BSI Wraps It Up

Caltech has successfully completed a $111-million fundraising effort that began in 1998 to expand the biological sciences, exceeding the original $100-million goal. Funds raised during the Biological Sciences Initiative (BSI) will make possible a new building, new professorships and fellowships, new faculty appointments, and a wide range of new research programs. "Caltech's biological heritage and traditional interdisciplinary strength give us a powerful advantage when addressing fundamental biological questions," says President David Baltimore. This research will result in new drugs and therapies to address diseases such as cancer and AIDS, and will also lead to a deeper understanding of how organisms develop and why they sometimes develop anomalies, as well as an understanding of the biological basis of higher-level brain functions such as consciousness and cognition.

Cochairs for the BSI were Caltech alumnus Ben Rosen (who has since been named chairman of the board of trustees), who contributed $5 million and thereby single-handedly met the campaign's goal for endowed graduate fellowships, and senior trustee Camilla Frost, who contributed $5 million toward construction of the Broad Center for the Biological Sciences.

The Broad Center is named for Caltech trustee and Los Angeles business and civic leader Eli Broad and his wife, Edythe, who provided $23 million—the lead gift—for the building. It will house about a dozen research groups working in such areas as structural, behavioral, and computational biology, and will also contain shared facilities for electron microscopy and magnetic resonance imaging. Additional funding for the building's construction and equipment has come

Work goes on apace inside and outside the Broad Center, slated to open for business in the summer of 2002.

from the estate of William Hacker (BS '31), which provided $8 million in capital funds and $1.4 million in discretionary funds. And more than 5,500 alumni responded to a challenge from Ron and Maxine Linde, in which the Lindes agreed to match new and increased gifts toward the naming of the Ronald and Maxine Linde/Caltech Alumni Laboratories on the Broad Center's ground floor.

The BSI endowed eight new professorships. Trustee Donald Bren contributed $10 million through the Donald L. Bren Foundation to support new faculty as Bren Scholars and eventually endow five Bren Professorships. Also, Caltech received $5 million from the late William and Georgina Gimbel, to be designated for the William T. Gimbel Discovery Fund in Neuroscience. The Keck Foundation, too, provided a $5-million Discovery Fund.

Caltech has already appointed several new young faculty members whose interests embody the initiative's interdisciplinary nature. For example, David Chan, assistant professor of biology, uses cell-biological, biophysical, and genetic approaches to study how membrane-bound systems like organelles and

John Hume to Give DuBridge Lecture

Northern Irish political leader John Hume, who regularly strode through tear gas and dodged rubber bullets in his quest for peace, will be the featured guest at Caltech's Lee A. DuBridge Distinguished Lecture. "A Conversation with John Hume" will take place Tuesday, November 20, at 8:00 p.m. in Beckman Auditorium. The *Boston Globe*'s Kevin Cullen, who served as the newspaper's bureau chief in Dublin and London, will conduct the interview.

Hume was the corecipient of the 1998 Nobel Peace Prize with David Trimble, leader of Ireland's Ulster Unionist party. Until recently, Hume led that country's Social Democratic and Labour Party (SDLP). Hume is Catholic; Trimble, a Protestant. Together they helped negotiate the so-called Good Friday agreement, which remains the basis for negotiations in Northern Ireland.

The event is free and open to the public. No tickets are necessary; at least 500 seats will be available on a first-come, first-served basis. Doors open at 7:30 p.m. For more information, call 626-395-4652 or, toll free, 888-222-5832. □—*MW* viruses fuse under certain circumstances. In particular, he is interested in understanding the fusion mechanism of mitochondria—organelles important for energy production and cell death. He also studies how the human immunodeficiency virus (HIV), the agent of the disease AIDS, enters human cells by fusing with the cell membrane. And Dianne Newman, the Clare Boothe Luce Assistant Professor of Geobiology and Environmental Engineering Science, is leading a project to investigate how microorganisms and Earth's near-surface environments have interacted over billions of years. Her work integrates molecular microbiology with geochemistry and field geology to try to identify chemical signatures of early life in the geological record.

"The biological sciences today present an intellectual challenge that is changing the environment at Caltech," said Mel Simon, the former chair of the Division of Biology, who played a pivotal role in the BSI. "So the resources are here, the vision is here, and some of the people are here. Now all we have to do is great science." □—*RT*

Undergrads Ride the "Vomit Comet"

Though the nickname "Vomit Comet" would scare most people off, four Techers couldn't wait to board NASA's modified KC-135 jet tanker last summer in the name of science. (The plane allows Earthbound scientists fleeting access to zero gravity by flying a parabolic trajectory that produces about 30 seconds of weightlessness; some people handle this worse than others.) Twice a year, university students across the country are encouraged by NASA's Johnson Space Center in Houston to submit proposals to its Reduced Gravity Student Flight Opportunities Program. The winners get to fly the Comet to conduct their experiments.

One of 2001's 35 winning teams consisted of Serena Eley, Dirk Englund, and John Ferguson, all senior physics majors, and sophomore aeronautics major Joseph Jewell. They made tiny droplets of a type of glass called ZBLAN—named for the zirconium (Zr), barium (Ba), lanthanum (La), aluminum (Al), and sodium (Na) it contains—that for some years now has been touted as the fiber-optic material of the future. The optical fibers that are the backbone of today's high-speed data lines are based on silicon dioxide, as is ordinary window glass, and transmit a fairly narrow range of wavelengths. Ultraviolet light, for example, is blocked—you can't get a suntan though a picture window. Near-infrared light is transmitted reasonably well, but the glass quickly turns opaque at longer wavelengths. And even in the visible spectrum, ordinary glass is pretty absorptive—try looking through a piece of glass end-on some time.

ZBLAN is a radically different material that contains no silicon or oxygen. It is a complex mixture of the five previously mentioned metals and fluorine—one of a family of "heavy-metal fluoride" glasses that has been known for about 20 years. ZBLAN is nearly perfectly transparent from the near-ultraviolet to the near-infrared. It's a very tricky material to make here on Earth, however, as molten ZBLAN generally begins to crystallize as it cools. Presumably, the heavier molecules—the zirconium and lanthanum fluorides—have the slightest tendency to sink, while the lighter ones rise. This inadvertent sorting leads to crystallization as like molecules congregate. Each crystal acts somewhat like a tiny mirror, and there go your optical properties—the sample turns milky. But previous experiments on the Comet and elsewhere have shown that zero-G ZBLAN retains its amorphous character as it cools, remaining crystal-clear.

Jewell (left) and Ferguson with the experimental setup, which was kept under helium to prevent oxygen or moisture contamination.

When you hit the top of the parabola, even a harness won't stop you from floating, as Englund (left) and Eley (below) discover.

So if fibers are the name of the game, why were the Techers making droplets? Because ZBLAN microspheres some 300 to 400 microns (millionths of a meter) in diameter could act as "resonators" to store photons of light for long periods of time. These resonators could be married to silicon chips to make oscillators, switches, modulators, and even tiny lasers. Such components are essential to fiber-optic networks, advanced surgical devices, CD players, supermarket scanners, and what have you. And resonators are a staple of the cavity quantum-electrodynamics (QED) experiments that might one day lead to quantum communications networks, quantum cryptography, and even quantum computers, and are of keen interest to the experiment's sponsors—Hideo Mabuchi (PhD '98), associate professor of physics; and Lute Maleki, senior research scientist, and Vladimir Iltchenko, senior member of the technical staff of the Quantum Sciences and Technology Group at JPL. "There has been a lot of excitement about the possibility of using microspheres for cavity QED, but a lot of technical groundwork has to be laid for it to be practical," says Mabuchi. For one thing, making crystal-free ZBLAN microspheres on the ground is no easier than making clear ZBLAN fibers—in fact, it has only been done once, says Maleki.

The experiment's goal is to compare the optical properties of three sets of microspheres made beforehand at Caltech and JPL with three sets made using the same procedures in zero gravity. The microspheres were made with a fiber splicer, which employs a tiny high-voltage arc to melt the ends of two optical fibers and fuse them. In this case, the students melted the tip of a single fiber, allowing surface tension to cause the molten glass to bead up into a sphere. "The result is like a lollypop, a fiber stem with a small sphere on the end," says Eley. The samples' Q factors are now being measured in the lab. "The Q factor is a quality factor," explains Maleki. "If you think of the microsphere as a cavity, the Q factor measures its resonance. The narrower the resonance, the longer the energy-storage time." "In a sense, it's like tapping a wine glass with a fork and measuring how long it takes to stop ringing," says Englund. "The longer it rings, the larger the Q factor."

Eley, Englund, Ferguson, and Jewell were at Johnson Space Center from August 22 to September 1. Several days of training led up to a "chamber flight" on August 28—a room the size of a school bus, says Ferguson, that simulates high-altitude conditions. "They make us breathe pure oxygen for half an hour to get the nitrogen out of our blood, and then they pump it down to 25,000 feet and see how we do. Some people don't feel much of an effect. But some people get really giddy, and some people can't do simple math problems, like 3 + 4, even with a pencil and paper. They do it partly to show us what it's going to be like if there's an emergency in flight and we lose cabin pressure, and partly to document our reactions."

The actual flights followed a couple of days later. Eley and Englund went first, on August 30, logging "about 26" parabolas before deteriorating weather forced them back to Earth. Ferguson and Jewell were slated to go the following day, on the last flight of the season. The weather did not let up, and the flight was very nearly scrubbed. But at the last minute, says Ferguson, "they got access to some airspace they don't normally have. And it turned out to be an absolutely perfect flight." Ferguson and Jewell did 32 parabolas—"close to 15 minutes of total weightlessness. We were lucky enough to be on a very special flight. It was the fourth 'no kill' flight, out of hundreds of flights in the past seven years, where no one actually hurled." The first 30 parabolas were zero-G and strictly business, but the last two were reduced gravity and just for fun. "They did one to simulate lunar gravity and one for Martian gravity. So instead of floating weightless, you drifted very slowly toward the floor. Or you could do pushups, and feel like the strongest man in the world."

The program pays for the training and the cost of the Comet flight, but the team had to raise money for equipment, transportation to and from Houston, and accommodations. Says Englund, "We've been very fortunate with our funding. There are not many schools that would support a group of undergrads wanting to do some science experiment as readily, and as generously, as Caltech and JPL did. JPL put up about $6,000 for fibers and some other things such as shipping the equipment. And Thomas Tombrello, the chair of Physics, Math, and Astronomy, put up a similar amount from the physics department." Each team must also participate in a community project, so the students will be presenting their experiments at a number of Southern California elementary and high schools. □—*DS*

Making Every Vote Count

Though over 100 million Americans went to the polls on election day 2000, as many as 6 million might just as well have spent the day fishing. Researchers at Caltech and MIT call these "lost votes" and think the number of uncounted votes could easily be cut by more than half in the 2004 election with just three simple reforms. "This study shows that the voting problem is much worse than we expected," said Caltech president David Baltimore, who initiated a nonpartisan study after the November election debacle. "It is remarkable that we in America put up with a system where as many as six out of every hundred voters are unable to get their vote counted. Twenty-first-century technology should be able to do much better than this."

According to the comprehensive Caltech-MIT study, faulty and outdated voting technology together with registration problems were largely to blame for many of the 4-to-6 million votes lost during the 2000 election. With respect to the votes that simply weren't counted, the researchers found that punch-card methods and some direct recording electronic (DRE) voting machines were especially prone to error. Lever machines, optically scanned, and hand-counted paper ballots were somewhat less likely to result in spoiled or "residual" votes. Optical scanning, moreover, was better than lever machines. As for voter registration problems, lost votes resulted primarily from inadequate registration data available at the polling places, and the widespread absence of provisional ballot methods to allow people to vote when ambiguities could not be resolved at the voting precinct.

The three most immediate ways to reduce the number of residual votes would be to:

- replace punch cards, lever machines, and some underperforming electronic machines with optical scanning systems;
- make countywide or even statewide voter registration data available at polling places;
- make provisional ballots available.

The first method, it is estimated, would save up to 1.5 million votes in a presidential election, while the second and third would combine to rescue as many as 2 million votes.

"We could bring about these reforms by spending around $3 per registered voter, at a total cost of about $400 million," says Tom Palfrey, a professor of economics and political science who headed the Caltech effort. "We think the price of these reforms is a small price to pay for insurance against a reprise of November 2000." Approximately half the cost would go toward equipment upgrades, while the remainder would be used to implement improvements at the precinct level, in order to resolve registration problems on the spot. The $400 million would be a 40 percent increase over the money currently spent annually on election administration in the United States.

In addition to these quick fixes, the report identifies five long-run recommendations.

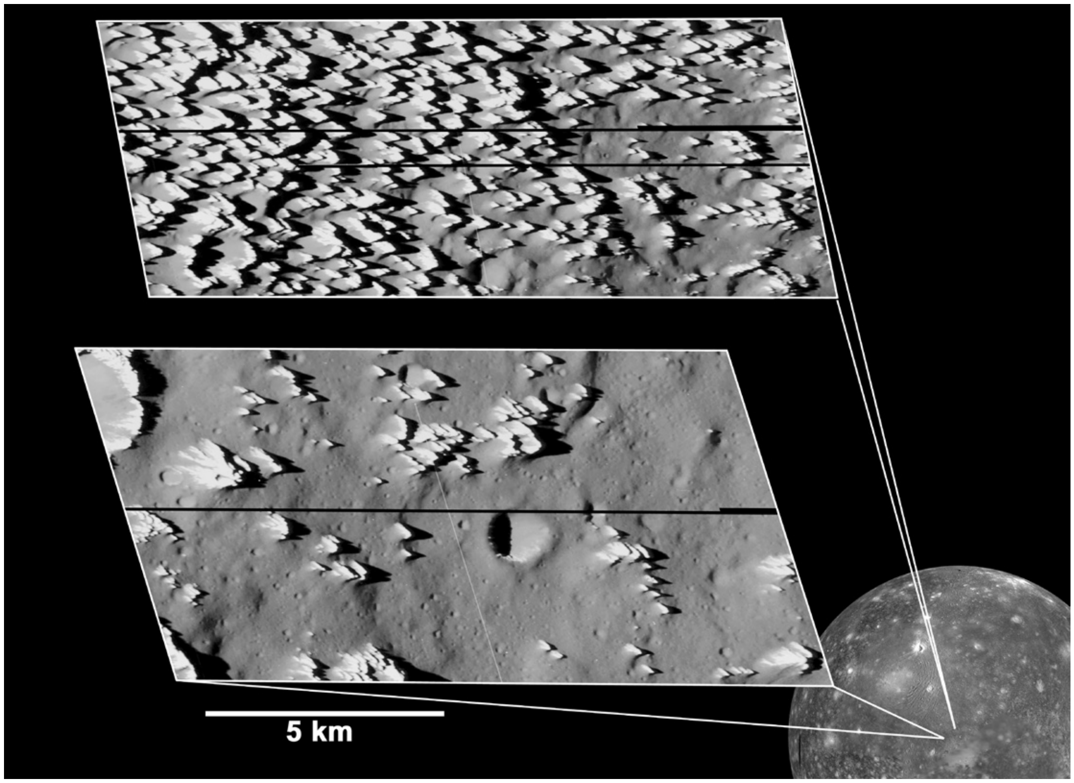
- First, institute a program of federal matching grants for equipment and registration system upgrades, and for polling-place improvement.
- Second, create an information clearinghouse and data-bank for election equipment and system performance, precinct-level election reporting, recounts, and election finance and administration.
- Third, develop a research grant program to field-test new equipment, develop better ballot designs, and analyze data on election system performance.
- Fourth, set more stringent and more uniform standards on performance and testing.
- Fifth, create an election administration agency, independent of the Federal Election Commission. The agency would be an expanded version of the current Office

of Election Administration, and would oversee the grants program, serve as an information clearinghouse and databank, set standards for certification and recertification of equipment, and administer research grants.

The report also proposes a new modular voting architecture that could serve as a model for future voting technology and offer greater opportunity for innovation in ballot design and security.

Despite the fact that there is strong pressure to develop Internet voting, the team recommends caution, due to the potential for fraud, coercion, hacking, and service disruptions. Also, many Americans are still unfamiliar with the technology.

Baltimore and MIT president Charles Vest announced the study on December 15, two days after the outcome of the presidential election was finally resolved. Funded by a $250,000 grant from the Carnegie Corporation, the study was intended to "minimize the possibility of confusion about how to vote, and offer clear verification of what vote is to be recorded," and "decrease to near zero the probability of miscounting votes." The report is publicly available on the Caltech-MIT Voting Technology Project Website, <http://vote.caltech.edu>. □—*RT*



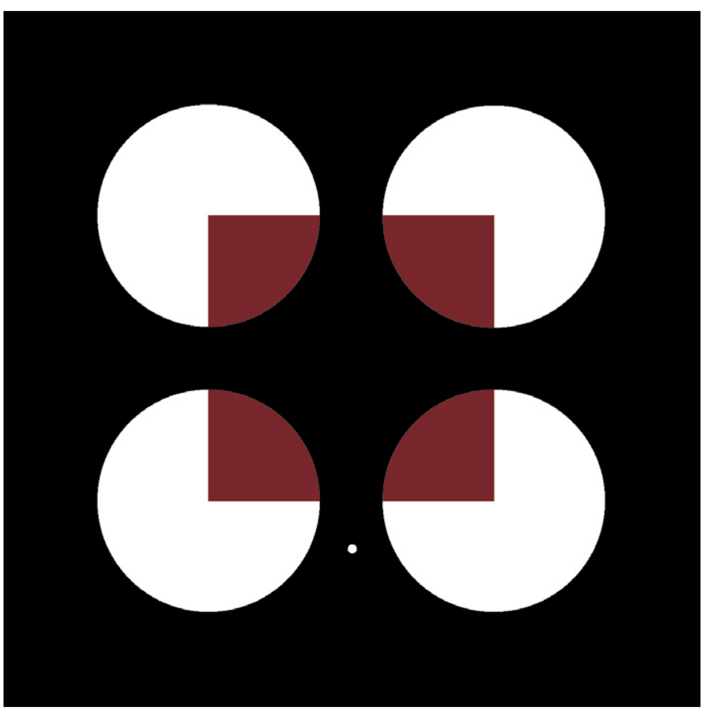
These weird spires on Jupiter's moon Callisto were revealed in the highest-resolution shot ever taken of anything in the Jovian system. Snapped by JPL's Galileo spacecraft in May 2001 as it whistled a mere 138 kilometers (83 miles) overhead, the smallest discernable features are about three meters (10 feet) across. The spires are about 80 to 100 meters (260 to 330 feet) tall, and they may consist of material ejected from the Asgard impact basin, which lies to the north of the sites. Callisto's dense cratering shows that its icy crust may be as much as four billion years old, but these spires indicate that the crust may not be completely frozen in time. As the icy spires seen in the top inset erode, the darker dust contained within them apparently slides down and collects in low-lying areas. The spires will probably disappear one by one over time, producing a scene similar to the bottom inset, where erosion on the plains has essentially ceased, as shown by the accumulation of craters.

Red Square, Green Square

If you stare at a bright red disk for a time and then glance away, you'll soon see a green disk of the same size appear and then disappear. The green disk, called an afterimage, has long been thought to be an effect of the "bleaching" of photochemical pigments or adaptation of neurons in the retina—merely a part of the ocular machinery that makes vision possible. Now, Professor of Biology Shinsuke Shimojo, leading a joint team from Caltech and NTT Communication Science Laboratories, has demonstrated that higher visual centers in the brain are involved. The team showed that an optical illusion in which the brain fills in a color that is not actually present in the visual stimulus could generate a reverse-color afterimage of the filled-in surface.

The team used a graphic in which a red semi-transparent square is perceived on top of the four white disks. Only the right-angled sections of the disks are colored, and there is no local stimulus or indication of redness in the central portion of the display, yet the brain fills in the "missing" red to give an impression of a red square. An observer staring at a real red square would see a reverse-color (green) square for a few seconds after looking at a blank screen. However, subjects who stared at this image and then at a blank screen usually saw four black disks, followed by a second, global afterimage of a solid green square. Try it yourself, by staring first at the white dot in the bottom center of the pattern below left for, say, 30 seconds, and then at the black dot directly below. (This works better on a luminous computer monitor than it does on the printed page, so don't be alarmed if you can't see it; just point your Web browser to http://neuro.caltech.edu/~kamitani/fillingInAfterimage.)

The fact that no light from



the center of the original square was red demonstrates that the effect was not merely caused by a leaking-over or fuzziness of neural adaptation, because the four white disks are at first clearly distinct as black local afterimages. So the global afterimage is distinct from a conventional afterimage. Were the local afterimages of the disks and wedges—but only those—induced first, and then the filling-in occurred to give an impression of the global square, just as the red filled in initially? This is called the "element-adaptation" hypothesis. Or, since circuits using cortical neurons are known to cause the red square's center to fill in, does this same circuit undergo adaptation to directly create the green afterimage—the "surface-adaptation" hypothesis?

Three lines of evidence support the second hypothesis. First, the local and the global afterimages were visible with different timing, and tended to be exclusive of each other. This argued against the first hypothesis that the local afterimages are necessary to see the global afterimage. Second, the strength of the global afterimage was positively correlated with how strongly the initial color filled in, as predicted by the surface-adaptation hypothesis but not by the element-adaptation hypothesis. Finally, the researchers prepared a dynamic stimulus designed specifically to minimize the local afterimages, yet to maximize the impression of color filling-in during adaptation. If the element-adaptation hypothesis is correct, then test subjects would not observe the global afterimage. If, on the other hand, the surface-adaptation hypothesis is correct, the observers would see a vivid global afterimage without local afterimages. The result turned out to be the latter.

The study has no immediate applications, but furthers the understanding of perception and the human brain, says Shimojo. "This has profound implications with regard to how brain activity is responsible for our conscious perception." According to Shimojo, the brain is the ultimate organ by which humans adapt to our environment, so it would make sense if it, as well as the retina, could modify its activity—and perception as a result—due to experience and adaptation. The paper, whose other authors are Yukiyasu Kamitani, a grad student in computation and neural systems; and Shin'ya Nishida of the NTT Communication Science Laboratories in Atsugi, Kanagawa, Japan, appears in the August 31 issue of *Science*. ☐—*RT*

The Origin of Sex

Biologists have long known the advantages of sexual reproduction to the evolution and survival of species. With a little sex, a fledgling creature is more likely to pass on the good mutations it may have, and at the same time would be more able to deal with the sort of environmental adversity that would send its asexual neighbors floundering into the shallow end of the gene pool. The only problem is figuring out how sex got started in the first place. Not only do many single-celled organisms do just fine with asexual reproduction, but mathematical models show that a sexual mutant in an asexual population is usually unable to compete successfully and pass on its genes. But postdoc Claus Wilke and Chris Adami, a faculty associate in computation and neural systems and a research scientist at the Jet Propulsion Lab, used "digital organisms" and simulations of RNA to conclude that established asexual bacteria could be nudged to evolve into sexual reproduction by environmental stresses that raise the mutation rate, such as perhaps catastrophic meteor or comet impacts or high radiation levels.

The "organisms" in Adami's Digital Life Laboratory are self-replicating computer programs that behave much like certain common bacteria. The organisms live in a dedicated portion of the computer's memory, and they must compete with one another for the processor time that allows them to reproduce themselves. The digital organisms offer the advantage that many generations can be studied in a brief period of time. "If you took a population of *E. coli* and subjected it to high mutation rates for many years—for example by irradiation or introducing mutagenic factors—at some point you might observe that exchange of genetic material, a precursor to sexual recombination, would become favorable to the organisms and thus selected for, if at the same time the environment changes fast enough that enough mutations are beneficial," Adami says. "But that's a very difficult experiment to pull off with living organisms because of the time involved, and because it is difficult to construct constantly changing environments in a petri dish. This is easier with digital organisms."

One reason the origin of sexual reproduction has been a mystery is because of an effect known as "mutation accumulation." Organisms tend to adapt so as to decrease the effects of mutations in order to become less vulnerable. But this kind of single-mutation robustness is poisonous to a sexually reproducing species, because deleterious mutations are allowed to accumulate and lead to a gradual loss of genes. This guarantees the extinction of sexual creatures when competing against asexual ones. But it can be avoided if the effects of mutations are compounding—that is, if the effect of two or more simultaneous deleterious mutations is worse than the combined effect of each of the mutations. Now an organism may be robust to a few mutations, but incapable of surviving a large number of them. Thus the mutations cannot accumulate.

Wilke and Adami found that a conservation law applies to the compounding of mutations and the fitness decay due to single mutations. This law says that robustness to a few mutations implies vulnerability to a large number, while robustness to many mutations must go hand in hand with vulnerability to single mutations. Thus, increasing robustness to single mutations automatically makes multiple mutations intolerable, removing organisms with multiple deleterious mutations from the population and allowing sexual recombination to reap the rewards from sharing beneficial mutations. Because stressful environments with high mutation rates push organisms to become robust to single mutations, the conservation law guarantees that this evolutionary pressure also pushes asexual organisms on to the road toward sexual recombination.

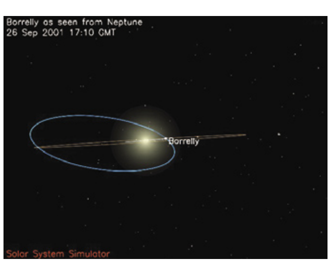
The researchers studied the evolution of digital organisms and RNA secondary structure, because accurate data on the decay of fitness and the effect of multiple mutations (either compounding or mitigating) on living organisms is quite rare. In the RNA study, the researchers used known sequences with well-understood folds and then tried various mutations to see which mutations mattered and which didn't, using a system that computationally predicts RNA secondary structure. The results supported the conservation law.

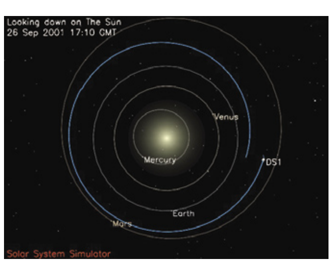
Though the study did not involve actual living organisms, Adami has collaborated in the past with experts on bacteria to demonstrate that the digital organisms are indeed realistic. In a 1999 study, for example, Adami's collaborator was a leading expert on the evolution of *E. coli*.

"The reason the origin of sexual reproduction has been such a big mystery is that we look at the world as it is now," Adami says. "But the early world was a much more stressful place, sometimes changing very rapidly. We can't say how or when sexual reproduction came to take hold in nature, but we can now say that high mutation rates can, under the right conditions, force an asexual organism to become sexual."

The paper was published in the July 22 issue of the Royal Society journal *Proceedings: Biological Sciences B*. □—*RT*

Comet Borrelly's roughly 6.9-year orbit stretches from just beyond Jupiter's to just within Mars's, and is tilted at an angle of about 30 degrees. Deep Space 1 caught Borrelly, which is "one of the most active comets that regularly visit the inner solar system," near its closest approach to the sun.



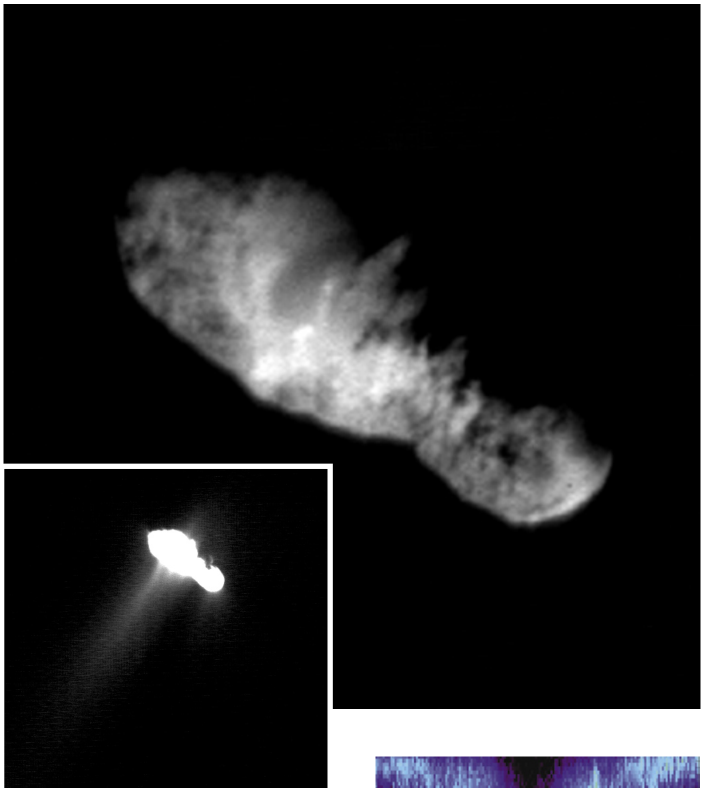


Deep Space 1 Meets Comet Borrelly

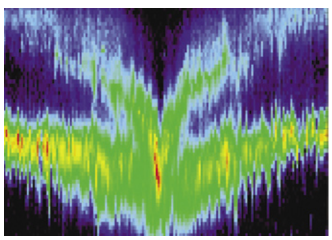
On September 22, an experimental JPL spacecraft named Deep Space 1 (DS1) took the most detailed pictures ever made of a comet's nucleus. The visuals were stunning enough, but the biggest payoff may come from the infrared imaging spectrometer, whose data are still being analyzed. Comets are frozen samples of the primordial solar system—water ice, dry ice, rock, and organic guck—and knowing what's in this one may tell us a lot about where Earth, and the life on it, came from. The flyby was not unlike going over Niagara Falls in a barrel, as Comet Borrelly had been heated to a frenzy of activity by its swoop into the inner solar system. Monstrous jets of gas and dust spew forth as the sun vaporizes the icy terrain, forming a vast cloud, or coma. The daredevil DS1, which was never designed for such a job and carries no shielding of any sort, plunged through the coma a mere 2,200 kilometers from the nucleus, and lived to tell the tale. (At the encounter speed of 16 kilometers per second, a dust grain 80 millionths of a meter in diameter packs the wallop of a bowling ball.) Meanwhile, DS1's plasma experiment, which includes ion and electron spectrometers, was busy analyzing the coma's gaseous components and gathering data on how they interact with the solar wind. (The solar wind is a stream of charged particles that pervades the solar system and pushes a comet's tail away from the sun.) This collection of data and images is but the latest bonus from a mission that has far outlived and outperformed everybody's expectations.

The telephone-booth-sized spacecraft—a midget compared to the school-bus-sized Cassini, or even the VW-bus-sized Galileo—was launched in October 1998. The first of the New Millennium series of high-risk, low-cost missions, its job was to flight-test a package of 12 new technologies for future use. These included an ion drive straight out of *Star Trek*, an autonomous navigation and control system that allows the spacecraft to figure out where it is and what to do next without help from Earth, and miniaturized camera, spectrometer, and electronics packages.

All of these newfangled gizmos had been thoroughly checked out to great acclaim by September 1999, when two months later the star tracker—ironically, a tried-and-true, off-the-shelf item—went belly-up. The star



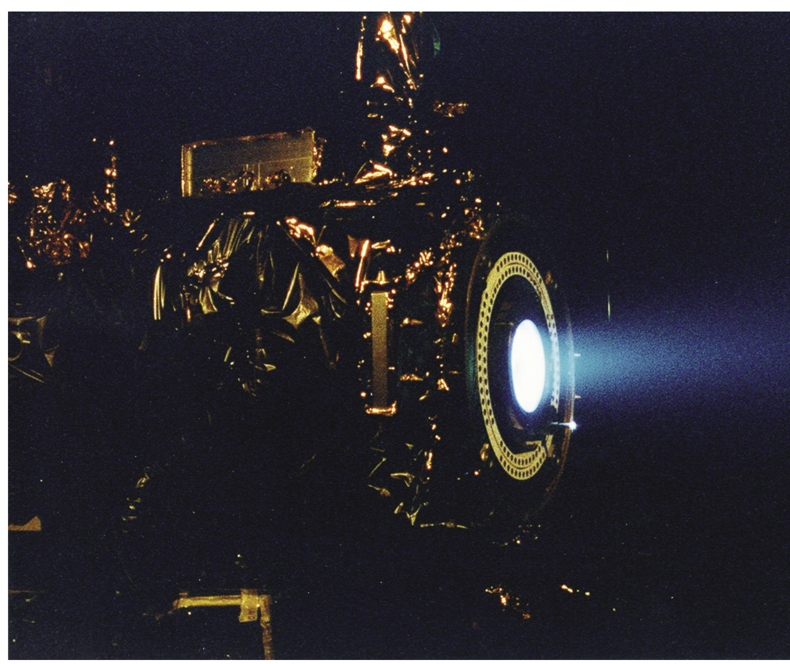
Left: Comet Borrelly's nucleus looks like an 8-kilometer-long bowling pin in this shot, taken 160 seconds before closest approach from a distance of 3,417 kilometers. The smallest visible detail is about 45 meters across. The line dividing the dark and sunlit sides is quite jagged, showing the terrain there to be ridged, even mountainous. This rugged region contains dark patches that appear to be higher than the surrounding areas. In some places, the dark material accentuates deep fractures that may be faults. The central region consists of brighter, smooth, rolling plains that seem to be the source of the dust jets seen in the faint inner coma (inset). This more distant view has been enhanced to show the dust, and reveals that the main jet has at least three smaller features spread over an active region about three kilometers long. A second jet is visible at lower right, as is a cloud of dust floating over the comet's dark side. Although the nucleus is overexposed, the dark side shows what appears to be a crater's rim catching the last rays of the setting sun. The sunlight is coming from below, so the comet's tail (not visible in these images) would be going out the top of the pictures.



Left: In this graphic, the horizontal axis represents DS1's flight path, and the energies of the ions DS1's plasma spectrometer encountered are plotted on the vertical axis. The color shows the number of ions at each energy, with blue being the fewest. The broad V is the solar wind slowing down as it slams into Borrelly's coma; the sharper V is a high-energy stream of ionized water molecules from Borrelly's surface. The comet's nucleus lies at the point of the Vs. It had been assumed that the ion flow around the nucleus would be symmetrical, but the red and yellow region on the left side indicates elevated ion concentrations that are probably related to the visible dust jets. The ions are heated to about 1 million Kelvin.

tracker, which has a field of view about the size of the Big Dipper, recognizes patterns in the background stars to tell the spacecraft which way it (and its camera, spectrometers, and antennas) are pointing. Since DS1 had already fulfilled its primary mission, the logical thing to have done would have been to give it a hearty thank-you and let it die a natural death. Instead, project manager Marc Rayman and his team worked out a way to reprogram the miniaturized experimental camera, which has a field of view about the size of the full moon, to take over the tracking job. Then they had to figure out how to coax the blindly flying spacecraft to point its high-gain antenna toward Earth so the new software could be uploaded. Fortunately, the sun sensor was still working, providing a reference point from which DS1 could sweep out a cone of space that included Earth. □—*DS*

Right: DS1's ion drive being tested in a vacuum chamber at JPL. A rocket engine burns a chemical fuel and shoots the expanding gas out a nozzle to generate thrust. This engine ionizes atoms of the inert gas xenon and accelerates them through a high-voltage grid. The thrust thus provided is very gentle—at full throttle, it's comparable to the force exerted by a single sheet of paper lying on your outstretched palm—but over the long haul it delivers 10 times the acceleration that the same weight of chemical fuel would.



"By virtue of the magnification afforded by the foreground cosmic lens, we are witnessing a source much smaller than a normal galaxy forming its first generation of stars."

Gravity's Magnifying Glass

Exploiting a phenomenon known as gravitational lensing, an international team of astrophysicists has detected a very small, faint stellar system in the process of its formation during the first half billion years or so of the universe's existence. The discovery is being reported in an upcoming issue of the *Astrophysical Journal*. According to lead author Richard Ellis, professor of astronomy and director of the Palomar Observatory at Caltech, the faint object is an excellent candidate for the long-sought-after "building blocks," thought to be abundant at early times, which later assembled to make present-day galaxies.

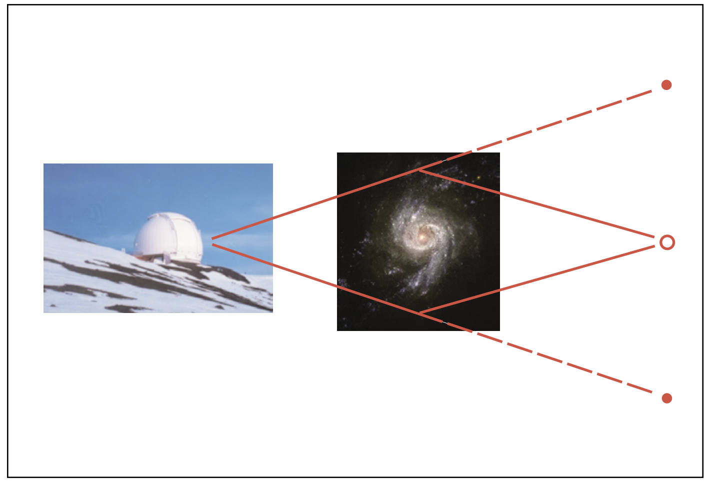
The discovery was made possible by systematically examining small areas in the tract of sky that we see through a massive intervening cluster of galaxies called Abell 2218, which is two billion light-years away. The cluster acts as a powerful gravitational lens, magnifying distant objects and allowing the scientists to probe how distant galaxies assembled at very early times.

Gravitational lensing, a dramatic feature of Einstein's theory of general relativity, means that a massive object in the foreground bends the light rays radiating from one in the background because mass curves space. As a result, an object behind a massive foreground galaxy cluster like Abell 2218 can look much brighter because the foreground object has bent additional photons toward Earth, in much the same way that the glass lenses in a pair of binoculars will bend more photons toward your eyes. This effect makes the system detected by Ellis and coworkers appear at least 30 times brighter than would be the case if Abell 2218 were not in the foreground. Without this boost, neither the Keck Telescopes nor the Hubble Space Telescope would have detected the object. Ellis explains, "Without the benefit of the powerful cosmic lens, the intriguing source would not even have been detected in the Hubble Deep Fields, historic deep exposures taken in 1995 and 1998."

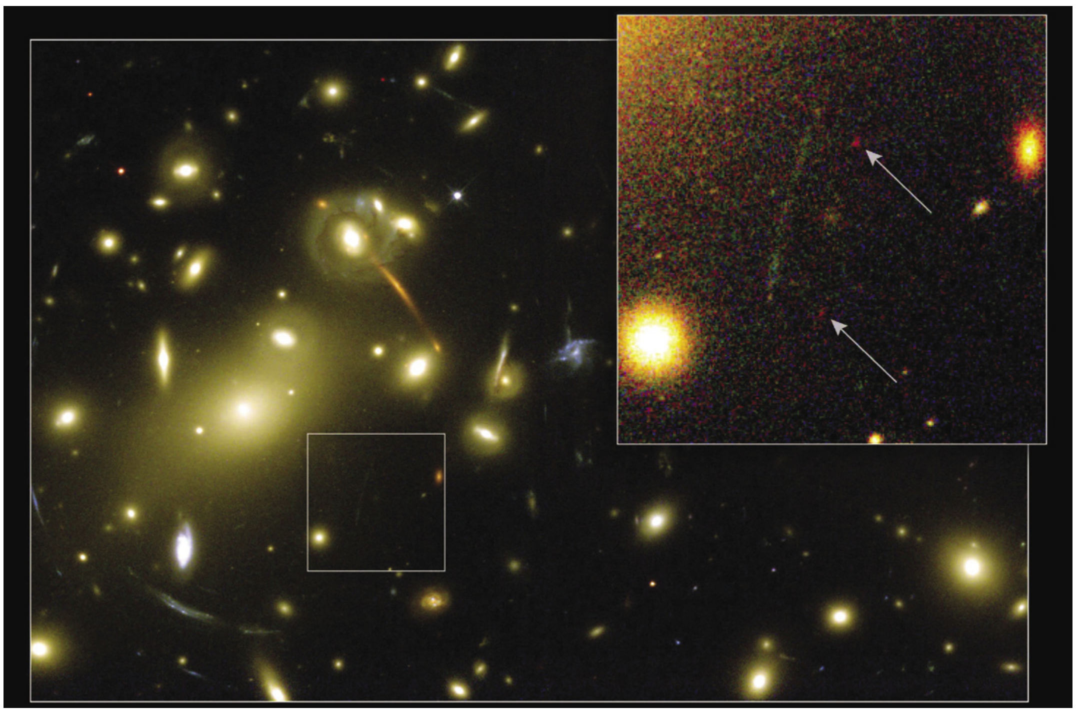
Using the 10-meter Keck Telescopes at Mauna Kea, the collaboration found a faint signal corresponding to a pair of feeble images later recognized in a deep Hubble Space Telescope picture. (Gravitational lensing can turn a single object into two or more images, as the light converging on the telescope will appear to be coming from different directions.) Spectroscopic studies made possible with the superior light-gathering power of the Keck confirmed that the images arise via the magnification of a single source diagnosed to be extremely distant and in the process of formation. And team member Jean-Paul Kneib of the Observatoire Midi-Pyrénées near Toulouse, France, an expert in the rapidly developing field of gravitational lensing, derived the magnification factor by determining the precise location of the pair of images in relation to the lensing cluster.

"The system contains about a million or so stars at a distance of 13.4 billion light-years, assuming that the universe is 14 billion years old," claims Ellis. "While more distant galaxies and quasars have been detected with the Keck Telescopes, by virtue of the magnification afforded by the foreground cosmic lens, we are witnessing a source much smaller than a normal galaxy forming its first generation of stars."

"Our work is a little like studying early American history," says grad student and team member Mike Santos. "But instead of focusing on prominent individuals like George Washington, we



Right: When light is bent by its passage around a massive nearby object, an observer—who will perceive the light rays as having traveled along straight lines—can see multiple images (solid circles) of the distant source displaced from its actual location (open circle); the "real" image will not be seen. Below: A Hubble Space Telescope image of the galaxy cluster, Abell 2218, used by Ellis and collaborators in their search for intrinsically faint, very distant star-forming systems. The image pair (arrowed) in the inset represents a single source gravitationally magnified more than 30 times by Abell 2218 and viewed at a distance of 13.4 billion light-years. The object contains only a few million stars, far fewer than a mature galaxy like the Milky Way.



want to know how everyday men and women lived. To really understand what was going on in the early universe, we need to learn about the typical, commonplace building blocks, which hold important clues to the later assembly of normal galaxies. Our study represents a beginning to that understanding."

The team concludes that the star system is remarkably young (by cosmic standards) and thus may represent the birth of a subcomponent of a galaxy. Santos explains, "The narrow distribution of intensity observed with the Keck demonstrates we are seeing hydrogen gas heated by newly formed stars. But, crucially, there is not yet convincing evidence for a well-established mixture of stars of different ages. This suggests we are seeing the source at a time close to its formation." The researchers infer that the stars had been forming at a rate of one solar mass per year for not much longer than a million years. Such a structure could represent the birth of a globular cluster, which are stellar systems recognized today to be the oldest components of the Milky Way galaxy. The work represents part of an ongoing survey to determine the abundance of such distant star-forming sources as well as to fix the period in cosmic history when the bulk of these important objects formed. □ —*RT*