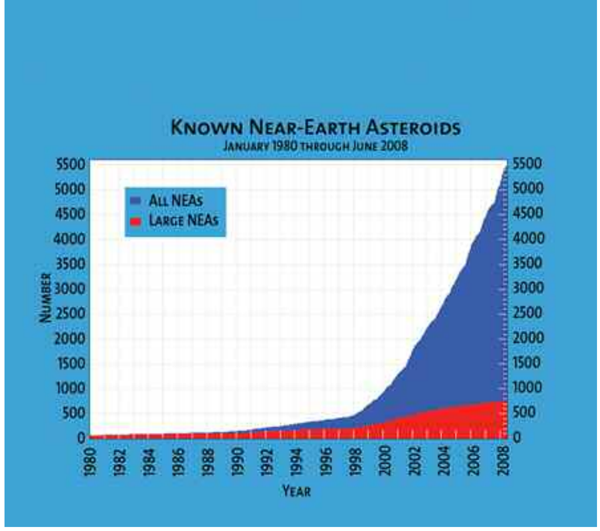


Given sufficient warning, we have the capability to deflect an incoming asteroid. This gravity tractor was designed based on the best current analysis of what we could actually produce with the technology we have on hand right now.
Illustration: Dan Durda

Although nowadays the threat is widely acknowledged, we've traveled a lengthy road to reach this point, going all the way back to the recognition by Edmond Halley in 1705 that certain comet orbits could intersect Earth's path. The 20th century opened without the knowledge of a single Earth-crossing asteroid and only a dim understanding of the nature of the many craters seen on Earth and the Moon. By 1908, however, humankind had seen its first reasonably well documented asteroid impact, in the remote Tunguska region of Siberia, although it would take scientists decades to fully grasp what had occurred. The first Earth-crossing asteroid, 1862 Apollo, was discovered in 1932, and the search for near-Earth asteroids was on. Well, sort of . . .

The truth is that, although sporadic efforts began in 1973, the search for near-Earth asteroids didn't really take off until NASA pledged in 1998 to pursue what became known as the Spaceguard Survey. The goal of the survey was to discover 90 percent of NEOs larger than 1 kilometer in diameter within 10 years. That effort has been immensely successful since 1998; researchers have discovered 564 of the 762 currently known kilometer-sized NEAs. Current estimates put the total number at about 940, so we have reached the end of the first decade of the Spaceguard Survey having cataloged about 80 percent of the target population. That is a bit short of the original goal but quite respectable considering that only about 20 percent had been cataloged when the survey got under way.

A powerful collision in the asteroid belt millions of years before the dinosaurs evolved on Earth may have been the source of the meteorite impact that ultimately killed them. Some of the fragments of such a large breakup might even have caused a few of the impact craters on the Moon and Venus. Illustration: Don Davis



In 1998, NASA launched the Spaceguard Survey with the goal of discovering 90 percent of "large" near-Earth asteroids (one kilometer or more) in ten years. Spaceguard has cataloged an impressive 80 percent of that target population, but it will take a few more years to reach the 90 percent goal. *Graphic: Alan B. Chamberlin, JPL*

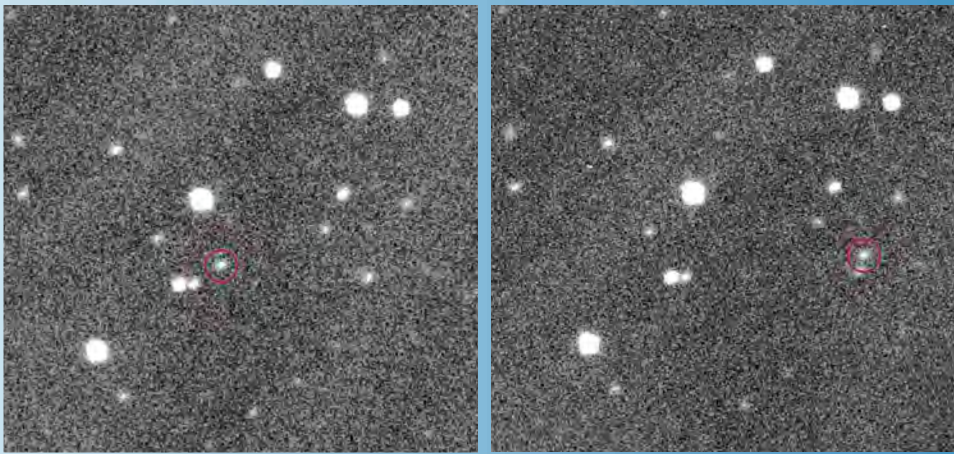
Unfortunately, even at current discovery rates, it will take several more years to inch up to the 90 percent goal. It is apparent that the discovery rates for kilometer-sized NEAs has started to slow; the low-hanging fruit has been picked, and the search continues for objects on orbits that only rarely present themselves for discovery.

Meanwhile, Congress has acted on a 2003 NASA study that recommended extending the search to much smaller sizes. It has commissioned the space agency to undertake a next-generation survey to find 90 percent of threatening objects 140 meters in diameter and larger by the end of 2020. That target size was chosen because it represents the level of survey needed to reduce the hazard from objects of all sizes by more than 99 percent of what it would be if we had never begun cataloging NEAs. Although NASA has not yet been allocated the funding to take up the new survey challenge, far more powerful search programs certainly will need to be brought to bear.

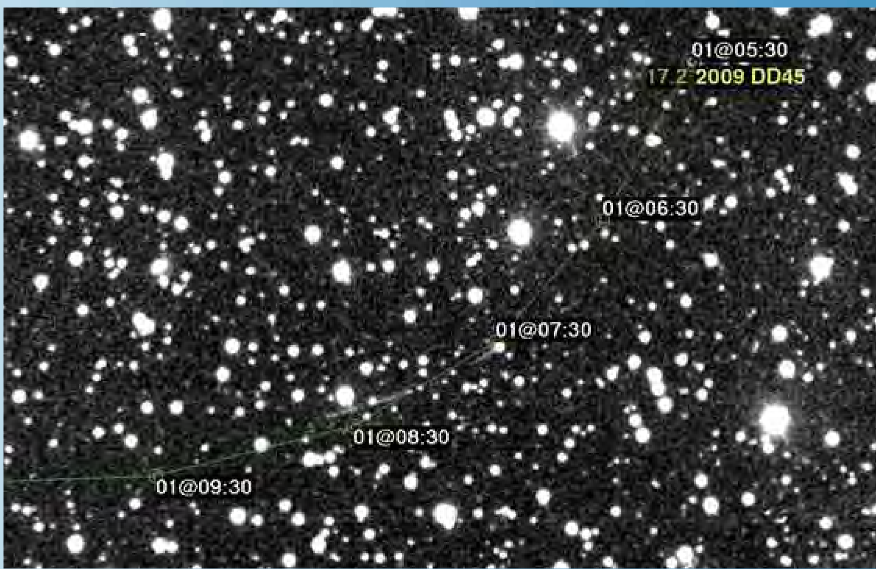
The advent of Pan-STARRS 1 therefore is timely. It should easily find the remaining kilometer-sized objects needed to achieve the Spaceguard goal, as well as making significant progress on finding smaller objects. The overall performance of a survey telescope depends upon how rapidly it can scan the night sky in search of moving objects and the faintness of ones it can detect. This is best measured by a telescope's so-called *étendue* (AY-tahn-doo), the product of collecting area and field of view. This measure takes into account the amount of sky covered as well as the depth. By this measure, PS1 will have six times the effectiveness of the top-performing NEO search instrument, the Mt. Lemmon Telescope of the University of Arizona's Catalina Sky Survey. PS1 represents a huge step forward, but still more powerful telescopes will be needed to search efficiently for 140-meter asteroids. Some of these, as we shall see later, are already in development.

How Asteroid Search Programs Work

Asteroid search programs operate by scanning areas of the sky repeatedly and checking to see which of the "stars" move against the background star field between successive



Observers using the Catalina Sky Survey Telescope in Arizona were first to spot asteroid 2008 TC3 speeding toward Earth on October 6, 2008. The author then confirmed its chances of collision to be 100 percent. These are sample frames from an animation tracking 2008 TC3 before its October 7 impact over Africa's Nubian Desert. *Images: NASA/Catalina Sky Survey*



On March 2, 2009, an asteroid 30 meters in diameter buzzed past Earth only 70,000 kilometers (40,000 miles) above the surface. That is only one fifth the distance between Earth and the Moon. NEO Shoemaker Grant winner Jean-Claude Pelle tracked the object, named 2009 DD45, from Moana Observatory in Punaauia, Tahiti. This view is composed of images taken one hour apart on March 1, the day before closest approach. *Image: © 2009 Noeline Teamo, Southern Stars Observatories. Courtesy of Jean-Claude Pelle*

images, which typically are separated by about half an hour. In the days of photographic plates, the movement would be detected visually through the use of a device known as a *blink comparator*, which allowed the user to quickly alternate back and forth between two photographic images. With CCD cameras and digital images, the "blinking" can be done on a computer screen, and several images can even be looped to form a movie of the sky, making the asteroids obvious as they slip along among the stars. For large-scale efforts, moving object detection had to be completely automated, with computer software identifying those points of light that appeared to move. This has been the norm for more than a decade, but the next generation of sky surveys will employ a subtly different approach.

At two images per minute, the 1.4-gigapixel Pan-STARRS 1 camera will produce a couple of terabytes of data every night, enough to fill hundreds of DVDs. (Fortunately, much better storage and archiving options are available!) As the survey progresses over months and years, these images will be gathered and sewn into a magnificent map of the static sky, revealing the largely constant elements of our celestial surroundings. Researchers will note any new objects, termed *transients*, that are seen in a particular image but not on the static sky map. Any transients that hold their position on the sky map will be investigated as possible supernovae, variable stars, and so on, whereas those that show movement in subsequent images will be passed on for further analysis as potential asteroids and comets.

Connecting the disparate transient detections according to which particular object, if any, they belong to is key to making the survey a success. The potentially hundreds of millions of apparently mobile transient detections, many so faint that they may not even be real but instead only puffs of noise in the camera electronics, make this a monumental computational and bookkeeping task. The Pan-STARRS 1 team has not taken this challenge lightly and has made a significant investment in this aspect of the survey, ensuring that they will be able to figure out, from night to night, month to month, and year to year, which detections go with which object.

After an NEA has been sighted by PS1 on at least three nights and those sightings have been linked, an orbit is automatically computed and transmitted, along with the associated positions and brightness measurements, to the Minor Planet Center (MPC). Subsequent sightings are sent in the same manner, and as the number of measurements increases, it is even possible to find earlier detections of the same object by revisiting unlinked measurements made in previous months and years. The MPC, which is located on the campus of Harvard University in Cambridge, Massachusetts, is the designated international clearinghouse for asteroid and comet observations made worldwide. The MPC compiles the data and makes them available to amateur and professional astronomers around the globe.

Among the MPC's customers are the two teams that operate impact-monitoring systems, one at the University of Pisa in Italy and the other at NASA's Jet Propulsion Laboratory. Their common objective is to learn as early as possible if an asteroid has a possibility of impacting Earth. Such a possibility is not particularly uncommon shortly after an asteroid is discovered because there is limited information about its present track, and future predictions are even more uncertain. If Earth does fall within the wide trajectory uncertainties of a new discovery, then a collision is possible, but by the same token, the probability of impact will be comparatively low. As more data are gathered, the uncertainty region shrinks and the impact probability rises, until the Earth is no longer in the possible path of the asteroid and the possibility of collision is eliminated. That is the nature of impact monitoring: things often look worse before they start to look better. In the rare case of a true future impactor, Earth would remain in the shrinking uncertainty region until the impact probability reached 100 percent.

Impact monitoring brings the vital benefit of ensuring the earliest possible warning of an impending impact. An unavoidable consequence is that the vast majority of (we hope all) potential impact warnings eventually will be downgraded and ultimately eliminated. This pattern has sometimes left the unfortunate perception that astronomers are fomenting asteroid scares that discredit the entire process. The only real alternative is a cure worse than the disease; that is, to keep these results secret, which thwarts the efforts of other observers to get as much data as soon as possible on the most interesting objects.

The truth tends to be far less alarming than an information vacuum, especially when the subject tends to prey upon the public's sense of dread and feeds so handily into conspiracy theories. With this pattern of information dissemination and use as a backdrop, the impact-monitoring teams work largely independently but communicate regularly, and they share their results promptly with the public.

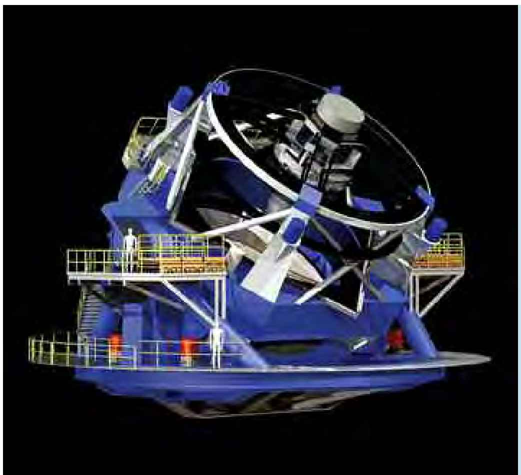
Next-Generation Surveys

Pan-STARRS 1, as amazing as it is, is only a technology demonstrator for a future system called Pan-STARRS 4 (PS4). That system would have four identical copies of the PS1 telescope and camera system, all imaging the same patch of sky and merging the four images to match the performance of a much more expensive 3.6-meter telescope. Designers have not yet finalized whether the four telescopes would be installed on a single huge telescope mount or each steered separately on its own mount. Similarly, the eventual location is not certain, but it could be sited on Hawaii's highest peak, Mauna Kea, where a number of the world's finest observatories already are situated. It is currently unclear when PS4 might become operational or how much it would cost.

A bit further downstream, the 8.4-meter Large Synoptic Survey Telescope (LSST), slated for initial survey operations in 2015, will be even more powerful and potentially able to complete, in 10 years of operation, the congressional goal of finding 90 percent of threatening objects 140 meters in diameter and larger. The LSST, expected to be developed through a public-private partnership, with significant funding expected from the National Science Foundation and the U.S. Department of Energy, may be the most ambitious astronomical instrument ever undertaken. In terms of étendue, PS4 will perform like four copies of PS1, which indeed is exactly what it will be, and LSST will be equivalent to an incredible 25 PS1s. It would have 150 times the capability of the best instrument now searching for asteroids.

These next-generation surveys will discover tens of thousands of PHAs, from kilometer-sized asteroids capable of causing global climate disruption and attendant crop failures, down to asteroids only tens of meters in diameter, too small to cause much noticeable damage. Many of the objects discovered by these surveys will appear threatening initially, but it is reasonable to assume that nearly all of them eventually will be ruled harmless. That's something that we'll have to learn to live with. There is, however, a fair chance that the next Earth impactor will actually be identified with many decades and perhaps centuries of warning time, which will provide ample opportunity for humankind to do what the dinosaurs couldn't.

Steve Chesley is a principal engineer with the Jet Propulsion Laboratory's Solar System Dynamics Group and part of NASA's Near Earth Object office. He developed and maintained Sentry, NASA's impact monitoring system, and is a collaborating scientist with the PS1 and LSST projects.



The 8.4-meter Large Synoptic Survey Telescope (LSST) will use a special three-mirror design, creating an exceptionally wide field of view. Scheduled to begin operations in 2015, LSST will be able to scan the entire accessible night sky in only three nights.

Illustration: LSST Corporation

Annual Report to Our Members

Dear Planetary Society Members, Donors, and Friends,

Please join me as I look back at The Planetary Society in fiscal year 2008: October 1, 2007 through September 30, 2008.

This has been a momentous year for the Society and for the world, a year filled with tremendous challenge, opportunity, and potential for change.

You have been at our side throughout, and you stand strong with us today. I appreciate your loyalty and generosity, which ensure that the Society can weather harsh times.

As a lifelong space enthusiast, longtime Planetary Society member, and chair of The Planetary Society Board of Directors, I am buoyed by your continued commitment to our cause. To explore, to push the frontiers of space, and to seek life beyond our own pale blue dot of a world is to better know and understand the cosmos and our own Earth.

Looking back over the year, we all should applaud our successes, only a few of which are the international Apophis Mission Design Competition, the touchdown of *Phoenix* in the Martian arctic—with my name and yours and The Planetary Society *Visions of Mars* library aboard—the go-ahead for our LIFE experiment to the Martian moon Phobos, and Town Hall meetings filled with people who are passionate about shaping our future in space—our fellow "Planetary Citizens"—which culminated in our Roadmap to Space.

Thank you for joining with me, and with all of us who constitute the grassroots Planetary Society, on this incredible journey.

Charting a Clear Course

Fittingly, given our view of Earth as one planet among many, and given our role as stewards of our planet, we began the fiscal year by accepting the prestigious Washington, D.C.-based Center for Strategic and International Studies' invitation to join its Working Group on Earth Observation and Global Change. This group, comprising representatives from science, industry, and government, will produce policy recommendations for national and international Earth observation strategies.

We complemented this work with a "Planet Earth" edition of *The Planetary Report*. This issue, sponsored by Northrop Grumman, addressed how our planet is changing—and how we, as citizens of Earth, must monitor these changes.

Thanks to renewed funding from the Kenneth T. and Eileen L. Norris Foundation, Planetary Radio enhanced its programming and added a new voice, that of Society Vice President Bill Nye the Science Guy®, whose weekly commentaries examine Earth and beyond.

The Society's Target Earth program marked the centennial of the Tunguska event, a major asteroid impact, and highlighted our efforts to protect our planet from near-Earth objects. Target Earth activities ranged from announcing the Apophis Mission Design Competition winners, to citizen advocacy, to a call for proposals for our Gene Shoemaker Near-Earth Object Grants, to Discovery Canada's television special *Asteroid Trackers*.

In February 2008, the Society awarded $50,000 to seven winners of the Apophis Mission Design Competition to "tag" this potentially dangerous asteroid. SpaceWorks Engineering, Inc. of Atlanta, Georgia, with SpaceDev, Inc. of Poway, California, took first place with their *Foresight* mission, and the (Atlanta) Georgia Institute of Technology *Pharos* mission took first place in the student category. European teams took second and third places.

New Visions of Mars

The Planetary Society celebrated when *Phoenix* landed safely at the Martian arctic in May. Your names and the Society's *Visions of Mars* library—a collection of 19th- and 20th-century science fiction and art inspired by the Red Planet—had touched down after 15 years of planning, bearing a message to the future and a tribute to the past.

Society Adviser Donna Shirley, President Jim Bell, and Executive Director Louis Friedman joined me and other New Millennium Committee members in Pasadena, California prior to our Planetfest landing celebration for a meeting and telecon in which we discussed our hopes and plans for the future. Adding to the thrill of the day, these plans were jump-started when an appreciative participant gave us a surprise unrestricted gift of $50,000.

Hundreds gathered at Planetfest; thousands more followed online or at satellite events. Mission scientists delighted the audience, and generous sponsorships made the event possible. Among the sponsors were Ball Aerospace & Technologies, Citizens Business Bank, Aerojet, NASA Jet Propulsion Laboratory, The Space Foundation, California Space Authority, and Visionary Forces.

The Society's worldwide network of volunteers hosted local *Phoenix* events, in addition to the many other public lectures, star parties, and planetary celebrations they created in their communities throughout the year.

A New Roadmap for Human Space Exploration

Our advocacy also took us to Mars, launched with a February 2008 workshop co-sponsored by Stanford University. "Examining the Vision: Balancing Science and

Exploration" convened 50 space experts to consider the United States' Vision for Space Exploration and other key space and Earth science priorities, and to suggest our future course.

Subsequent Planetary Society Town Hall meetings and our Space Priorities Survey gathered input from our members and the public. The result is the November 2008 publication *Beyond the Moon: A New Roadmap for Human Space Exploration in the 21st Century*.

The Roadmap presents a sustainable, international human space exploration program and calls for "a new and flexible program, based on a series of important first-time achievements and an international commitment to exploration and discovery." The Roadmap is on our website at *planetary.org* and is now in the hands of space policy leaders worldwide.

Full Speed Ahead

Today, more than 50 years since the launch of *Sputnik* and our first Space Age, and nearly 30 years since Carl Sagan, Bruce Murray, and Louis Friedman founded the Society, I am confident that with you, my fellow Planetary Citizens, we have the opportunity, desire, and ability to craft a vibrant future for The Planetary Society and, indeed, for the future of space exploration.

True to our mission, we continue to search for signs of extraterrestrial intelligence. You gave generously to our SETI projects in both hemispheres: The Planetary Society Optical SETI telescope in Massachusetts and our radio search in Argentina. When we get a signal, you'll be listening.

And whether it's a new physics or a more mundane explanation of the *Pioneer* anomaly, your generous

Balance Sheet

For the Fiscal Years Ended September 30, 2004, 2005, 2006, 2007, and 2008 in thousands of dollars

	Total All Funds:				
Assets	**FY2008**	**FY2007**	**FY2006**	**FY2005**	**FY2004**
Current Assets					
Cash and Cash Equivalents and Investments	1,316	1,612	1,304	1,511	1,572
Membership Dues and Misc. Receivables	29	32	206	277	209
Inventories	39	42	50	64	53
Prepaid Expenses	39	37	26	49	51
Total Current Assets	**1,423**	**1,723**	**1,586**	**1,901**	**1,885**
Land, Building, and Equipment	**618**	**617**	**655**	**683**	**638**
Total Assets	**2,041**	**2,340**	**2,241**	**2,584**	**2,523**
Liabilities	**FY2008**	**FY2007**	**FY2006**	**FY2005**	**FY2004**
Accounts Payable and Accrued Expenses	154	286	195	206	129
Deferred Dues and Grant Revenue*	1,115	1,134	1,065	1,147	1,247
Total Liabilities	**1,269**	**1,420**	**1,260**	**1,353**	**1,376**
Net Assets (Deficits)	**FY2008**	**FY2007**	**FY2006**	**FY2005**	**FY2004**
Unrestricted	192	389	633	844	(96)
Temporarily Unrestricted	578	529	346	385	1,241
Permanently Restricted	2	2	2	2	2
Total Net Assets	**772**	**920**	**981**	**1,231**	**1,147**
Total Liabilities and Net Assets (Fund Balances)	**2,041**	**2,340**	**2,241**	**2,584**	**2,523**
Revenues	**FY2008**	**FY2007**	**FY2006**	**FY2005**	**FY2004**
Membership Dues	1,207	1,212	1,299	1,366	1,538
Donations/Grants	1,613	1,835	1,180	1,610	1,230
Bequests	170	3	37	72	0
Other **	184	205	396	208	282
Total	**3,174**	**3,255**	**2,912**	**3,256**	**3,050**
Expenses	**FY2008**	**FY2007**	**FY2006**	**FY2005**	**FY2004**
Member Development and Fundraising	556	534	443	421	380
Publications: Print and Web	552	467	535	554	721
Education and Information	184	228	182	117	121
Programs ***	353	364	432	418	455
Member Services	271	345	338	343	331
Administration	304	305	317	312	338
Projects	899	805	798	579	703
Special Solar Sail Expenses	202	267	117	428	132
Total	**3,321**	**3,315**	**3,162**	**3,172**	**3,181**

* Income received but not yet recognized ** Admissions, interest, net sales, royalties, etc. *** Events, lectures, tours, and expeditions

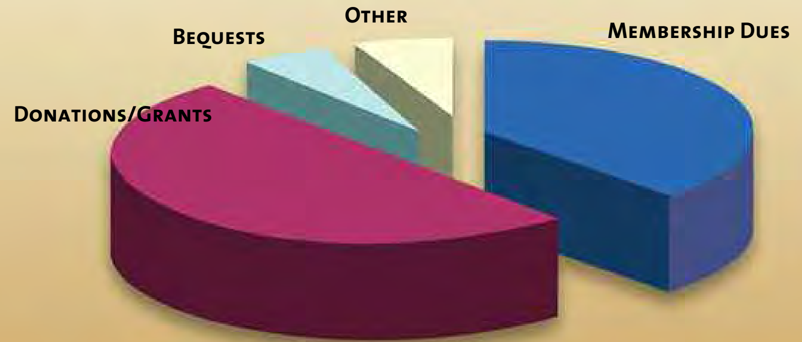
donations helping to fund *Pioneer* data recovery and analyses will have been vital to solving the mystery.

Our partnership with the Secure World Foundation to develop an International Lunar Decade (ILD) to coordinate lunar exploration through a worldwide space agency framework blossomed. NASA enhanced the ILD with its coordination of an International Lunar Network of geophysical monitoring stations on the Moon.

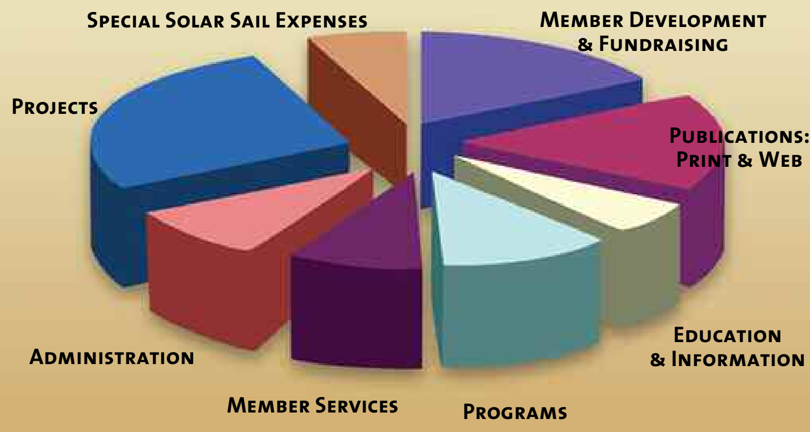
Could life have traveled between planets? You are helping find the answer. Donations from our members, including significant seed funding and a web challenge grant, kept our Phobos LIFE (Living Interplanetary Flight Experiment) project on track to the Martian moon Phobos. LIFE's collection of living organisms will begin a three-year journey to Phobos and back to Earth aboard the *Phobos-Grunt* mission, slated to launch later this year.

We remain committed to flying the first flight with light. We are working on hardware for a new spacecraft, and we are crafting partnerships to encourage the development of solar sail technology, including alliances with NASA Ames Research Center.

Fiscal Year 2008 Revenues



Fiscal Year 2008 Expenses



Your Investment Makes an Impact

Like you, I've been buffeted by the world's economic crisis. I've had to make difficult personal choices, and I've had to make equally difficult decisions as I helped chart a secure course for The Planetary Society.

Our balance sheet reflects a difficult economy, evidenced by a continued drop in membership dues and donations. We are reaching out to new audiences with our popular blog, website, and events. As much as possible, we are minimizing operating expenses while we continue to offer the stellar programs and projects you and the public have come to expect. We continue our quest for a positive future.

Without you, the Society cannot exist. It's that simple. Please introduce a friend, relative, or coworker to The Planetary Society; give memberships to the young people in your life; or create your legacy with a planned gift. You help in many ways—with gifts of cash or securities, matching gifts, bequests, and donations of time and expertise.

I am grateful for your support, and I hope that you take pride in all that we have accomplished this past year. Together, we will make a significant impact on our future in space and on our pale blue dot of a planet.

Thank you.
Sincerely yours,

Dan Geraci
Chair, Board of Directors

Dan Geraci is chair of The Planetary Society's Board of Directors and a member of the Society's New Millennium Committee. He also operates IronAge Consulting Corp, a management and strategic marketing company.

World Watch

Washington, D.C./Paris, France—NASA and ESA (the European Space Agency) have selected the next "flagship" mission for outer planets exploration: the Europa Jupiter System Mission. The selection follows a year-and-a-half-long study of missions to four destinations of interest: two of Jupiter's moons (Europa and Ganymede) and two of Saturn's moons (Titan and Enceladus).

In 2006 and 2007, the U.S. Congress approved a new start for Europa exploration, but at that time, NASA did not want to commit to making requests for mission funding for future years. The Planetary Society campaigned strongly for the mission, and although we won congressional support, NASA refused to start development and instead initiated studies of several candidates. In parallel, ESA considered its own outer planets mission concepts.

Then the two space agencies joined forces to study two candidates:

- Europa Jupiter System Mission (EJSM): to investigate the characteristics of subsurface oceans, with a U.S. orbiter focused on Europa and a European orbiter focused on Ganymede.
- Titan Saturn System Mission (TSSM): with a European Titan lander to float on a hydrocarbon lake, a balloon to investigate the atmosphere, and a U.S. orbiter to study Titan and investigate Enceladus and other Saturn moons.

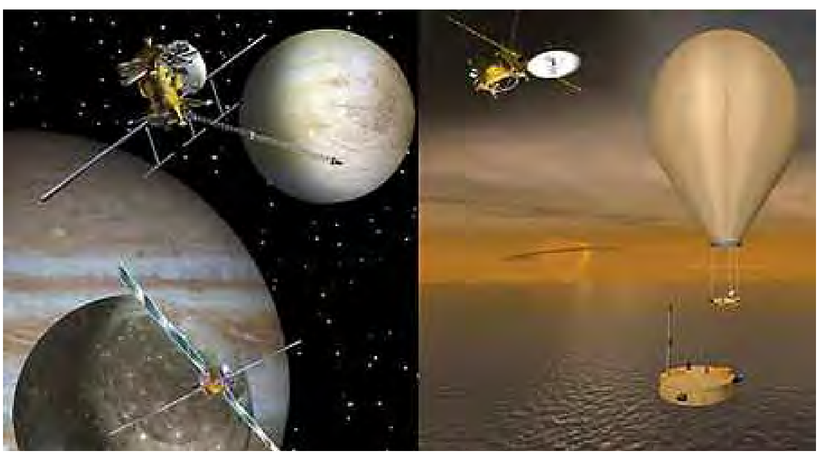
This February, NASA and ESA announced that EJSM won the competition. They also agreed that TSSM was worthy of further study for launch after EJSM.

Either mission will return terrific science. As an engineer, I found the Titan mission, with its balloon and lander, more exciting, but the lure of Europa's ocean of liquid water, warm enough to support life, is not to be denied.

Now we are happy, albeit impatient. We at The Planetary Society wish the mission had been started three years ago, because even with this decision, it won't launch before 2020 and will not reach orbit until 2028.

We are also looking forward to the European-American partnership, which will allow more science and excitement to be accomplished than either NASA or ESA could have achieved alone.

We haven't given up hope that even more can be accomplished with the addition of another international partner. Just as the Europa mission was announced, American, European, and Russian scientists were meeting in Moscow to discuss lander concepts to reach the icy surface. It is unlikely that Russia could be ready for a major role, even for the 2020 mission—the Russians have never done an outer planets mission or a planetary mission lasting longer than one year. Perhaps, however, they can make a contribution based on their successful planetary landers (they are still the only nation to have landed on Venus) and their launch vehicle capabilities.



Artist concept of the proposed Europa Jupiter System Mission (left) and the Titan Saturn System Mission (right). *Image: NASA/JPL*

From around the world—Russia launched its first science mission in several years: *Koronas-Foton* is now orbiting Earth to observe solar activity and the Sun's corona. It was launched on a Tsyklon-3 rocket. The director of the Russian Space Agency, Anatoly Perminov, said that Russia will launch 39 civil spacecraft this year—more than in any recent year and more than any country in the world.

Iran joined the ranks of spacefaring nations with the launch of its first satellite, *Omid* (hope), on a rocket derived from North Korean and Chinese ballistic missile technology.

The first-ever collision of two satellites occurred on February 10, between a working U.S. Iridium spacecraft and a Russian communications satellite that was believed to be nonfunctioning and spinning out of control. The resulting debris, which is predicted to last for 10,000 years, could be a hazard for other satellites in orbit, most worryingly for the Hubble Space Telescope, which is scheduled for another repair mission in the late spring. NASA is now studying the danger.

Whether the debris hazard is immediate or not, it is certain to draw attention to the orbital debris that surrounds Earth, as well as to the need for spacefaring nations to work together to deal with it.

These latest developments remind us that space is now a place for human hopes, to be sure, but also for our foibles.

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

Questions and Answers

Do the orbital planes of exoplanets show any correlation (if only a statistical tendency) with the rotational plane of the Milky Way? Or are their alignments completely random with respect to the galactic plane?
—Peter Hook
Charlottesville, Virginia

I've never seen a study comparing exoplanetary orbital planes with the galactic orbital plane, but I'd be surprised if there was a correlation. Planets form in the planes of the protoplanetary disks of infant stars. Many of these disks have been imaged, and they appear to have random orientations. The planets that form in these disks therefore also should have randomly oriented orbital planes.

Incidentally, most of the 300 or so known exoplanets were detected by either the radial velocity (a star's wobble caused by a planet's tug) method or the transit method (periodic dimming caused by a planet crossing in front of the star). These techniques measure a planet's motion in only one or two dimensions, so we actually don't know the orbital planes of most planets.
—ANDREW HOWARD,
University of California, Berkeley

From time to time, we receive similar versions of the following question. Brent Archinal's answer was first published in our July/August 2001 column. —Editor

The majority of extrasolar planetary systems have been identified through either radial velocity monitoring or the transit method of watching for periodic dimming as the planet passes in front of its star. Because these techniques image extrasolar planets' motions in only one or two dimensions, we don't actually know the orientation of their orbital planes. *Illustration: Courtesy of Fahad Sulehria,* novacelestia.com

On Earth the prime meridian of longitude was based on the observatory at Greenwich. How is longitude determined on other planets and moons?
—David Bonn
Peregian Beach, Queensland, Australia

The prime meridian of planetary bodies other than Earth is defined by international agreement through the Working Group on Cartographic Coordinates and Rotational Elements of the Planets and Satellites. This is a joint group of the International Astronomical Union and the International Association of Geodesy. The prime meridian (that is, the zero-degree meridian) is usually defined by a particular feature, such as a small crater, on planetary bodies with a solid surface.

The choice of the feature is essentially arbitrary. For moons that are tidally locked to their primary planet (like Jupiter's Galilean satellites or Earth's Moon), the prime meridian usually faces the primary planet, and a feature is selected on or near that meridian.

In the case of Mars, a dark marking now known as Meridiani Sinus was (arbitrarily) chosen in the early 19th century to define zero-degree longitude. The positions of objects determined during later telescopic observations were referenced to that feature. When *Mariner 9* was able to take close-up photographs of Mars in the early 1970s, it was possible to determine the coordinates of surface features with much higher accuracy. At that time, while matching the zero-degree longitude system of the old telescopic method as much as possible, the center of a small (500-meter-wide) crater named Airy-0 was chosen to define Mars' prime meridian. Using a single object (a crater in this case) to make such a definition corresponds to the situation in the late 19th and early 20th centuries, when Earth's prime meridian was defined by the position of the Airy transit circle in Greenwich, England.

For planets with no solid surface, such as Jupiter and Saturn, or for the Sun, planetary coordinates are defined in one of two ways. One method entails first determining an approximate rotation rate by timing the passage of some reasonably long-lived atmospheric feature. This feature is then assigned an arbitrary longitude value, and the rotation rate is assumed constant. Using such a starting point and rotation rate allows longitude to be defined anywhere on the body in the future, even if the atmospheric features slowly drift away from their original coordinates.

A second method of defining coordinates involves timing variations in the radio emission from the particular body, thus determining the rotation rate of its magnetic field and core. Again, selecting an arbitrary starting point in time and assuming the derived rotation rate to be constant allow longitude to be defined in the future. Of course, atmospheric features would also move relative to such a system.

Earth's case is special because longitude here is no longer defined by a single surface feature (like the Airy transit circle) but by a weighted average of the positions derived by modern instruments that constantly measure our planet's orientation and its position in space. These instruments include networks of radio telescopes, satellite and lunar laser ranging systems, and Global Positioning System satellite receivers. The International Earth Rotation Service, based in Paris, uses data from these instruments to define latitude and longitude on Earth, as well as coordinates in the sky and the difference between them, which is the orientation of Earth in space.

In the future we hope that a permanent network of landers and/or observatories will be operating on the surface of Mars. At that time, the coordinates there may be redefined based on observations from those instruments.

—BRENT ARCHINAL,
United States Geological Survey

Factinos

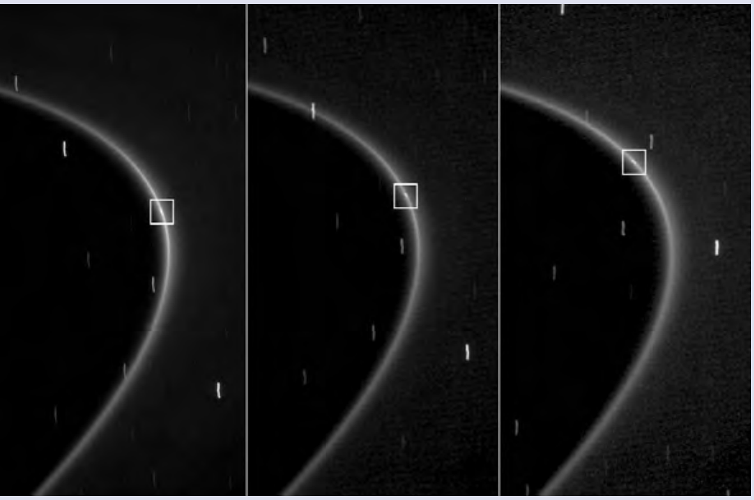
Cassini scientists have found another, albeit tiny, moon around Saturn (see images below). The moonlet is about half a kilometer (a third of a mile) across. *Cassini* imaging team members found the little satellite embedded within a partial ring, or ring arc, in Saturn's tenuous G ring while analyzing images acquired over the course of about 600 days.

The scientists first imaged the moonlet on August 15, 2008 and then confirmed its presence by finding it in two earlier images. They have since seen the moonlet on multiple occasions, most recently on February 20, 2009. The little moon is too small to be resolved by *Cassini*'s cameras, so its size cannot be measured directly. The team estimated the moonlet's size by comparing its brightness with that of another small Saturnian moon, Pallene.

Within the faint G ring, there is a relatively bright and narrow, 250-kilometer-wide (150-mile) arc of ring material that extends 150,000 kilometers (90,000 miles), or one-sixth of the way around the ring's circumference. The newly discovered moonlet moves within this ring arc. Earlier *Cassini* measurements suggested that this partial ring may be produced from relatively large, icy particles (such as this moonlet) embedded within the arc.

"Before *Cassini*, the G ring was the only dusty ring that was not clearly associated with a known moon, which made it odd," said team member Matthew Hedman of Cornell University. "The discovery of this moonlet, together with other *Cassini* data, should help us make sense of this previously mysterious ring."

—from the Jet Propulsion Laboratory



This sequence of images shows the path of a newly found moonlet in a bright arc of Saturn's faint G ring. The pictures were taken by* Cassini *over the course of about 10 minutes on October 27, 2008. Unlike the streaks in the background, which represent distant stars smeared by the camera's long exposure time of 46 seconds, the small streaks inside the G ring move along the ring in the way scientists would expect if an object is embedded there. **Images: NASA/JPL**

Pluto's atmosphere is surprisingly high in methane, causing it to be warmer than the dwarf planet's surface. This may be due to patches of pure methane or a methane-rich layer covering Pluto's surface.

Scientists using the European Southern Observatory's (ESO's) Very Large Telescope (VLT) at Paranal, Chile have found that the atmosphere is hotter than the surface by 40 degrees (although it still only reaches a frigid –180 degrees Celsius, or –290 degrees Fahrenheit). Pluto's surface temperature is about –220 degrees Celsius (–360 degrees Fahrenheit.)

The team made its discovery with the CRyogenic InfraRed Echelle Spectrograph (CRIRES), which is attached to the VLT. "It is fascinating to think that with CRIRES we are able to precisely measure traces of a gas in an atmosphere 100,000 times more tenuous than the Earth's on an object five times smaller than our planet and located at the edge of the Solar System," said ESO's Hans-Ulrich Käufl. "The combination of CRIRES and the VLT is almost like having an advanced atmospheric research satellite orbiting Pluto."

—from ESO

Society News

The Planetary Society—Why Invest Now?

One of the best parts of my job is talking with you, our members and friends around the world. Sometimes your ideas are the focus of a staff meeting, or your compliments a welcome boost to our work, especially in difficult economic times like these.

Recently, I got a note from Brian Hays, one of our newest members of The Planetary Society's New Millennium Committee. I'm sharing Brian's letter because, to quote him, "as a brand new member in times of tight money, perhaps the context of why I joined up (after being a standard member for many years) would be of value." I agree, and I hope you will, too.

"I have a business that is doing OK during the recession, but I'm not a multimillionaire by any means. Still, I'm very lucky to be doing fine financially.

After watching retirement funds and other investments evaporate (or, in this environment, should I say "sublimate"?) significantly, instead of giving in to the immediate impulse to buy a bigger mattress to hold more cash, I looked at what I thought was really worth investing in anymore.

The Planetary Society has always been something I supported both verbally and with contributions for various projects, but in small amounts.

With the hope of having past earnings double themselves in retirement investments being dashed for the moment, and knowing how projects that depend on contributions are usually hardest hit in hard times, I decided that I would literally get more back from investing in the people of The Planetary Society than from any mutual fund.

"Invest" means a lot more than getting money for money.

Investing in people who make great things happen has a guaranteed return—something financial markets specifically deny. They proved their point."

Want to share your reasons for supporting The Planetary Society? Call me at (626) 793-5100, e-mail me at *andrea.carroll@planetary.org*, or send mail to my attention at The Planetary Society, 65 N. Catalina Ave., Pasadena, CA 91106-2301 USA.

Thank you for your investment!
—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 2008 financial staatement was in conformity with accepted accounting principles.

Copies of the financial statement are available upon request.
—Lu Coffing,
Financial Manager

Members' Dialogue

Save Money and Paper

As a member of The Planetary Society, I get a kick out of knowing that I am contributing—both financially and socially—to something special. I also appreciate the letters I receive asking for monetary contributions to help out this cause or that. But I am a student and the 35 U.S. dollars I contribute is about the limit of my financial altruism.

I want to help, but I can't. I can't help but feel dismayed that The Planetary Society is likely spending the greater part of 35 dollars a year to send six magazines and a dozen-odd letters all the way to me in Australia.

Therefore, the best way for me to help is to ask to opt out of snail-mail. Don't get me wrong, I still want to know what donation drives are being run; I just don't need a hectare of the Amazon to stay informed. I'd simply prefer to receive the correspondence by e-mail. You already have the letters typed up, and you already have mass–e-mailing capability.

So, as a Planetary Society member I would ask that we consider having an opt out for physical notifications. For those members who are perfectly happy with e-mails, they'll get that warm, fuzzy feeling from knowing that they're saving the environment and also saving The Planetary Society the very money they keep asking for. If 1,000 members decided that they preferred e-mail, then there would be several thousand dollars that could be better spent within the Society.

We'll give when we can give, regardless of the communique medium.
—KEN McLEAN
Melbourne, Australia

Please send your letters to
Members' Dialogue
The Planetary Society
65 North Catalina Avenue
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or e-mail: *tps.des@planetary.org*

Keeping Our Eyes to the Skies!

"Is Anybody Out There?" Poster
This astounding image, obtained by the Two Micron All Sky Survey, reveals only a fraction of the 400 billion stars in our own Milky Way galaxy.
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Target Earth T-Shirt
We live in a busy solar system! The dangers our planet faces from near-Earth objects (NEOs) are the focus of The Planetary Society's Target Earth program. From our Apophis Mission Design Competition and our campaign to save the Arecibo telescope's radar tracking of NEOs to the Society's ongoing Gene Shoemaker Near-Earth Object Grants, we're helping to prepare Earth to avoid disaster from the skies.
Adult sizes: S, M, L, XL, XXL   1 lb.   **#598**
Regular price: $22.17   **Member price: $19.95**

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

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Spacecraft Science Kits
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Member price: $15.75

#525   Hubble Space Telescope
#560   *Voyager*

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Nebula Poster
22" x 34"   1 lb.   **#315**
Regular price: $15.00
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Regular price: $11.11
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The bollide that blew up in the air over Siberia's Tunguska region in 1908 vaporized before it hit the ground. Nevertheless, the incident is still referred to as an impact. *The Tunguska Event* shows what the resulting shock wave and plume may have looked like. The hot lower vapor, still surging forward, has just cooled from the white-hot intensity that caused flash fires on the ground. Near the middle and at the tail end of the plume, clouds from smaller bursts are starting to rise.

Artist Don Davis uses the computer as his canvas, mostly for animated images shown on the domes of modern planetariums. He was the first animator to create astronomical content for full-dome video and, to date, has produced more art for this young digital medium than anyone else.