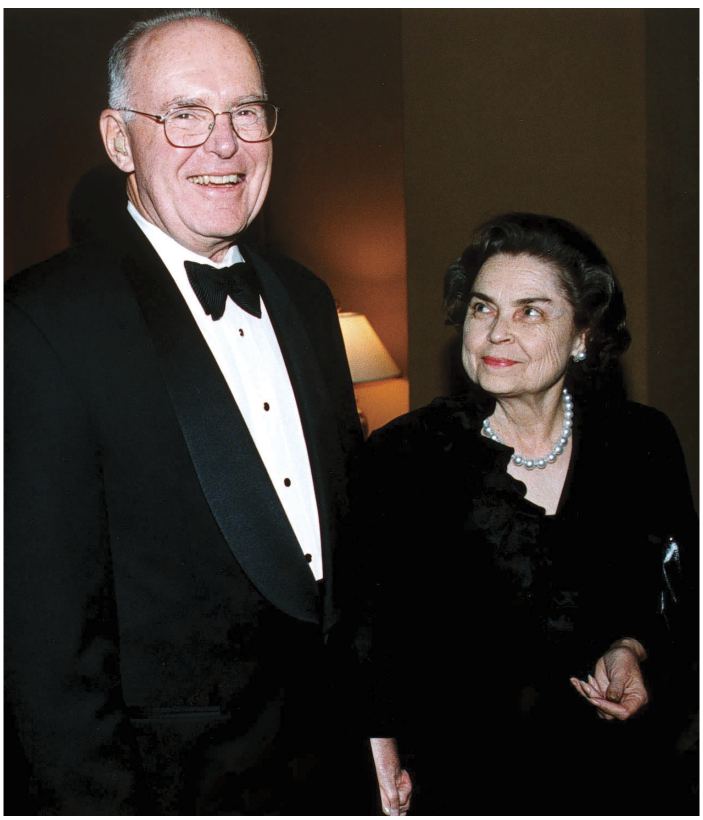
The Moores Step Up To the Plate



Gordon and Betty Moore.

Caltech has received two gifts totaling $600 million, half from Intel cofounder Gordon Moore (PhD ’54) and his wife Betty and half from the Gordon and Betty Moore Foundation. Together they are the largest donation ever to an institution of higher learning. Moore said the gift is intended to allow Caltech to continue to do what it does best—collaborative work between disciplines—and to keep Caltech on the forefront of science and technology. “Caltech has a unique ability to do multidisciplinary work—partly because of its size and partly because of its history. It is described as being a national treasure and it certainly is. The education I received there has served me well. We are hoping this gift will position the institute well as it moves forward.” Betty Moore, a graduate of San Jose State College in journalism, is very active in the couple’s numerous philanthropic activities. She says Caltech has been an important part of her life during her 51-year marriage and she is pleased to be able to support it with this gift. “We’ve been very fortunate in our lives and we feel it’s time to give back. We enjoy seeing the students and knowing that we’re helping them.”

The couple formed the Moore Foundation in November 2000 and set up offices in San Francisco. The foundation’s main focus is the environment, scientific research, higher education, and the Bay Area. The foundation’s grants of $300 million over a 10-year period and the Moore’s $300 million gift over five years are for educational and scientific programs to be mutually agreed upon.

Moore has been a Caltech trustee for 18 years, and served as chairman of the board from 1993 to 2000. The couple’s generosity to the Institute has included the establishment of the Gordon and Betty Moore Presidential Discovery Fund, which is intended to allow faculty to explore new and unique ideas. They also funded the G. E. Moore Electronic Materials and Structure Laboratory, the Gordon and Betty Moore Undergraduate Scholarships, and the Gordon and Betty Moore Laboratory of Engineering. □—*JP*

The Kerckhoff Marine Biological Laboratory, as seen from the end of its dock.

Misadventure on the High Seas

All the three Caltech marine chemists wanted as they set out on a small powerboat was to collect water samples—but before long, they found themselves in over their heads.

Jess Adkins, assistant professor of geochemistry and global environmental science; new staff member Diego Fernandez, an assistant professor of physical chemistry on leave from the University of Buenos Aires; and Jeff Mendez, a graduate student in environmental science and engineering, were on a routine outing from Caltech's Kerckhoff Marine Biological Laboratory in Corona del Mar on November 27 when strong gusts and five-foot waves capsized their craft.

"We had finished our first sample and turned around to go back, when a swell came at us and we realized we were in deeper than we thought," Adkins recounted. "We strapped everything down and put on life jackets, and then we took a wave that put us shin deep in water." He put out a radio SOS, noting their location with the boat's global positioning system (GPS), just minutes before another wave overturned the boat and plunged them into the frigid water.

Fortunately, the Mayday call was picked up right away. With the GPS information, an Orange County Sheriff's Department harbor patrol boat found the trio in about half an hour and took them to the harbor patrol base in Newport Beach. They suffered mild hypothermia but no other injuries. (The 24-foot boat, owned by Caltech's Division of Biology, was salvaged upside down, Adkins said. "There was no damage to the body, but the electronics and engine will probably have to be replaced.")

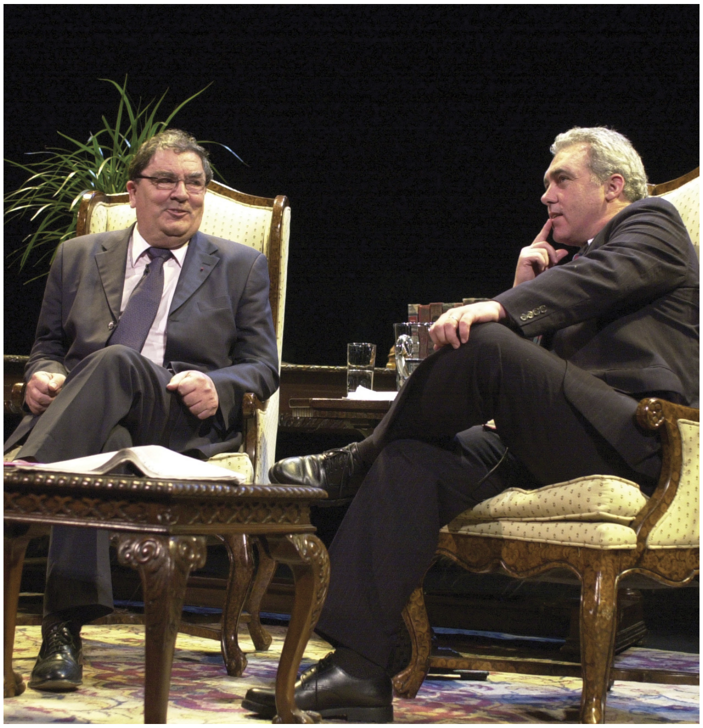
In retrospect, his perspective on the event has evolved, Adkins said. "As it was happening, I focused on what we had to do to stay afloat and stay warm. I always had the sense it would turn out fine. I didn't get scared until we actually got rescued." It wasn't that he hadn't realized the danger, but survival instincts kept him calm. "I knew it was a pretty bad situation, but we just had to do what we could. Whaling and thrashing about wouldn't have gotten us rescued any sooner."

Adkins also highly praised the officials who rescued them. "The harbor patrol and sheriff's department were fantastic. They deserve all the credit, getting out there so quickly."

The researchers' goal, which is also the basis for Mendez's doctoral thesis, was to collect samples weekly in order to study concentrations of metal in the water over time. "Once you know the variations over a few months, seasons, or years, the data let you do an 'event response' in cases such as an oil spill or storm-drain runoff," Adkins explained. "In particular, we're interested in Santa Ana winds and the dust they deposit on the ocean surface."

The trip was one of several the group had taken to determine the project's feasibility, he said, so the researchers will likely stay grounded for the next few weeks and rethink the logistics, possibly hooking up with oceanographers at USC and UCLA. In any case, he said, future excursions will definitely involve "a bigger boat."

Meanwhile, Adkins feels just about back to normal. He was in the classroom as scheduled for a guest lecture two days later. "It maybe wasn't my best lecture ever. I apologized that it was so disjointed—I hadn't had enough time to work on it." □—*DK*



Above: Nobel Peace Prize co-winner John Hume (left) was chatted up by Kevin Cullen (right), *The Boston Globe*'s former bureau chief in Dublin and London, at the DuBridge Distinguished Lecture on November 20. Hume, a Roman Catholic and until recently the leader of the Social Democratic and Labour Party, shared the 1988 prize with protestant David Trimble, leader of the Ulster Unionist party, for their work toward peace in Northern Ireland. A streaming video of the event can be viewed at http://kkk\atcaltech.caltech.edu/theater/.

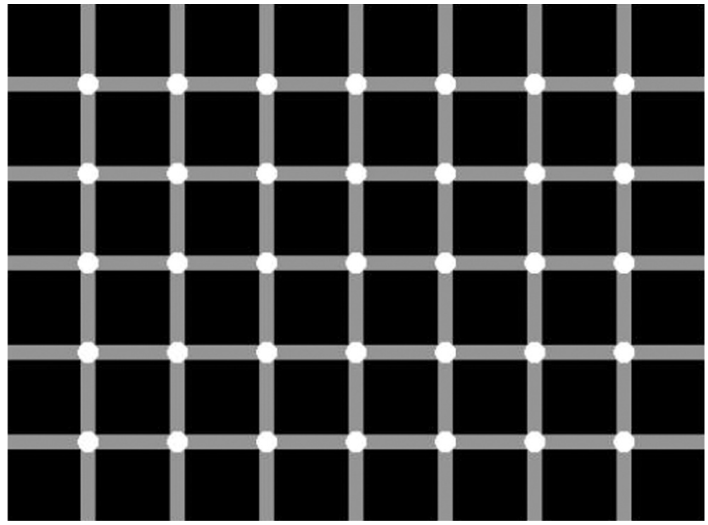
Hot and Cold Running Neutrons

It's really too bad that Superman has X-ray vision. Not that there's anything wrong with that, but if he'd had neutron vision, he'd be able to see a lot more. Neutrons, like X rays, can behave as waves. When you fire a beam of neutrons (or X rays) into a chunk of matter, some of them ripple off the atoms in the sample, and the angles which the waves are strongest tell you how those atoms are arranged. But X rays interact with electrons, so that the more electrons an atom has, the easier it is to see. Because neutrons interact with atomic nuclei, all kinds of atoms are visible, even hydrogen. Neutrons can even find out what the atoms are doing. If the wave sets up a vibration in the sample, the neutron's frequency will drop by the amount of energy lost and the neutron will slow down. Or the wave can cancel out an existing vibration, punting the neutron to a higher frequency and speeding it up. (These collisions are called "inelastic," as opposed to "elastic" ones in which no energy is exchanged. And they don't have to be single-atom collisions—some of the vibrations are ensemble affairs.) So you need a device that not only tells you where the neutron went but how long it took to get there. Such machines have been around for about 50 years, says Professor of Materials Science Brent Fultz, but the catch is that you need a lot of neutrons—a "bright source," in the lingo—to make them work well. Otherwise it's like trying to read the fine print in a phone book by flashlight. The Spallation Neutron Source (SNS), now under construction at the Department of Energy's Oak Ridge National Laboratory in Tennessee, will be the brightest neutron source in the world by a factor of 10, and Fultz is principal investigator of a team building an instrument to take full advantage of it.

This instrument, called

Right: The SNS's physical plant, drawn in on an aerial photo of the construction site. The hydrogen ions are made in the front-end building, and shoot down the linear accelerator, or linac, en route to the accumulator ring and eventually the mercury target.

How many black dots do you see in the white circles? In fact, there aren't any. In this optical illusion, the black dots appear and vanish in a manner correlated with their fellows in both space and time. The phenomenon spans about four unit cells (a unit cell is a crystal's basic repeating structure) and has a frequency of roughly four cycles per second. ARCS will measure correlated vibrations and spins on similar scales in real crystals.

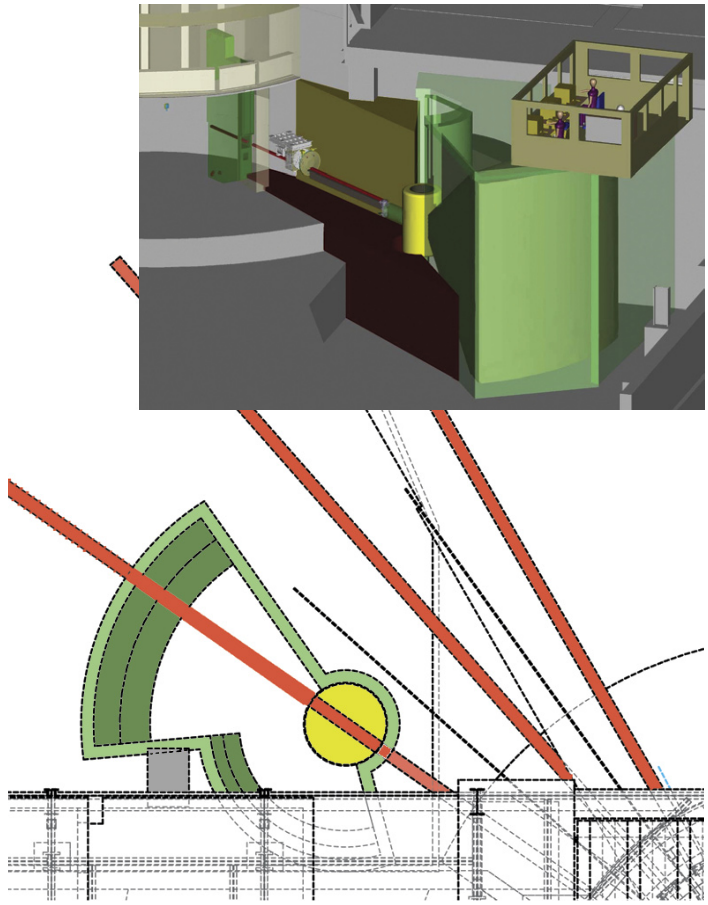


ARCS (short for **A** high-**R**esolution direct geometry **C**hopper **S**pectrometer, whose complete, vowel-impaired acronym would have been utterly unpronounceable) is one of five instruments slated to be on line when the SNS opens for business in 2006. The Department of Energy will spend $15 million on ARCS—a modest sum compared to the entire project's $1.4 billion price tag. As an instrument at a national facility, ARCS will be open for use by all comers, but Fultz and therefore Caltech in general will get a guaranteed time allotment. Eventually, the SNS will host 18 instruments to be built over a 10-year period, and will make the United States the world leader in neutron science—a distinction we'd lost to Europe over the past couple of decades.

The SNS will be a busy place indeed. Neutrons have no electric charge so they don't ionize the samples they penetrate, and because they can "see" hydrogen atoms, you can use them to study the structures of proteins, DNA, and whatnot. And each neutron is a tiny magnet, so it interacts with magnetizable materials. Thus everybody from basic biologists to drug designers to the folks who develop ever-smaller hard drives for your computer will be standing in line, not to mention the chemists looking to create better catalysts or develop new materials with made-to-order properties. And since the neutron's speed determines the frequency of its associated wave, you can tune the neutron beam to the energy range of your choice.

ARCS looks for inelastic collisions ranging in energy from a few millielectron volts (meV) to 500 meV, which are quite gentle and require very slow neutrons. They're called thermal neutrons in the trade, as room temperature is equivalent to about 25 meV. This range is particularly intriguing as it includes phonons, or quanta of vibrational energy that have been linked to high-temperature superconductivity; magnons, which are magnetic spin waves that move through a material like wind through a wheat field and may lead to a theory of quantum magnetism; and a host of other vibrational modes. These vibrations contribute a degree of randomness, or entropy, to a material, and that's what Fultz is interested in. The atoms in a crystal sit in preferred positions, like the marbles in their wells in a game of Chinese checkers. As the vibrational energy increases, the atoms stray farther and farther out of position. This disorder creates vibrational entropy. But entropy has many faces. As the "game" heats up, the red and blue balls intermingle and gaps open up between them, increasing the configurational entropy. At some point, the atoms have become so thoroughly rearranged that the crystal takes on a brand-new form—a so-called phase transition. Even the "board" itself can change—perhaps morphing from a triangular grid into a square one, as in Western checkers. But a few years ago, Fultz discovered that vibrational entropy alone could cause phase transitions, even if the crystal also had a lot of conformational entropy. "I'm pretty proud of that," says Fultz. "It's not every day that you find a new type of entropy that's important in thermodynamics." So Fultz and his grad students are using neutron scattering to find precisely where the entropy in various phase transitions comes from.

The SNS is Big Science. The system starts out with hydrogen atoms that have been given an extra electron each so that they have a negative charge. These get fired down a 300-meter-long particle accelerator that revs them up to energies of 1 billion electron-volts, the equivalent of 1 megawatt of electricity and six times Caltech's entire power consumption. At the far end of a quarter-mile of plumbing—the same length as a drag strip!—they shoot through a micron-thick carbon foil that strips off their electrons, leaving naked protons that are dumped into a storage ring the diameter of a Wal-Mart parking lot. Sixty times a second, or roughly once every 1,200 orbits, a kicker magnet flings the ring's entire contents out in a pulse less than a millionth of a second long. This slug of screaming-hot protons slams into 5.6 liters (76 kilograms) of mercury, banging some of its neutrons loose in a process called spallation. (In the outside world, "spallation" means to knock flakes or slabs off a larger body, such as when you chip concrete with a hammer.) Mercury was chosen because it has a bucketful of neutrons—120 per nucleus, on average—and because, being a liquid, it can be pumped through the hot zone. It takes 1,500 liters of mercury cycling continuously through a cooling system to handle the punishment. So



ARCS has been assigned beam line 18, the leftmost of the three shown in red in the plan view. The neutron detector fills a three-story, high-vacuum chamber (light green); for comparison, note the size of the control room in the 3-D view. The detector (olive), built in two sections to accommodate a concrete pillar (gray), wraps 60° vertically and 160° horizontally around the sample chamber (yellow).

you get a boatload of neutrons, which is good, but they're almost as hot as the protons, which is bad. In order to cool them a million- or billionfold, to the point where they're actually usable, they pass through a "moderator," which is a bath full of either water or liquid hydrogen, depending on how cold you want them, en route to the experimental stations.

The neutrons come flying out in all directions, so the 18 experimental stations are arranged around the mercury target like the spokes of a wagon wheel. Each experiment therefore has a pie-slice-shaped piece of real estate in which to set up shop, which leads to some design challenges, says Fultz. You can either build a small detector close to the source, or a big one farther away. The ARCS team opted for the close-in approach for maximum neutron intensity. Once the neutrons hit the sample, they again scatter to all points of the compass; thus the detector has to surround the sample as completely as possible. Wedging a big detector into the pointy end of the space is further complicated by an unhandily placed concrete pillar that supports an overhead crane and, incidentally, the roof. The details of the design are still being worked out, Fultz says, as some things depend on what the neighbors on the adjoining beam line decide to do—the exact boundaries between the instrument spaces are negotiable—and on what other chopper spectrometers wind up being built. "If they build another one that's optimized for magnetic studies, we'll optimize for vibrational studies, for example, and this governs where we put our detectors."

Even after passing through the moderator, the neutrons still have an assortment of speeds, which is where the Fermi chopper comes in. The chopper is a rapidly spinning cylinder pierced by a slit through which the incoming neutrons pass. The rate at which the cylinder rotates governs the speed of the neutrons that make it through, and the moment when the slit is in alignment (i.e., open) sets the reference time that allows you to measure whether the inelastic collision has sped the neutron up or slowed it down. The chopper, the helium-3-filled detector tubes (which can tell where the neutron has hit to within a few square centimeters), and the rest of the hardware are not too far beyond off-the-shelf technology.

Argonne National Laboratory's Doug Abernathy, the instrument scientist and project manager, is responsible for putting it all together and will be on-site to supervise construction.

Meanwhile, Fultz will be overseeing the design of the software that runs the hardware, collects the time-of-flight and position data from the detectors, and calculates each neutron's momentum in order to measure the sample's vibrational and magnetic energies. In typical Caltech fashion, this means assembling a multidisciplinary team—for example, Oscar Bruno, professor of applied and computational mathematics, has been working on more efficient methods for tracing scattered neutrons through the sample. "Software development has historically been neglected in the neutron-spectroscopy community, which means that people haven't been able to extract all the science that's available in the data," says Fultz. "Each run gives about half a gigabyte of data—not big by high-energy physics standards, but still modestly large. And this is where Caltech can really make a contribution, by developing not only a software package for this instrument but also standards and procedures the entire community can use." Caltech's Center for Advanced Computing Research (CACR) has considerable expertise in this area, so Fultz is collaborating with software integrator Michael Aivazis, a member of the professional staff at CACR.

Compatibility issues run rampant, says Aivazis. The package will contain many disparate pieces of code contributed "typically by scientists whose main focus is to solve a particular problem. They generally produce code that contains the right science done very well but that is very hard to extract from its context." Aivazis has created a software framework, or environment, in which the assorted bits of code can coexist. Called Pyre for PYthon Research Environment (Python being the language it was written in), it "grabs pieces of code written in Fortran, C, C++, and what have you, and produces a veneer, if you will, that gives you access to how they do physics without your having to be a software engineer. You don't need the specialized knowledge that went into producing the code in order to use it successfully in your application." Pyre also reduces the risk that innocent changes in one person's code may produce astonishing results in the other's. Aivazis will be in charge of setting standards for how data is handled and exchanged between the codes, and making sure that all the pieces play well with one another.

But in the long run, says Fultz, Caltech's biggest contribution may be in opening new avenues of research. "In the past, these instruments have been treated as a piece of hardware—you come in with your sample and you get a result. We're trying to make a deeper connection with theory in order to design better experiments. There's a lot of science involved in figuring out how to write the software, so we'll be doing extensive prototyping work on other machines before ARCS is running. ARCS won't miss many neutrons, and we want to be sure we take full advantage of our capabilities. That's what I find most rewarding—the voyage of discovery to learn what the machine can do." □—*DS*

Tech Today Debuts

What Nobel Laureate is speaking on campus today? Is there a basketball game this week? And what was the latest on business mileage reimbursement from Human Resources? You'll find it all at *Tech Today* (http://atcaltech.caltech.edu/tech-today/), a Web site brought to you by *At Caltech* and *Caltech 336*. Each weekday, *Tech Today* provides you with current campus news and events at a glance in a single, convenient, user-friendly page. The site includes a wealth of links to Caltech and JPL divisions, resources, and calendars; international and local news sites such as the BBC, CNN, *New York Times*, and *Los Angeles Times*; science magazines and journals; search engines; and even the daily menus for Chandler and Avery dining halls. Check it out . . . today! □—*DK*

There's Air Out There (Sort Of)

Astronomers using NASA's Hubble Space Telescope have made the first direct detection of the atmosphere of a planet orbiting a star outside our solar system and have obtained the first information about its chemical composition. Their observations demonstrate that it is possible to measure the chemical makeup of the atmospheres of extrasolar planets and perhaps search for the chemical markers of life beyond Earth.

The planet orbits a yellow, sunlike star called HD 209458, a seventh-magnitude star (visible through an amateur telescope) lying 150 light-years away in the constellation Pegasus. Its atmospheric composition was probed when the planet passed in front of its parent star, allowing astronomers to see light from the star filtered through the planet's atmosphere.

Lead investigator David Charbonneau of Caltech and the Harvard-Smithsonian Center for Astrophysics, Timothy Brown of the National Center for Atmospheric Research, and colleagues used a spectrometer called the Space Telescope Imaging Spectrograph (STIS) to detect the presence of sodium in the planet's atmosphere. "This opens up an exciting new phase of extrasolar planet exploration, where we can begin to compare and contrast the atmospheres of planets around other stars," says Charbonneau. The astronomers actually saw less sodium than predicted for the Jupiter-class planet, leading to one interpretation that high-altitude clouds in the alien atmosphere may have blocked some of the light. The findings will be published in the *Astrophysical Journal*.

The Hubble observation wasn't tuned to look for gases expected in a life-sustaining atmosphere, which in any case is improbable for a planet as hot as this one. Nevertheless, such observations could potentially provide the first direct evidence for life beyond Earth by measuring unusual abundances of atmospheric gases caused by the presence of living organisms.

The planet orbiting HD 209458 was discovered in 1999 through its slight gravitational tug on the star. Based on that observation the planet is estimated to be 70 percent the mass of the giant planet Jupiter, or 220 times more massive than Earth. Subsequently, astronomers discovered the planet passes in front of the star, causing the star to dim very slightly for the transit's duration. This is the only example of a transit among all the extrasolar planets discovered to date.

The planet is an ideal target for repeat observations because it transits the star every 3.5 days—the extremely short amount of time it takes to whirl around the star at a distance of merely 4 million miles from the star's searing surface. This precarious proximity heats the planet's atmosphere to a torrid 1,100° C.

Previous transit observations by Hubble and ground-based telescopes confirmed that the planet is primarily gaseous, rather than liquid or solid, because it has a density less than that of water. (Earth, a rocky planet, has an average density five times that of water.) These earlier observations thus established that the planet is a gas giant, like Jupiter and Saturn.

The planet's swift orbit allowed for observations of four separate transits to be made by Hubble in search of direct evidence of an atmosphere. During each transit a small fraction of the star's light passed through the planet's atmosphere on its way to Earth. When the color of the light was analyzed by a spectrograph, the telltale "fingerprint" of sodium was detected. Though the star also has sodium in its outer layers, the STIS precisely measured the added influence of sodium in the planet's atmosphere.

The team—including Robert Noyes of the Harvard-Smithsonian Center for Astrophysics and Ronald Gilliland of the Space Telescope Science Institute in Baltimore, Maryland—next plans to look at other colors of the star's spectrum in hopes of detecting methane, water vapor, potassium, and other chemicals in the planet's atmosphere.

As other transiting giants are found in the next few years, the team expects to characterize the chemical differences among their atmospheres, helping astronomers better understand a bizarre class of extrasolar planets dubbed "hot Jupiters." These planets are the size of Jupiter but orbit closer to their stars than does Mercury in our solar system. While Mercury is a scorched rock, hot Jupiters have enough gravity to hold onto their atmospheres, though some are hot enough to melt copper.

Conventional theory is that these giant planets could not have been born so close to their stars. Gravitational interactions with other planetary bodies or gravitational forces in the circumstellar disk must have carried these giants via spiraling orbits precariously close to their stars from their birthplace farther out, where they bulked up on gas and dust as they formed.

Proposed moderate-sized U.S. and European space telescopes could allow for the detection of many much smaller Earth-like planets by transit techniques within the next decade. This will be very challenging, since finding a planet orbiting at an Earth-like distance will mean a much tighter orbital alignment is needed for a transit. And the transits would be much less frequent for planets with an orbital period of a year, rather than days. Eventually, study of the atmosphere of these Earth-like planets will require meticulous measurements by future larger space telescopes.

The Space Telescope Science Institute is operated by the Association of Universities for Research in Astronomy for NASA under contract with the Goddard Space Flight Center, Greenbelt, Maryland. The Hubble Space Telescope is a project of international cooperation between NASA and the European Space Agency. The National Center for Atmospheric Research's primary sponsor is the National Science Foundation. □

SIRTF Science Center Dedicated

With the snip of a ribbon, the top three floors of the Keith Spaulding Building of Business Services became the Space Infrared Telescope Facility (SIRTF) Science Center. SIRTF, to launch in late 2002, will join the Hubble Space Telescope, the Compton Gamma-Ray Observatory, and the Chandra X-Ray Observatory as NASA's fourth "Great Observatory," each looking at a different portion of the electromagnetic spectrum. SIRTF sees the "thermal" infrared from 3 to 180 microns, which is absorbed by Earth's atmosphere, and will be looking for objects like brown dwarfs and newborn planetary systems. The Science Center will schedule SIRTF's observations, and process and distribute its data. Before wielding the scissors, Caltech president David Baltimore remarked, "I love the symbolism of turning an administrative building into a science center—sort of swords-into-plowshares." He then praised Provost Steven Koonin (BS '72) for organizing the "heroic" process of relocating the multitudinous folk of Business Services in order to create the space.

Among the invited guests was Gerry Neugebauer (PhD '60), Millikan Professor of

Some 30 years ago, George Housner (MS '34, PhD '41), Braun Professor of Engineering, Emeritus, noticed that this branch had moved from its cutout in the parapet of the arcade by Parsons–Gates. He realized that the tree was tilting, which is why heavy steel columns now brace it. However, he's not standing next to Millikan Pond. Several views of campus are included in a set of murals depicting Pasadena landmarks that have been painted on hoardings at the newly opened Paseo Colorado in downtown Pasadena.

Physics, Emeritus, one of the founding fathers of infrared astronomy. At the dawn of his career, he worked with a strip-chart recorder wired to a single-element sensor. By the time he retired in 1998, detector arrays of a million pixels had become commonplace (see *E&S*, 2001, No. 1).

SIRTF continues in that tradition, having, as JPL director Charles Elachi (MS '69, PhD '71) put it, "orders of magnitude improvement in resolution and spectral coverage" over its predecessor, IRAS.

NASA Associate Administrator for Space Science Edward Weiler noted that the original 1994 design weighed 5,700 kilograms and cost $2 billion. The launch version weighs 950 kilograms and costs only half a billion, thanks to a revolutionary mission plan in which the telescope trails Earth rather than orbiting it, safely away from its heat. In the deep freeze of deep space, SIRTF needs only 60 percent of IRAS's coolant for a mission projected to last six times as long. —*DS*

The SIRTF Science Center was dedicated on October 22. At left, from left: Charles Elachi; B. Thomas Soifer (BS '68), professor of physics and director of the new center; David Baltimore; and Edward Weiler. At right, Marcia and Gerry Neugebauer.

A New International Power Grid

Today's powerful science projects require equally powerful computers. Complex experiments in such fields as physics, biology, and astronomy will depend on the ability to access and manipulate hugely complex quantities of data. Now a new computing "grid" will provide researchers with the computational power of an entire scientific community. The National Science Foundation has awarded $13.65 million over five years to establish the International Virtual Data Grid Laboratory. The iVDGL will bring together 15 universities and four national laboratories to connect an international network of powerful computers at 40 locations worldwide, notes Caltech professor of physics Harvey Newman, one of iVDGL's coleaders.

The grid, which is expected to come on-line next year, is similar to an electric utility grid in that it can tap into power—in this case, computing power—at multiple locations, creating one ultra-powerful computer that will be available to scientists around the world. The iVDGL grid will reach into Europe and Asia through partners in England, Italy, Japan, and other countries.

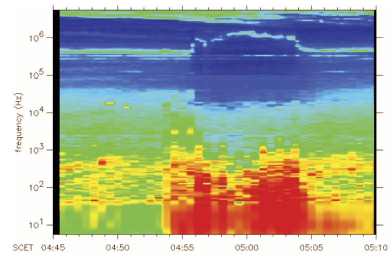
Among other large-scale experiments, the grid will serve the Laser Interferometer Gravitational-Wave Observatory, or LIGO, a joint project of Caltech and MIT. (Gravitational waves are distortions of space and time caused by accelerating masses such as exploding stars or vibrating black holes.)

The computing power generated through the grid will be staggering. The grid will be capable of handling quantities of data measured in petabytes. One petabyte is equivalent to one million gigabytes, which is roughly the amount of data contained in 100,000 personal computer hard drives. Its computational speed will be staggering too, eventually measured in petaflops. One petaflop equals one thousand trillion calculations per second. The grid will be powerful enough for hundreds of users worldwide to run jobs simultaneously, although exceptionally large processing jobs will be able to use the entire grid.

Besides Caltech, several universities are member institutions of the LIGO Scientific Collaboration. They include Pennsylvania State University, the University of Texas at Brownsville, and the University of Wisconsin at Milwaukee (UWM). Funds from iVDGL will be used by the group to build a data analysis center for LIGO at Penn State, and also provide for the upkeep and operation of an existing facility at the UWM.

"The iVDGL represents an important first step in the establishment of a computational grid that can be accessed by both the LIGO Laboratory and the LIGO Scientific Collaboration," says Caltech member of the professional staff Albert Lazzarinito, the group leader of LIGO's data analysis team. "This will enable us to perform computationally intensive data manipulations and astrophysical searches using other NSF-funded national resources that exist outside our laboratory." —*MW*

POLEWARD, HO!



Above: The plasma-wave spectrometer's output during the 25 minutes of closest approach over the north pole. Time runs from left to right; the vertical axis is the frequency of the waves; and the colors represent each wave's intensity at that frequency, with red being the most intense. The plasma density inside the flux tube is more than 10 times higher than the plasma outside.

Galileo skimmed over Io's north pole on August 6 and under the south pole on October 16, collecting a host of close-up pictures and other data on the solar system's most volcanic family member.

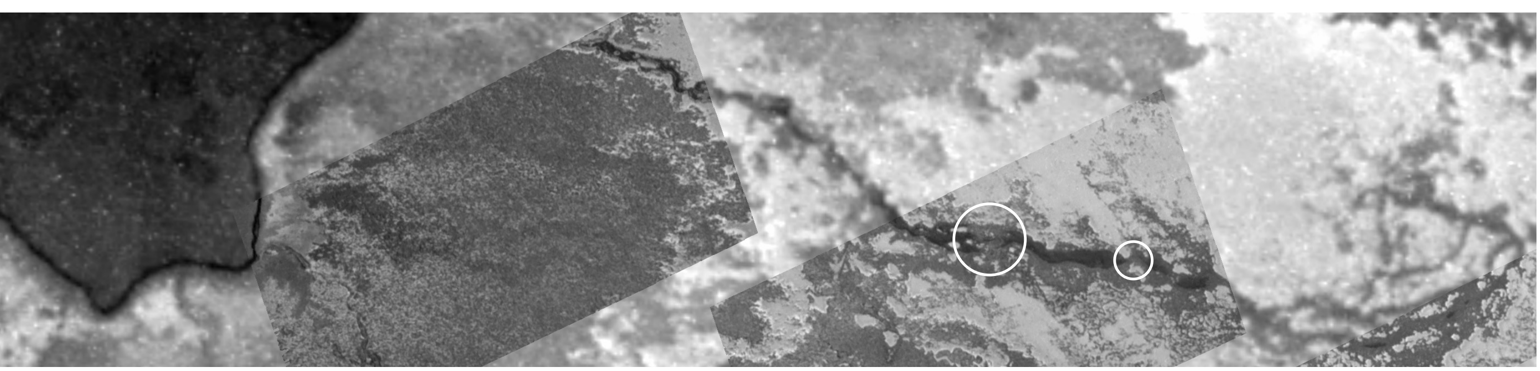
The polar course was charted to determine whether Io has an internally generated magnetic field, the way Earth does. Io is bathed in Jupiter's powerful field, and Galileo crossed the field lines that actually pass through Io. Previous equatorial flybys had shown that Jupiter's field changes in Io's vicinity, but the field strengths and orientations picked up by Galileo's magnetometer at the poles showed that these changes are caused by electric currents flowing through the sea of charged particles, or plasma, in Io's surroundings rather than by currents flowing in Io's interior. This means that Io's molten iron core does not churn convectively, as Earth's does, probably because the core is heated from without as Io's outer layers flex like a stress-busting squeeze ball in Jupiter's crushing gravitational grip. Earth's core, by contrast, is heated from within as the liquid outer core slowly gives up its heat and condenses onto the solid inner core.

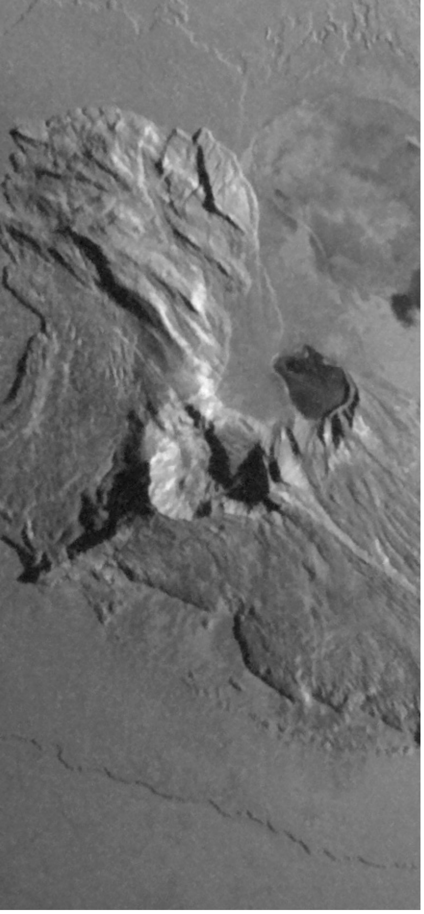
The magnetometer also discovered very localized currents flowing along field lines above two active volcanic regions. Mapping these currents may reveal more volcanic plumes, which are hard to find photographically unless the camera catches them edge-on.

Meanwhile, the plasma-wave spectrometer went nuts over each pole, recording a powerful burst as the spacecraft passed through the "flux tube" where the plasma rides the magnetic field lines connecting Jupiter and Io. (The plasma, incidentally, comes from the sulfur and other guck spewed from Io's volcanoes, which gets ionized once aloft.)

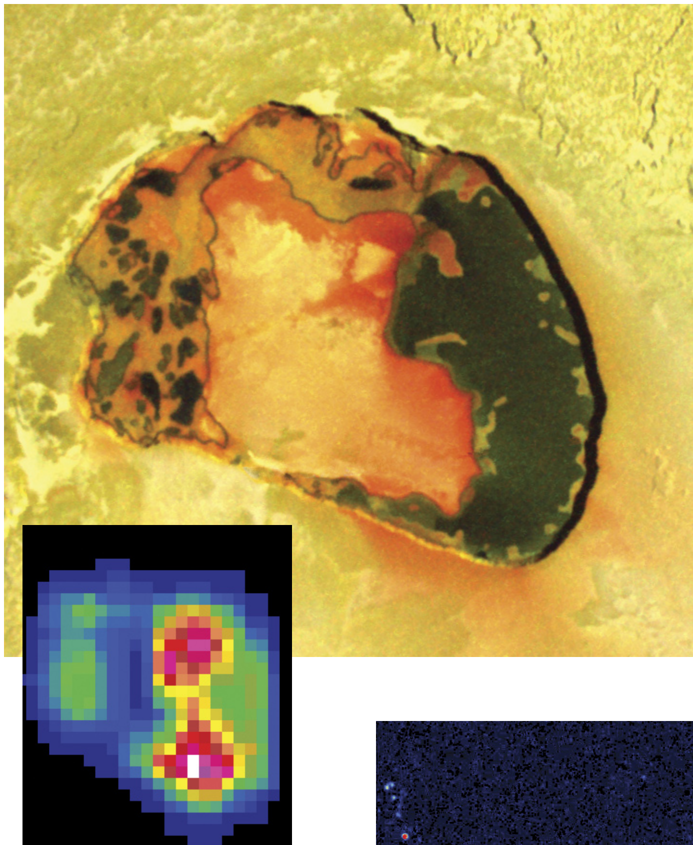
It was hoped that Galileo would fly through the plume of Tvashtar, a volcano that had been erupting furiously seven months earlier. Tvashtar, alas, had gone dormant, but the spacecraft caught a whiff from a previously unknown volcano some 600 kilometers farther south. The particles detected by the plasma-science package were no more than a few minutes old, and appeared to be "snowflakes" of sulfur-dioxide molecules containing up to about 20 molecules each. Analysis of the temperature and impact speed of the particles could say a lot about what's going on down in the volcanic vent. □—*DS*

Below: This dark river is a lava channel draining Emakong Patera, the dark region at left, near Io's equator. The channel fed the surrounding bright lava flow, which runs for hundreds of kilometers. How the lava could stay molten for so long on Io's frigid surface was a mystery, but images taken on October 15 at a resolution of 30 meters per pixel show two places (circled) where the surrounding flow roofed the channel over for about 1,500 and 450 meters, respectively, insulating the lava. The background image has a resolution of 150 meters per pixel.





Above: Tohil Mons rises 5.4 kilometers—not quite as tall as Alaska's Mount McKinley (6.2 km), but dwarfing anything in the Lower 48. This view was taken with the sun low in the sky, so that shadows would throw features like the 500- to 800-meter-high cliffs to the upper left into sharp relief.



Above: Tupan Patera, named for a Brazilian thunder god, displays a dazzling range of colors in this only slightly enhanced image. The dark regions to the left and right are still-warm lava, which glows in the infrared (inset—white is hottest). The central area is relatively cool and may be an island. There, gaseous sulfur from the volcanic vents has condensed into various red and yellow materials; the green regions appear to indicate a chemical reaction between molten red sulfur and molten lava—the best evidence yet for such a reaction.

Below: This high-resolution infrared image of Pele at night (top) shows details 60 meters in length. Pele is believed to be a lava lake, and the string of bright spots may be where the lake's crust is breaking up against the caldera's wall, revealing hot lava beneath. Such linear features have been seen before in low-resolution images. The large, bright regions at right are new and may mark where the lava is sloshing violently and overturning large chunks of crust. Both types of activity are shown in the bottom picture of the Puu Oo caldera in Hawaii. Pele's lava is about 1,400 Kelvins, comparable to lavas erupted by Kilauea in Hawaii.