MD/PhD, Caltech–USC

The Kenneth T. and Eileen L. Norris Foundation has established a fund to support two Caltech grad students a year in a joint MD/PhD program with the University of Southern California. The program will allow both schools to attract the nation's best graduate students interested in medically related research. Students will spend their first two years in med school at USC, taking preclinical science courses, with summers spent at Caltech gaining exposure to the academic research environment. They will then come to Caltech, spending three to five years on their PhDs before returning to USC for the final two clinical years.

The first two students are already here, having completed their two preclinical years at USC. One student is working with Professor of Biology Paul Sternberg, who studies genes that control behavior during cell (and cancer) development. The second student will be working in the Cardiovascular Fluid Dynamics Research Laboratory, established by Professor of Aeronautics Morteza Gharib (PhD '83).

Now, That's What I Call Student Aid!

Rea and Lela Axline.

The estate of Rea (BS '31) and Lela Axline has given Caltech $60 million—the largest single bequest from an individual donor in the Institute's 108-year history—to fund graduate and undergraduate scholarships. The gift is also one of the largest ever, in all of higher education, for direct student support. The donation was one of three major gifts announced by the estate following the December 24 death of Lela Axline. (Rea died in 1992.)

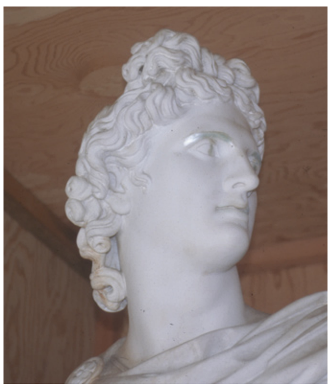
According to President David Baltimore, the gift could make Caltech the foremost institution in the world in terms of providing educational support for future scientists and technologists. "Providing sufficient graduate and undergraduate student aid to attract the very best students to Caltech is one of our greatest challenges," Baltimore said. "The Axlines' magnificent endowment for student aid will enable us to make great strides toward addressing these critical needs."

During the Depression, Rea Axline developed and patented a process for coating metal alloys onto other metal objects. The process became especially important during World War II, when the U.S. military began coating submarines, tanks, and other vehicles. After the war, Axline cofounded Mountain Metallurgic, which was sold to Perkin-Elmer Corp. in 1971.

Lela "Jackie" Axline was a renowned artist whose abstract paintings received much critical attention in the 1950s. She taught at the Staten Island Academy, and later became involved in the San Diego Museum of Art. □—*RT*

Above, left: Time was not on Apollo's side. (Nor were persons unknown.) His right hand was missing all five digits; he was also minus a more personal set of appendages. This latter loss inspired some sophomoric wit to quote the Rolling Stones—"I can't get no satisfaction"—on his belly in blue ink (above, right). The same art critic (or at least, the same pen) drew hair in his left armpit.

Sympathy for Apollo



Above: Apollo, seen here in his crate, acquired spiffy pearlescent eyebrows at some point. The dark brown stains that are visible on his hair and right shoulder may be iron deposits from dripping water. Below: Conservators John and Stephanie Griswold in their studio with their current project, an Italian pastoral lass from 1888.

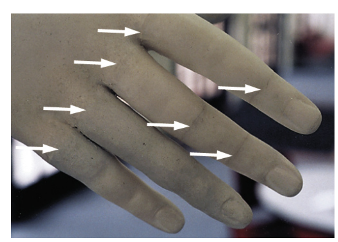
Caltech's Apollo Belvedere, recently reinstalled in glory in the lobby of the Braun Gym, has taken a long, strange trip over the last 25-plus years—from Throop Hall to Dabney Gardens to the steam tunnels to a warehouse. (See *Caltech News*, 1998, No. 3.) Like many travelers, he got pretty dirty; unlike most, he lost more than his luggage. Getting him in shape to meet his public would take something more than a hot shower and fresh clothes. The job went to John and Stefanie Griswold, who both hold master's degrees in art conservation and had previously done projects for the Huntington Library and the Getty Museum, among other places.

Caltech's Apollo is a hunk (of fine-grained white Carrara marble) with a history—carved in Rome the year the Institute was founded, he'd graced Throop Hall since 1910. He's a faithful copy of a first-century Roman copy of a lost Greek bronze from the fourth century B.C. The Roman one stands in the Vatican Museum's Belvedere Courtyard. Hence the name.

So how do you give a hot shower to something you can't scrub? Marble scratches easily, doesn't resist harsh chemicals, and is very porous—a real dirt magnet, and very difficult to get clean. But Apollo needed cleaning desperately: along with the weathering and grime that outdoor art is heir to, he'd suffered from graffiti in pen, pencil, and nail polish (or possibly paint), not to mention mineral stains. The Griswolds gave him a soft-bristled brushing-and-vacuuming, followed by a soap-and-water wash, applied as a mist from a squirt bottle, and lightly blotted with soft towels so as not to rub the grime in. The ink and crud that remained deep in the pores had to be drawn out with a series of chemical poultices—mud packs, if you will, not unlike exfoliation treatments at a beauty salon. Two different formulations were used up to five times each in the worst spots, followed by a couple of carefully chosen solvent cocktails. Even so, faint marks linger. "There's a lot of chemistry in conservation," says John, whose BA is in Art History. "The proudest day of my life was the day I passed organic chemistry as a prerequisite for grad school."

The next job was to replace Apollo's missing pieces. Art *conservators*, as opposed to *restorers*, abide by a version of the Hippocratic oath: first, do no harm. According to John, in the old days the restorer—who would have been a classically trained sculptor in his own right—would have evened off the missing fingers' broken stumps, carved new fingers to match, and cemented them on. The idea was to make the statue look as if it had never been broken. A conservator, by contrast, leaves the jagged edges unaltered. If the

Right: The restored right hand contains seven fragments of the original fingers, including the complete index finger (in two pieces) and the outer two-thirds of the little finger. The middle finger was rebuilt from four pieces, and the ring finger was pretty much created from scratch. The joint lines (arrowed) are clearly visible, and the ring finger has a different "look" because it's not solid marble.



Apollo presides over his rededication as Professor of History Robert Rosenstone, chair of the Institute art committee, speaks.

missing pieces ever turn up, they'll fit exactly. Clay models of the replacement pieces were fitted to the breaks. Silicone molds were made from the models, and new parts cast from an epoxy especially formulated not to yellow with age. Pulverized marble (after a protracted search, Stefanie found a suitable block in a stone yard in Sun Valley; John had to crush it himself with a mallet) gave the epoxy the right color and texture; fumed silica ("amazing stuff," says John, "it's almost like spun glass—it's so airy it will float right off the spatula; we have to wear masks when we use it") thickened the mixture while maintaining the right degree of translucency. The parts were glued on with another epoxy that can be dissolved away if the original pieces should be found. And, in a spirit of intellectual honesty that will resonate with Techers, conservators leave their handiwork visible—the statue appears whole to the casual glance, but a closer look reveals the seams. □—*DS*

We're Off to See the Comet

Stardust, the first spacecraft designed to bring a sample from a comet back to Earth, lifted off from Cape Canaveral at 1:04 p.m. Pasadena time on February 7, 1999. Built by Lockheed Martin Astronautics, the mission is being managed by Caltech's Jet Propulsion Laboratory.

Stardust will arrive at Comet Wild-2 (pronounced "Vilt-2") on January 2, 2004, and will collect particles flying off the comet's nucleus and attempt to sample a stream of interstellar dust that flows through the solar system. Captured in a glass foam called aerogel, the cometary and interstellar dust samples are protected by a clamshell-like capsule that will parachute into the Utah desert in January, 2006. □

CBI Sees First Light

The Cosmic Background Imager, or CBI, still a-building in the Physical Plant lot on Holliston Avenue (see *E&S*, 1998, No. 1), saw first light on Monday, January 18, 1999. The telescope has three of its 13 radio receivers installed—enough to begin doing interferometry. Jupiter, hanging conveniently in the afternoon sky, came through loud and clear. The receivers were then cooled to their operating temperature of 6 Kelvin, and second light (Jupiter again) was on Saturday the 23rd. (Sorry, folks, the data is all numbers and no pictures—the receivers

Below: The Cosmic Background Imager with its white dome open. The three squat cylinders each house a one-meter radio dish.

are still being calibrated.) A small champagne celebration followed on the 25th, with the provost and the division chair in attendance.

As described in *E&S*, 1996, No. 4, the CBI is designed to map subtle fluctuations in the temperature of the microwave-length background radiation emitted some 300,000 years after the Big Bang. In human terms, this is equivalent to taking pictures of an embryo within a few hours of conception. These fluctuations are on the order of 10 millionths of a degree, and cover patches of sky that may range from twice the diameter of the full moon down to about one-tenth of the moon's diameter.

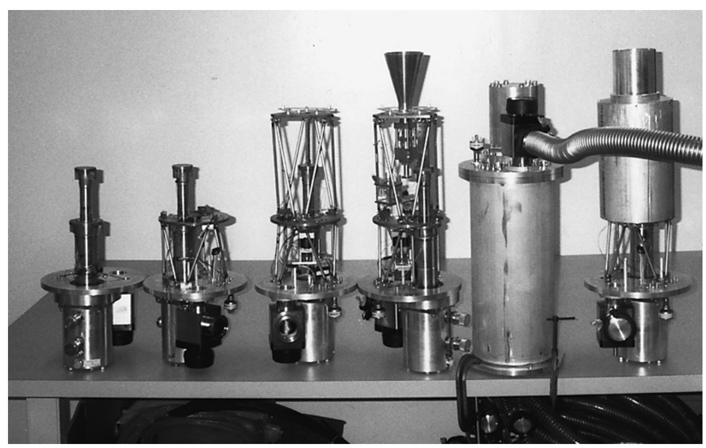
Current theories of how the universe formed posit that fluctuations of approximately this size and intensity should exist, but each theory makes different predictions about their specific size and exact nature. The past decade has seen an avalanche of papers on the subject, and, if the theorists are to be believed, getting clear pictures of the fluctuations would enable astronomers to determine the age and size of the universe conclusively, predict whether the universe will continue expanding forever or will eventually collapse back on itself in the so-called Big Crunch, and see the seeds of the first galaxies. Thus the CBI and a balloon-borne telescope named Boomerang, built by Professor of Physics Andrew Lange's group, are poised to make a fundamental contributon to cosmology. (Boomerang, which successfully completed an 11-day flight in Antarctica last December, operates at different frequencies and uses radically different measuring techniques to cover larger angular scales than the CBI; these complementary instruments form a two-pronged attack on the problem.)

Left: No, grad student John Cartwright isn't working in a soup kitchen in his spare time. He's calibrating a receiver by covering it with a thermal microwave source that's been dunked in liquid nitrogen. The drums shield the receivers from each other, and the white covers are Teflon weather shields. Right: Project Scientist Steve Padin hooks up a power meter that will display the receiver's output. The underside of the radio dish is visible inside the drum; the cylinder sticking out the bottom is an aluminum vacuum chamber that insulates the cooled receiver, just as a thermos bottle does.

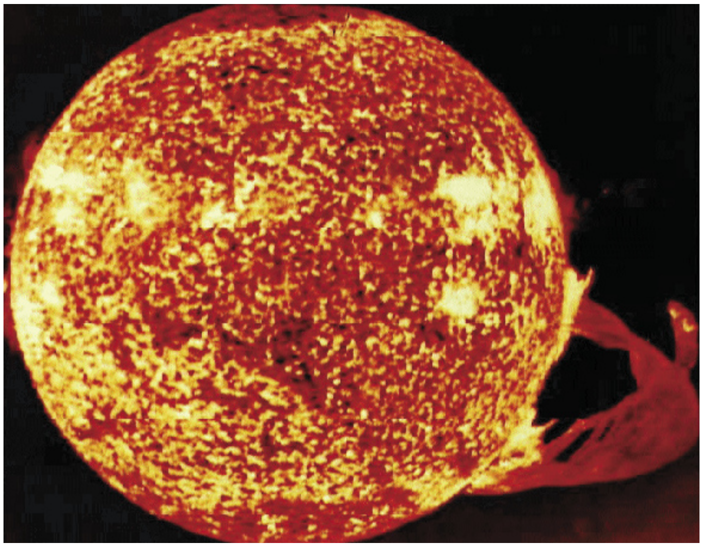
The CBI should be fully assembled and tested by April, at which point the receivers and other delicate gear will be removed and crated up, and the telescope mount will be bolted to a 40-foot "flat rack" (essentially a couple of girders) for the voyage to Chile, where it will be trucked to the 5000-meter-high Llano de Chajnantor, about 40 kilometers east of San Pedro de Atacama. The astronomers hope to start observing by August.

Anthony Readhead, professor of astronomy, is leading the CBI team, which includes Project Scientist Steve Padin; Senior Research Associate Tim Pearson; Caltech staff members Russ Keeney, Walter Schaal, Martin Shepherd, and John Yamasaki; and grad students John Cartwright, Jonathan Sievers, and Pat Udomprasert; as well as collaborators from the Universities of Chicago, Pennsylvania, and Chile; NASA, and the European Southern Observatory.

The CBI-Boomerang combo holds great promise, but other groups are in the hunt, too. So Caltech has taken the calculated risk of building the CBI before having all the cash in hand to pay for it. Another $3.5 million or so needs to be raised. □—*DS*



Above: Receivers in various stages of assembly sit on a lab bench in the subbasement of Robinson. The cone on top is the microwave feed horn, which sticks up into the bottom of the radio dish and acts as the eyepiece, as it were. The central pillar is a phase shifter, which is used to measure the signals that leak between receivers. And the scaffolding is thin tubes of stainless steel, which has a very low thermal conductivity and isolates the warm parts of the receiver from the feed horn and the low-noise amplifier, which are at 6 K. The receiver with a hose on it is being tested for leaks by grad student Jon Sievers (right).



Left: The planet Jupiter would fit comfortably under the arch of this solar prominence, photographed by astronauts aboard Skylab in 1973.

Twisting the Night Away

If an electric current flows along the arch, it twists up. When it becomes too twisted, it erupts.

Jutting from the sun like giant McDonald's arches, but big enough to handle Earth (or even Jupiter) at the drive-through window, solar prominences are the sun's most, well, prominent, feature. They often writhe into odd, twisted shapes, and may remain more or less stable for weeks, but sometimes they erupt violently—wreaking havoc on our magnetosphere, messing up radio transmissions, and occasionally damaging spacecraft. These prominences take on their shapes for the same reason that a magnet makes iron shavings form an arc on a sheet of paper. The sun's substantial, and very complex, magnetic field pokes out of the solar surface here and there, like stray strands poking out through holes in a shrink-wrapped ball of string. Plasma—hot, electrically charged particles emitted by the sun—is trapped in the magnetic field, with the plasma's glow revealing the field's shape. If an electric current flows along the arch, it twists up. When it becomes too twisted, it erupts.

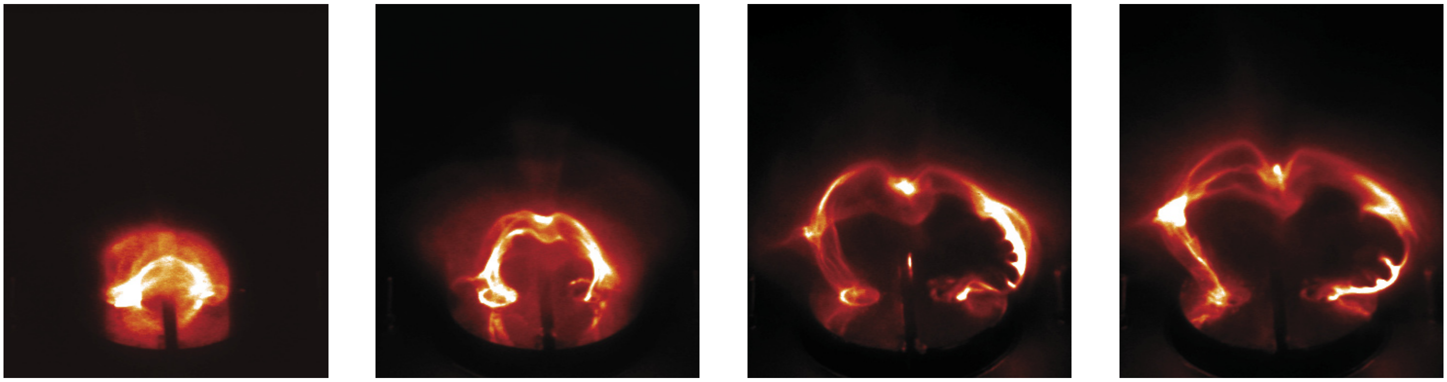
Paul Bellan, professor of applied physics, sees exploring the physics of solar prominences as a stepping stone toward the development of fusion reactors. Fusion, which powers the sun, is the forcible merging of two atomic nuclei, releasing enormous energy. Nuclei repel one another, so you have to slam them together really hard, and in order for them to be traveling that fast, they have to be heated into plasma. And the plasma must be confined long enough to recoup the energy invested into heating it up in the first place, which so far has proved impossible to do—the best containment strategy to date, a magnetic "doughnut" called a tokamak, has come within about a factor of two of breaking even.

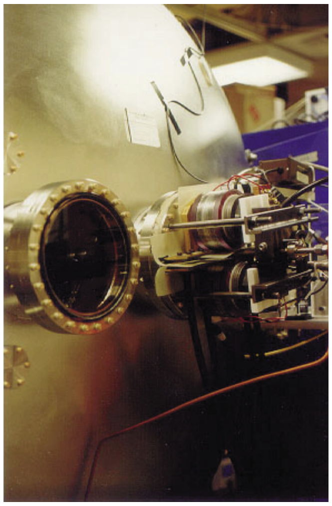
Unfortunately, reactors based on tokamaks would be large, complex, and expensive to build. Bellan thinks solar prominences are like spheromaks, which are magnetic "soap bubbles" that actually organize themselves into existence—set up the right conditions and, presto, they form from natural instabilities in the plasma. While a tokamak-based reactor would probably confine the plasma more efficiently, a spheromak design would be much smaller, simpler, and less expensive.

The behavior of both prominences and spheromaks is governed by their magnetic helicity—the twist of their magnetic fields, like the threads on a bolt. Once created, helicity tends to be conserved. Over the short term, this means that as the prominence writhes, it continuously seeks the lowest possible energy state for that helicity value. (Picture a marble being tossed around in a mixing bowl—the marble always rolls to the lowest point in the bowl.) These equilibrium states of minimum energy and conserved helicity are also seen in spheromaks. And, happily, fusion physicists don't have to work out a blow-by-blow mathematical description of how they got there, because any kind of instability sends them that way automatically.

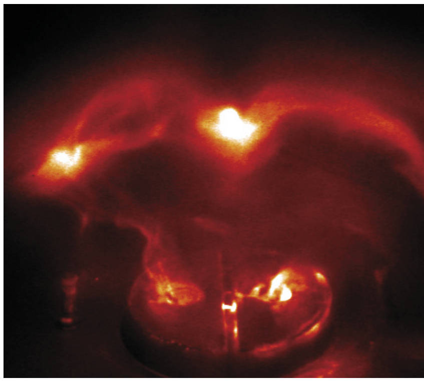
Over the longer term, the electric currents in a prominence pump helicity into it, winding it tighter and tighter until no equilibrium state exists, like a bulging drop of water on a faucet—add one water molecule too many, and the drop falls. The prominence suddenly erupts, shedding a magnetic cloud that carries the excess helicity off into interplanetary space.

"If you're staring through a telescope at the sun in order to study solar prominences, you have to wait a long time to see something interesting," says Bellan. "You can't





Above: The plasma gun is mounted on one end of the vacuum chamber, next to a viewport. The stubby cylinders are magnetic coils that generate a magnetic field of 3 kilogauss—typical of sunspots, with which active prominences are normally associated, and 10,000 times stronger than Earth's surface field at the equator. The electric field that twists up the prominence is created by a 200-pound capacitor that can deliver 72,000 amps in five millionths of a second.



Above: A sequence of images of a miniature prominence at (from left) 3.0, 4.0, 5.0, 5.5, and 6.5 millionths of a second. Even with ultra-high-speed cameras, you can only get one exposure per experiment, so this "movie" is actually a set of portraits of different prominences. This is one of Bellan's "pressure cooker" experiments. The distance between the feet of the arch is about five inches.

control the parameters, and you can't measure everything. But by making a miniature version of a prominence in a laboratory experiment, you have nearly complete control, and can arrange it to do interesting things which can then be carefully diagnosed."

Bellan's experiments take place inside a stainless steel vacuum vessel nearly five feet in diameter and six feet long. The miniature prominence is formed by a specially designed plasma gun that applies several thousand volts to the poles of a horseshoe magnet, turning a puff of hydrogen gas between the poles into plasma. Plasma is "cotton candy with the conductivity of steel," in Bellan's words, so an electric current begins flowing from pole to pole. The current creates its own magnetic field, which interacts with the original magnetic field to cause twisting and instability. "It's somewhat like blowing bubbles of magnetic field," says Bellan. "The more current you give it, the more it bulges out and the more twisted it gets." The whole show is over in a few millionths of a second, which means that anyone looking into the window of the vacuum vessel sees just a bright flash of pink light. To really see what has happened—that is, to see the geometry of the plasma arc—Bellan and his graduate student Freddy Hansen use a pair of digital cameras that have a shutter speed of 10 billionths of a second to make stereo pictures. "The experiment mimics the actual three-dimensional dynamics on the sun and should be very helpful for understanding what is really going on; it's an excellent way to check the various theoretical models," says Bellan. Adds Hansen, "When comparing our experiment to the sun, the actual numbers will be different, but the important thing is that the relative magnitudes of the magnetic forces, plasma pressures, temperature gradients, and so forth stay the same."

Bellan and Hansen are now applying extra magnetic fields to the prominence to try to shape it and control its eruption. "We're putting more bricks on the lid of the pressure cooker, if you will," Bellan says. "The prominences on the sun don't always erupt, but the ones we make in the lab do, because we force them to. We're working with a phenomenon that wants to maintain its topology, but then we force it to break the topology so we can see what happens. This is of great interest to the fusion community." The next step will be to build a second plasma gun, so two prominences can be shot at each other and collide. □—*RT&DS*