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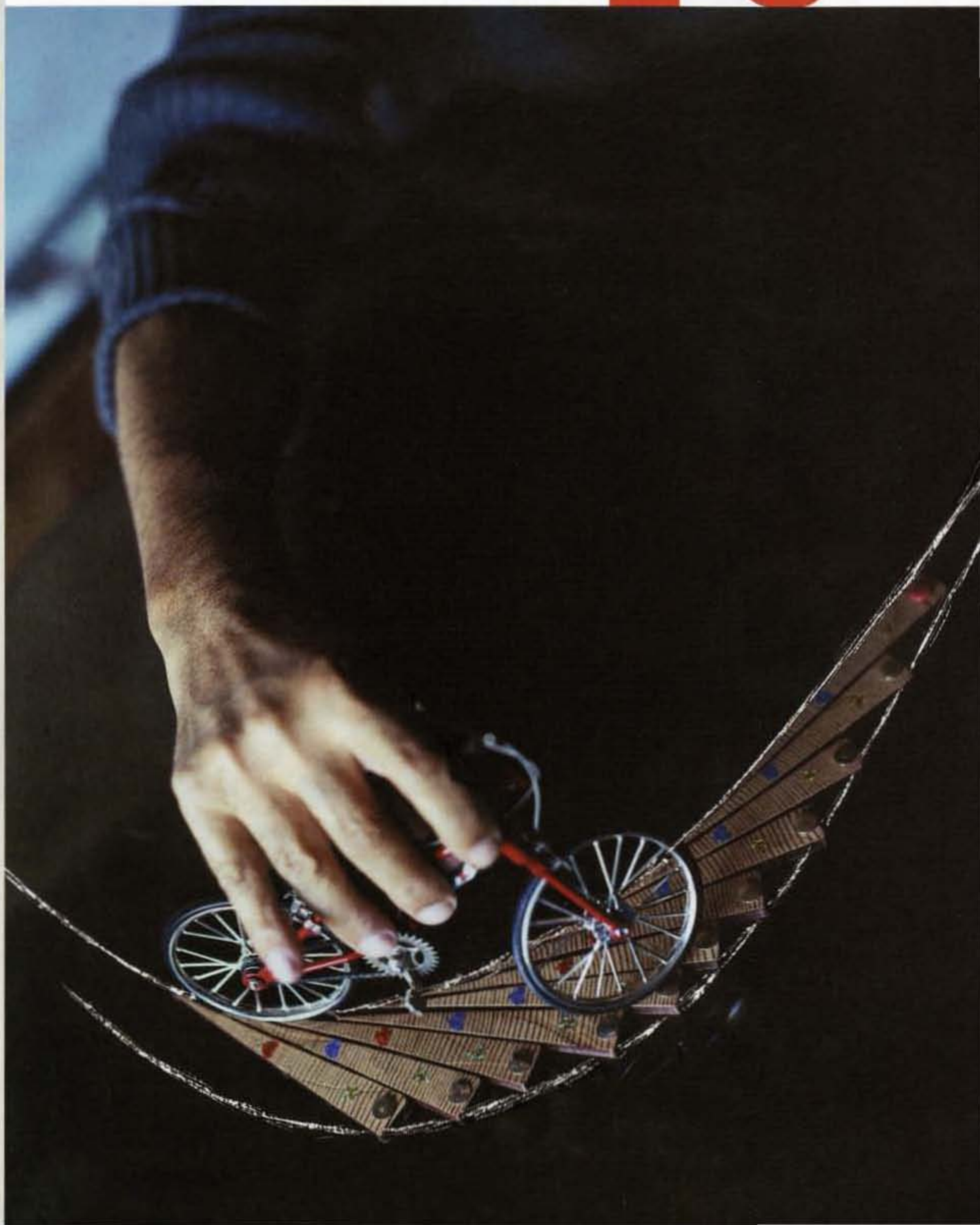

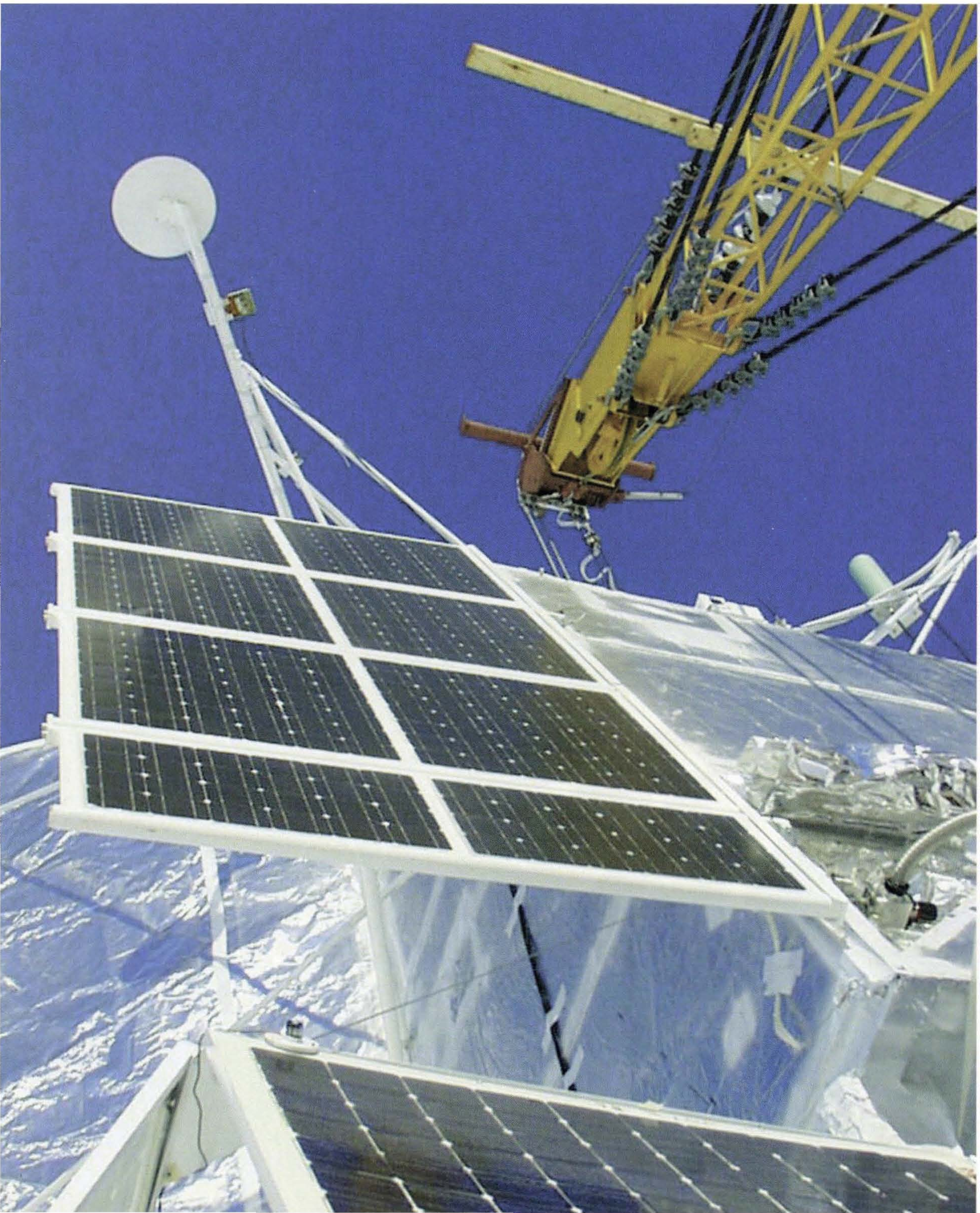

The coldest thing in Antarctica last December lay protected from stray sunlight within these shiny Mylar panels. It was a detector, cooled to less than three-tenths of a degree above absolute zero by liquid helium-3, designed to map residual heat from the birth of the universe in unprecedented detail. The story of what the Balloon Observations Of Millimetric Extragalactic Radiation ANd Geophysics (BOOMERANG) project discovered begins on page 10.

ENGINEERING AND SCIENCE

California Institute of Technology

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On the cover: A new method of "visual" calculus using tangents (represented here by wooden wedges) can make higher mathematics kid's play. Well, almost. See for yourself in the article beginning on page 22.

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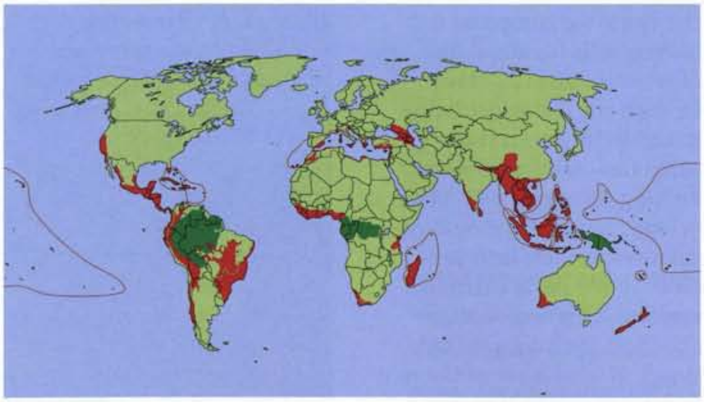
On September 12, ground was broken for the Broad Center for the Biological Sciences (below), Caltech's flagship building for biology in the Genome Era. Named for Caltech trustee Eli Broad and his wife, Edye, the Broad Center will house a dozen or so research groups working in such areas as structural, behavioral, and computational biology, as well as shared facilities for electron microscopy and magnetic resonance imaging. Above are, from left: John Rudolph of Rudolph and Sletten, the contractors; L.A. mayor Richard Riordan; Mel Simon, Biaggini Professor of Biological Sciences, who chaired the biology division during the planning process; Eli Broad; Pasadena mayor Bill Bogaard; Edye Broad; James Freed of Pei Cobb Freed & Partners, the architect; John Abelson, Beadle Professor of Biology and chair of the Broad Center Building Committee; David Baltimore, president of Caltech; and Gordon Moore (PhD '54), chair of the Board of Trustees.

Defying Nature's End

Almost everyone knows that we're hurtling toward a global extinction crisis more devastating than the one that nuked the dinosaurs, with humankind in the role of the killer asteroid. And for the past decade, there has been a steady stream of conferences on the issue. In fact, Jeff McNeely, chief scientist for the World Conservation Union (WCU), likes to show a cartoon of a ragged guy in extremis crawling through the desert toward a long, bare table behind which sit several solemn folks in suits. The man exclaims, "Thank God! A panel of experts!" On August 22 to 26, Caltech hosted "Defying Nature's End: A Practical Agenda for Saving Life on the Planet," organized by the Center for Applied Biodiversity Science (CABS) at Conservation International (CI), in collaboration with the WCU. Gordon Moore (PhD '54), co-founder of Intel, chair of the Caltech Board of Trustees, and member of the board of CI, brought the event to campus and co-chaired it. But this was "not just another biodiversity conference," said Stuart Pimm, the conference's scientific chair and professor of ecology at the Center for Environmental Research and Conservation at Columbia. The international group of world-class scientists, economists, and businessmen—"the 'A-Team' of biodiversity," in the words of co-chair E. O. Wilson, the University Research Professor at Harvard—had convened to put together a set of concrete proposals that can be done now, with existing scientific and economic resources.

This is possible because roughly 60 percent of Earth's terrestrial biodiversity is found in 25 "hotspots," which are extremely threatened places that comprise 1.4 percent of the planet's surface—an area three times the size of Texas. Protect them, and you're halfway home. Some of this land is already in parks and reserves, of course, but most of it isn't. Add in the last big wilderness areas remaining—the Amazon and Congo forests, and the island of New Guinea—and you have 80 percent of all species living on 4.8 percent of the land area, a region about the size of the lower 48 states. Offshore, most of the life (and 99 percent of the world's fisheries) lies in 10 percent of the ocean—the shallow waters of the continental shelves. "How many of you would bring back the moa and the dodo?" asked Callum Roberts, a senior

The last three big tropical forests are shown in dark green; hotspot areas are in red. Although the amount of red on the map is impressive, appearances are deceiving—the actual patches of wilderness are scattered through the red zones, and constitute about 12 percent of the acreage shown. Hotspot ecosystems, by definition, have less than 30 percent of their original extent left. And for that dwindling habitat to qualify as a hotspot, it must host at least 1,500 species of native plants—partly because plants don't wander off and are thus easier to count, and partly because the abundance of plant species correlates directly with the abundance of mammals, birds, and insects.



The ring-tailed lemur of Madagascar is vulnerable to extinction through habitat loss. Less than 5 percent of Madagascar's primary vegetation remains today.

For more information, visit <www.cabs.conservation.org>.

lecturer in the Department of Environmental Economics and Environmental Management at the University of York. "In the ocean, we can. Their marine equivalents are still out there. Tackling biodiversity loss in the seas is like turning the conservation clock on land back to before World War II. It's a fantastic opportunity." Take the island of St. Lucia in the Caribbean, he said, where fully protected marine sanctuaries alternate with fishing grounds. In the three years since the scheme was enacted, fish stocks have tripled in the reserves and doubled in the fisheries, even though the latter have had to absorb all the fishermen displaced from the sanctuaries.

The conferees drew up an "ecological business plan," as it were, predicated on the assumption that, like any other business plan, nobody was going to invest in it if it didn't set out measurable goals. The attendees broke up into working groups organized around such topics as hotspots, marine ecosystems, freshwater ecosystems, tropical forest wilderness areas, the links between biodiversity and human health, economic incentives and disincentives for conserving biodiversity, and the societal forces driving environmental change. Armed with extensive background reports nearly a year in preparation, each group was told to come up with short- and long-term scientific goals, decide how those goals could be quantized and verified—calculating soil erosion rates from satellite images, for example, or doing spectral analysis of satellite data to map the percentages of various kinds of trees in a parcel of forest—and to draw up a budget for achieving them. Gustavo Fonseca, CABS executive director, compared it to the Apollo moon missions in scope and urgency, and said, "Practical solutions will get the job done, and our estimates of the costs are front-loaded to produce tangible results quickly."

A 50-page blueprint emerged. One portion of it deals with how best to protect the land. It is generally impractical, for example, to buy threatened habitat outright. Many developing nations are understandably sensitive about foreigners—even well-intentioned ones—owning large tracts of territory, and outright ownership feeds the perception that conservation is a luxury the First World can afford while at the same time preventing the Third World the fair use of their own resources. But one can pay the local landowners—generally, the government at some level—so much per year not to, say, mine tin or cut trees. (Or to cut only one or two high-value species of tree and then turn the area into a protected zone, in the arboreal equivalent of dehorning a rhino to save it from aphrodisiac hunters.) CI already has such "conservation concessions" programs in various stages of development in Suriname, Guyana, Bolivia, Peru, Brazil, and Cambodia. Protecting the necessary land in the hotspots and jungles will cost about $28 billion.

Jungle land is cheap, but hotspot land isn't—that's where humans are encroaching the fastest, so there are many bidders for it. Southern California is in one, for example, and we all know what the real estate market is like out here. So another portion of the blueprint laid out a strategy for integrating recent developments in computer technology, data storage, and remote sensing—a field broadly called GIS, or Geographic Information Systems (see *E&S*, 1996, No. 2)—with new and existing databases on the holdings of museums around the world to figure out exactly what lives where, who eats whom, and how their lives affect ours (and vice versa). This will allow the most threatened areas to be identified and priorities to be set, and can be done for a measly $10 million.

But the linchpin of the whole scheme is the establishment of a network of Local Biodiversity Facilitation Centers—at least one per hotspot. In the words of the summary report, these are to be "the war rooms and nerve centers" for the actual day-to-day conservation efforts. Each hotspot presents its own problems—jurisdictional and cultural as well as ecological—so a one-size-fits-all centralized approach just won't work. "Protecting the land means something very different in California than in the Congo," notes Pimm, adding, "Once the land is protected, we can't just declare victory and come home—we have to help the local people become better stewards." This takes a combination of research and education—for example, figuring out economic alternatives to slash-and-burn farming, so that the displaced farmers become forest guards rather than poachers. The centers are to be staffed by local people as much as possible, although growing the requisite crop of experts won't happen overnight—the entire nation of Gabon, for example, has four PhD biologists. Running each center will take about five million bucks a year. With 12 centers initially proposed, this comes to \$60 million per year, or \$600 million for the next 10 years.

The oceans, some 50 years behind the land in terms of despoliation, are equally laggard when it comes to species mapping. A good portion of the GIS and database work will go toward figuring out where the oceanic (and freshwater, such as rivers) hotspots are. Some of them, such as the Caribbean and Philippine Seas, will clearly be contiguous to the land ones and can share centers, says Pimm, but others, including the East African Rift lakes, will need centers of their own.

The long-term goals have to do with ending "perverse subsidies"—for example, an oft-quoted statistic was that the world's commercial fish harvest sells for about half of what it costs to obtain it, with the difference being made up by government programs—and with reimbursing countries with undeveloped land for the ecological services their land provides to the industrialized nations. Forget that stuff about all the undiscovered drugs in what's left of the rain forest—how much is it worth not to slowly broil in our own juices? All that greenery is pulling carbon dioxide out of the air and retarding global warming, and that's just the tip of the (melting) iceberg of what the land does. Robert Costanza, director of the University of Maryland's Institute for Ecological Economics, presented an economic model that attempts to put explicit dollar values on such ecosystem services—a notoriously tricky business—and concluded that they are worth roughly \$33 trillion a year, larger than the world's GNP. Clearly, if the rain forest countries were to get even a small slice of that, it would go a long way toward protecting the forests.

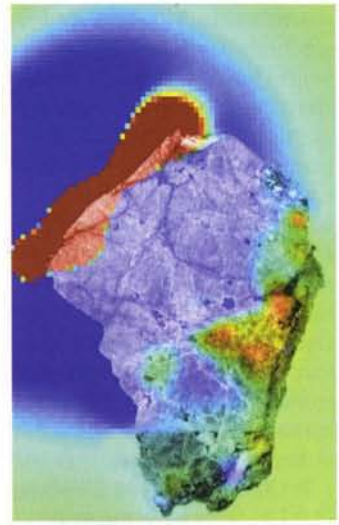
CI has set itself a deadline of one decade to raise the money, and they think it can be done. Peter Seligmann, chairman of the board and CEO of CI, recalled that a few years ago at a CI conference in Seattle, "A young guy came up to me and said, 'OK, how much would it take to get this done? Because clearly \$100 million is peanuts.' I said, 'About \$3 billion.' He said, 'Do you have the scientific data to back that up?' I said, 'Sure. We have tons of data.' He said, 'That would be fun!' Turns out he was one of the earliest employees of Microsoft, and had just retired at a very early age. He said Microsoft had conquered the world once already, and now he and his cohorts were looking for new challenges. It's a whole new world."

The down payment was made at the conference when James Wolfensohn, president of the World Bank, announced the creation of the Critical Ecosystem Partnership Fund to the tune of \$150 million. The fund will make grants to local groups in developing countries, and is designed for rapid response with minimal red tape. It "will help us find solutions that allow poor people [in hotspots] to have a better way of life, while at the same time conserving the biodiversity on which their long-term survival depends," he said. CI, the World Bank, and the Global Environment Facility (a 166-nation organization based in Washington, D.C.) have each pledged \$25 million to the fund over the next five years, with the balance to be sought from outside donors; CI will oversee its day-to-day management. □—*DS*

In other wildlife news, the arrow in this close-up points to the elk referred to in last issue's piece on the fire at LIGO's Hanford site. And the Hanford observatory met a major milestone on October 20, when, for the first time, laser beams shot simultaneously down both arms of the shorter, two-kilometer-long interferometer system. Dubbed "first lock," this is the rough equivalent of "first light" on a new telescope. Full operation is anticipated in the year 2002.

In slash-and-burn agriculture, the forest is burned off to clear land for subsistence farming. Without the trees' deep roots to hold it in place, the land quickly begins eroding, becoming useless after just a few crops. This river in Madagascar is choked with red-brown silt that used to be topsoil; the badlands behind it used to be a tree-clad hill.

Leapin' Microbes!



In this composite picture of the sample, magnetic data has been superimposed on a photomicrograph. The colors show the field intensity and direction perpendicular to the plane of the page. Blue is up, red is down, and green is zero. The red region at upper left is the meteorite's "skin," which has been heated and reoriented. The interior shows a patchwork of colors, reflecting the original orientations.

According to one version of the "panspermia" theory, life on Earth could originally have arrived here by way of meteorites from Mars, where conditions in the youth of the solar system are thought to have been more favorable for the creation of life from nonliving ingredients. The only problem has been how a meteorite could get blasted off Mars without frying any microbial life hitching a ride. But a study of the celebrated Martian meteorite ALH 84001 shows that the rock never got hotter than 105° F during its journey from the Red Planet to Earth—even during the impact that ejected it from Mars, or while plunging through Earth's atmosphere before landing on Antarctic ice thousands of years ago. In the October 27 issue of *Science*, grad student Benjamin Weiss, undergrad Francis Macdonald, Professor of Geobiology Joseph Kirschvink (BS, MS '75), and their collaborators at Vanderbilt and McGill Universities describe results obtained when testing several thin slices of the meteorite with a device known as an Ultra-High Resolution Scanning Superconducting Quantum Interference Device Microscope. The machine, developed by Franz Baudenbacher and other researchers at Vanderbilt, is designed to detect microscopic differences in the orientation of magnetic fields in rock samples, with a sensitivity up to 10,000 times greater than existing machines.

"This shows the meteorite made it from the surface of Mars to the surface of Earth without ever getting hot enough to destroy bacteria, or even plant seeds or fungi," says Weiss, the paper's lead author. "Other studies have suggested that rocks can make it from Mars to Earth in a year, and that some organisms can live in space for several years. So the transfer of life is quite feasible." ALH84001 has been the focus of numerous studies in the last few years because some scientists think there is evidence of fossilized life within it. The issue has never been resolved, but Weiss says that doesn't matter. "In fact, we don't think that this particular meteorite brought life here," he says. "But computer simulations of ejected Martian meteorites demonstrate that about one billion tons of rocks have been brought to Earth from Mars since the two planets formed." Many of these rocks make the transit in less than a year, although ALH84001 took about 15 million years. "The fact that at least one out of the 16 known Martian rocks made it here without heating tells us that this must be a fairly common process," says Kirschvink.

The sample the Kirschvink team worked with is about one millimeter thick and two centimeters in length and somewhat resembles the African continent, with one side containing a portion of the original surface of the meteorite. The team found an intense, highly aligned magnetic field near that surface, which is to be expected because it got very hot upon entering Earth's atmosphere. Any weakly magnetized rock will align its magnetization with the local field direction when heated to its "blocking temperature." But the sample's interior had randomly oriented magnetization, meaning it had not reached its blocking temperature since before leaving Mars. And when the researchers gently heated another slice taken from the interior of the meteorite, they discovered that the rock started to demagnetize at temperatures as low as 40° C (105° F), demonstrating that it had never been heated even to that level.

Thus, a radiation-resistant organism that can do without energy and water for a year could have made the journey from Mars to Earth, and such hardy critters, including the bacteria *bacillus subtilis* and *deinococcus radiodurans*, do exist. "Realistically, we don't think any life forms more complicated than single-celled bacterial spores, very tough fungal spores, or well-protected seeds could have made it," Kirschvink says. "They would also have had to go into some kind of dormant stage."

Though the study does not directly address the issue of life in meteorites, the authors say the results eliminate a major objection to the panspermia theory—that any life reaching Earth by meteorite would have been heat-sterilized during the violent ejection of the rock from its parent planet. Other studies have already shown that a meteorite can enter Earth's atmosphere without its inner material becoming hot. The results also demonstrate that critical information could be lost if rocks brought back from Mars by a sample-return mission were heat-sterilized, as has been proposed.

If life ever evolved on Mars, it is likely to have jumped repeatedly to Earth over geologic time. Because the reverse process—the transfer of Earth life to Mars—is dynamically much more difficult, it may be more important to instead protect any Martian biosphere from Earthly microbes. Says Kirschvink, "The Martian biosphere, if it ever evolved, would most likely have been brought to Earth billions of years ago, and could have participated in the evolution and diversification of bacterial life here. So there is at least a chance that we are in part descended from Martian microbes."

The research was partially funded by NASA's Astrobiology Institute, an international consortium headquartered at NASA's Ames Research Center. The JPL group that sponsored the Caltech work is one of the Institute's 11 lead teams. □—*RT*

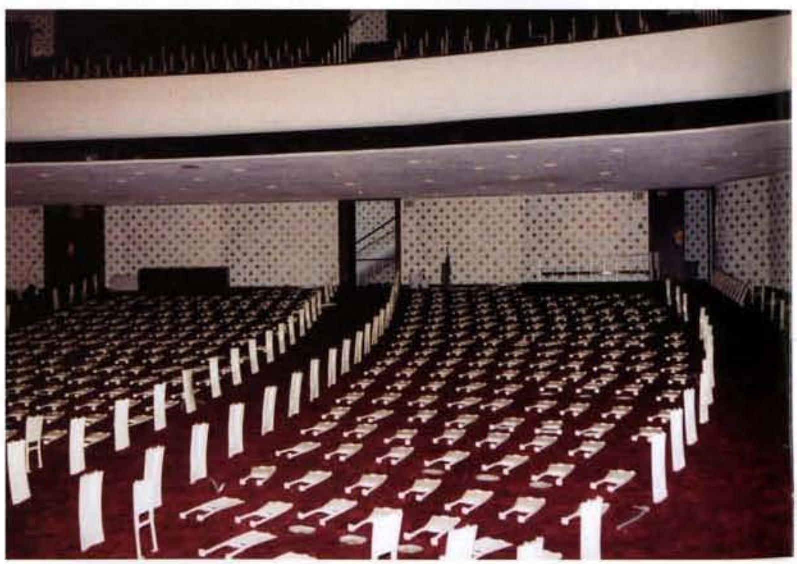
CIT, USC Can Help You See (Not UC)

You don't need glasses if you have 20/20 vision, but that one set of numbers doesn't say much else about how well you can see. Until now, measuring the rest of the central visual field has been a laborious process. The fastest (and most expensive) machine takes as much as 40 minutes per eye, and the data collected is sparse. But a new test, developed by Wolfgang Fink, a postdoc in the lab of Steve Koonin (BS '72), provost and professor of theoretical physics; and Alfredo Sadun, professor in the Department of Ophthalmology and Neurological Surgery at the Doheny Eye Institute of the Keck School of Medicine at USC, takes five minutes, gives detailed sensitivity information over the entire central visual field, and requires only a PC with a touch-sensitive screen. The software, which will be distributed worldwide on the Internet, could automate diagnoses of many eye diseases, and even some classes of brain tumors.

"If you think of the visual field as an island in a sea of darkness," says Sadun, "old-fashioned perimetry essentially sent boats toward the island from various directions until they hit the shoreline." But the interior remained uncharted, and, if contrast sensitivity equals elevation, that interior resembles a volcanic island: the summit is the fovea, the patch of retina about half a millimeter square

Watson Lectures Set

The lineup of Watson lectures has been annouced for this winter and spring. Leading off on January 17 is "The Physics of Snow Crystals," by Professor of Physics and executive officer for physics Ken Libbrecht (BS '80). Then on February 21, JPL's Michael Kobrick will speak on "Planetary Phrenology: The Lumps and Bumps of the Earth." Earth's atmosphere takes its lumps on March 14, when Associate Professor of Atmospheric Chemistry and Environmental Engineering Science Paul Wennberg tackles "Chlorofluorocarbons, Climate Change, and the Future of Stratospheric Ozone." The molecular motif continues on April 11 with "Understanding the World, One Molecule at a Time," by Associate Professor of Applied Physics Stephen Quake, and on May 9 with "In Praise of Permissiveness: Coaxing Cells to Make Novel Macromolecules," by David Tirrell, McCollum–Corcoran Professor and professor of chemistry and chemical engineering and chair of the Division of Chemistry and Chemical Engineering. The season concludes on May 23 with "The Coming Revolution in Photography," by Carver Mead (BS '56, MS '57, PhD '60), Moore Professor of Engineering and Applied Science, Emeritus. As usual, all lectures are at 8:00 p.m. in Beckman Auditorium, and are free and open to the public. □



Watson audiences are sitting pretty. Beckman Auditorium, which was built in 1963, got a thorough rehab over the summer that included new seats, shown here being installed over the new carpet.

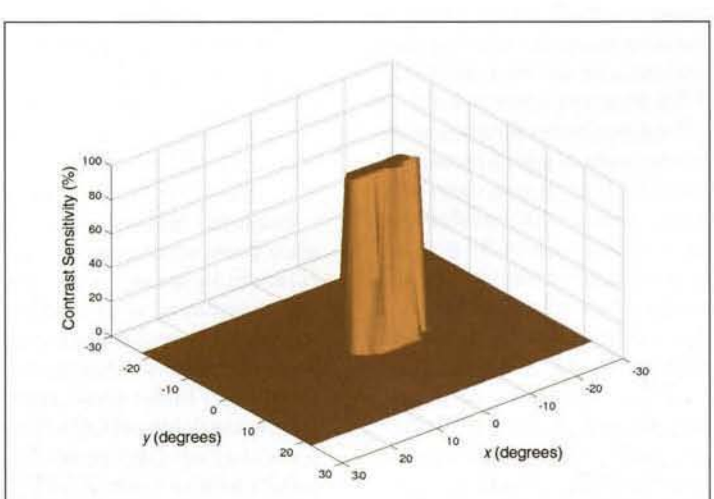
where we see most sharply. Nearby is a bottomless crater—the blind spot, where the optic nerve leaves the eye. And all around, the land slopes down to the sea. In a healthy eye, the descent is gradual and smooth. But disease can erode the terrain into razorback ridges, gullies, and even cliffs of blindness.

About 25 years ago, says Sadun, campimetry was invented, which, in effect, scatters a platoon of parachutists across the island and measures the altitudes where they touch down. The 40-minute method takes data at six-degree intervals—a few dozen points in all. But the new method, called the 3-D Computer-Based Threshold Amsler Grid test, is like dropping a whole battalion of paratroopers spaced as closely to one another as you like. To take the test, the patient closes one eye and stares at the touch screen, which displays a so-called Amsler grid of dark gray lines on a black background. Bright green letters flash by at random in the middle of the grid, setting the benchmark for the mapping by giving the patient something to focus on. The patient outlines the grid's visible portions with a fingertip, after which the computer ups the contrast by 5 to 20 percent and the process repeats. (One could do this up to 255 times—once for every possible shade of gray your monitor can display—but five levels is plenty for most purposes.) The computer assembles the set of tracings into a 3-D map of the visual field, and the test is repeated with the other eye. "It's a lot easier on the patient," says Fink. "In the old method, you had to stare at this red dot for the whole 40 minutes, which takes a lot of concentration. Little kids and old people can't do that very well. But a constantly changing letter naturally attracts the eye, and it takes only a minute or so to trace each contrast level. Then you can take a break before going on to the next one." Fink created the software to display the grids and compile and render the results; an earlier version developed by Sadun used graph paper printed in various shades of gray ink, and the outlines the patients drew on the paper had to be tabulated by hand.

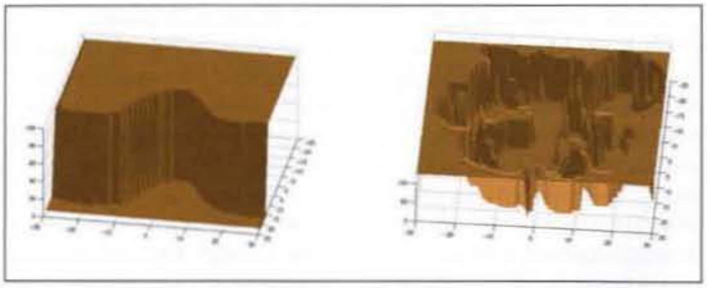
Many eye diseases carve characteristic landscapes. Glaucoma (below), for example, is caused by high fluid pressure within the eyeball compressing the optic nerve, which dies slowly from the outside in. The patient gradually loses peripheral vision, winding up with tunnel vision before going blind altogether—the volcano erodes to a lava plug that ultimately collapses. In macular degeneration, by contrast, patients lose their central vision first. The early stages of macular degeneration look like Meteor Crater in Arizona—a steep-sided hole in the middle of the field. As the disease progresses, landslides occur around the crater's rim, broadening the crater's floor and sloping its walls outward. Macular degeneration occurs as the retinal pigment epithelium cells (the eye's garbagemen, who live behind the light-sensing cells and soak up excess light and the chemical byproducts of vision) are done in by a lifetime of wear and tear. In the early, "dry" stages, the accumulating trash kills the cells above, cleanly knocking out a portion of the field to produce the crater. Later, in the "wet" stages, one or more blood vessels grow in through gaps between the cells and then leak. The extra fluid distorts the retinal cells' positions, degrading the surrounding visual field and eroding the crater wall. "We can tell the difference between anatomical lesions and functional lesions," says Sadun. "An anatomical lesion—a scar—is an abrupt cliff. Functional impairments, like those caused by leaking fluid, are gradual slopes. And now we can pinpoint the fluid's source." If caught early, the wayward blood vessel can be destroyed with a laser and the condition contained.

Above: The early, "dry" stages of macular degeneration, rendered as a wire grid and a contour map.

Below: Mapping a person with normal vision would produce a plateau at 100% contrast sensitivity across the entire measured field. This glaucoma patient has an extreme case of tunnel vision. The retinal coordinate system on the *x* and *y* axes is centered on the fovea.



The best example of the test's power so far is distinguishing anterior ischemic optic neuropathy (AION) from optic neuritis. AION is a small stroke that affects the optic nerve. It hits one in 6,000 people at about 60 years of age, but it can strike people as young as 30. It's untreatable and can destroy most or all of the visual field, and if it occurs in both eyes—which happens about one-third of the time—you can go blind. AION looks like the sea cliffs at Big Sur, with the precipice dividing what's still getting blood from what isn't. In optic neuritis, on the other hand, the nerve fibers get attacked by the body's own immune system in a process very like multiple sclerosis; in fact, optic neuritis may progress to MS. Optic neuritis strikes one in every 3,000 to 4,000 people, and peaks at age 20. "Up to now, the two diseases have normally been differentiated and diagnosed on the basis of age," says Sadun. "If you have a 20-year-old, odds are it's optic neuritis, and if it's a 50-year-old, it's probably AION. But what if the patient is 40? You can't be sure." Again, most of the visual field can be destroyed, but the damage done by optic neuritis looks quite different. Because the disease attacks bundles of nerve fibers at random, you get a badlands of



AION (left) produces a cliff of blindness, while optic neuritis (right) creates a far more complex landscape.

jagged hills and valleys of irregular depth. And the important thing is, optic neuritis may be treatable if caught early enough. The rogue immune response can be subdued, the nerve damage reversed, and the descent into MS sometimes prevented.

The eye is a window to the brain in more ways than just letting light in. In theory, says Fink, tumors in many parts of the brain can be detected there, as long as they impinge on a set of neurons used in visual processing. "There are classic patterns of visual impairment that are known to be associated with certain tumors. If we could expand and refine that library of patterns, the ophthalmologist could tell the neurosurgeon where to focus the CAT scanner to most likely find a tumor. Then the surgeon would be able to image it and deal with it appropriately." The collaboration is looking at pituitary adenoma—a common brain tumor, in which one the chief symptoms is partial vision loss caused by the tumor pressing against the optic nerve. "Most brain tumors are benign," says Sadun. "So the issue becomes, do we leave it in or not? Will we do more harm than good if we try to take it out? These are the most agonizing decisions we have to make." But a series of visual field tests done over a span of several months could show if the tumor is growing slowly enough that it's safe to leave it in.

This brings up another important point—the third dimension of contrast sensitivity provides a powerful diagnostic tool, but the fourth dimension of time may prove more important still. "We are now looking at the steepness of the slope and its change over time as measureable parameters," says Sadun. Does the patient start out with a deep hole that just gets wider, like a gravel quarry, or does it grow like a gentle valley? There's a wealth of data for tracking a disease's progress and recommending treatment options.

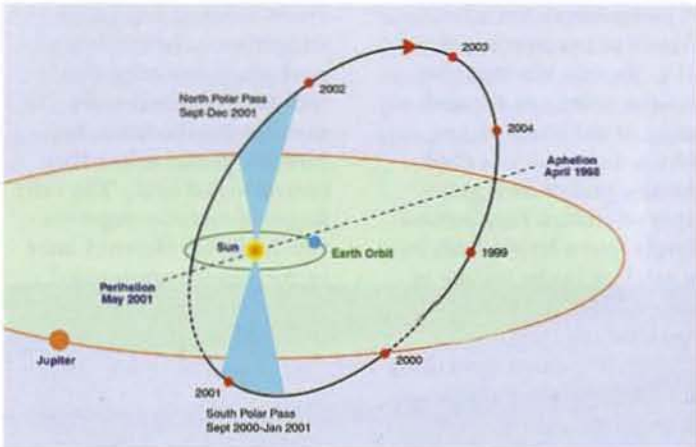
The collaboration envisions a central database, perhaps at the World Health Organization's headquarters in New York, in which the characteristic patterns of all sorts of conditions would be accumulated. Doctors all over the world could send in patients' maps via the Internet, and pattern-recognition software such as a neural network (see *E&S*, Summer 1990) would offer a statistical diagnosis. Such a system could be on line in a year or two, says Fink, who already has developed such a system for a related test. It clearly won't replace the ophthalmologist, but for those common diseases where clear-cut patterns exist, it could make a big difference to general practitioners in remote corners of the world. □—*DS*

For more information, see <www.wfbabcom5.com/wf335.htm>. And the "Eyemovie" shown on the back cover of *Caltech News*, Volume 34, No. 3 (another of Fink's projects) is now available on CD at <www.wfbabcom5.com/wf324.htm>.

Tales of Brave Ulysses

The Ulysses spacecraft, managed by JPL for the European Space Agency and NASA, marked its tenth anniversary on October 6. Ulysses' mission is to study the sun's heliosphere at high solar latitudes. The heliosphere is the vast region of interplanetary space dominated by the solar wind—an outflow of charged particles from the sun. There have been plenty of heliospheric studies near the equator, but the heliosphere around the poles is fundamentally different because of the sun's powerful magnetic field, whose poles roughly coincide with the geographic poles. The lines of force emerging from the poles act as a conduit for the solar wind, as well as for charged particles from outer space called cosmic rays.

Ulysses' solar polar orbit goes to 80 degrees north and south—like traveling from the northern tip of Greenland to Antarctica—the only spacecraft ever to reach such high solar latitudes.



Above: Ulysses' second orbit around the sun. The orbit has a six-year period.

Ulysses is currently near the south pole, at latitudes it last visited during September 1994, at the minimum point of the solar cycle. Solar activity—which runs in an 11-year cycle and manifests itself in such things as increases in sunspots, solar flares, and the aurora borealis—is now at its maximum, and scientists are eager to see what's going on up there. □

The John W. Lucas Adaptive Wind Tunnel was dedicated on November 15. The tunnel replaces the historic 10-foot wind tunnel, a mainstay of the Graduate Aeronautical Laboratories (GALCIT) since 1930. (See *E&S*, 1997, No. 2.) Funded by the Richard M. Lucas Foundation and named for Richard's brother John, a longtime JPL staff member, the new tunnel can simulate 175-mile-per-hour winds and has "smart" walls in its test section that can be flexed by computer control to manipulate the air flow around the model being tested. The facility tour included the still-under-construction test section, where we see, from left: Hans Hornung, Johnson Professor of Aeronautics and director of GALCIT; Mark Lucas, son of Genevieve and John W. Lucas; Harry Ashkenas (MS '46, ENG '50), of JPL; Genevieve Lucas; John W. Lucas; and Paul Joas of the Lucas Foundation.

Art, the Universe, and Everything

Back in the 1920's, Edwin Hubble used the Mount Wilson Observatory overlooking Pasadena to prove that the universe has no center. But it does, and it's right here in Pasadena—through May 2001, anyhow. That's when *The Universe*, a multicultural, multimedia exploration of the cosmos as interpreted by artists and scientists throughout the centuries, is being put on by eight Pasadena institutions. A collective opening reception will be held on February 3, when most of the programs begin.

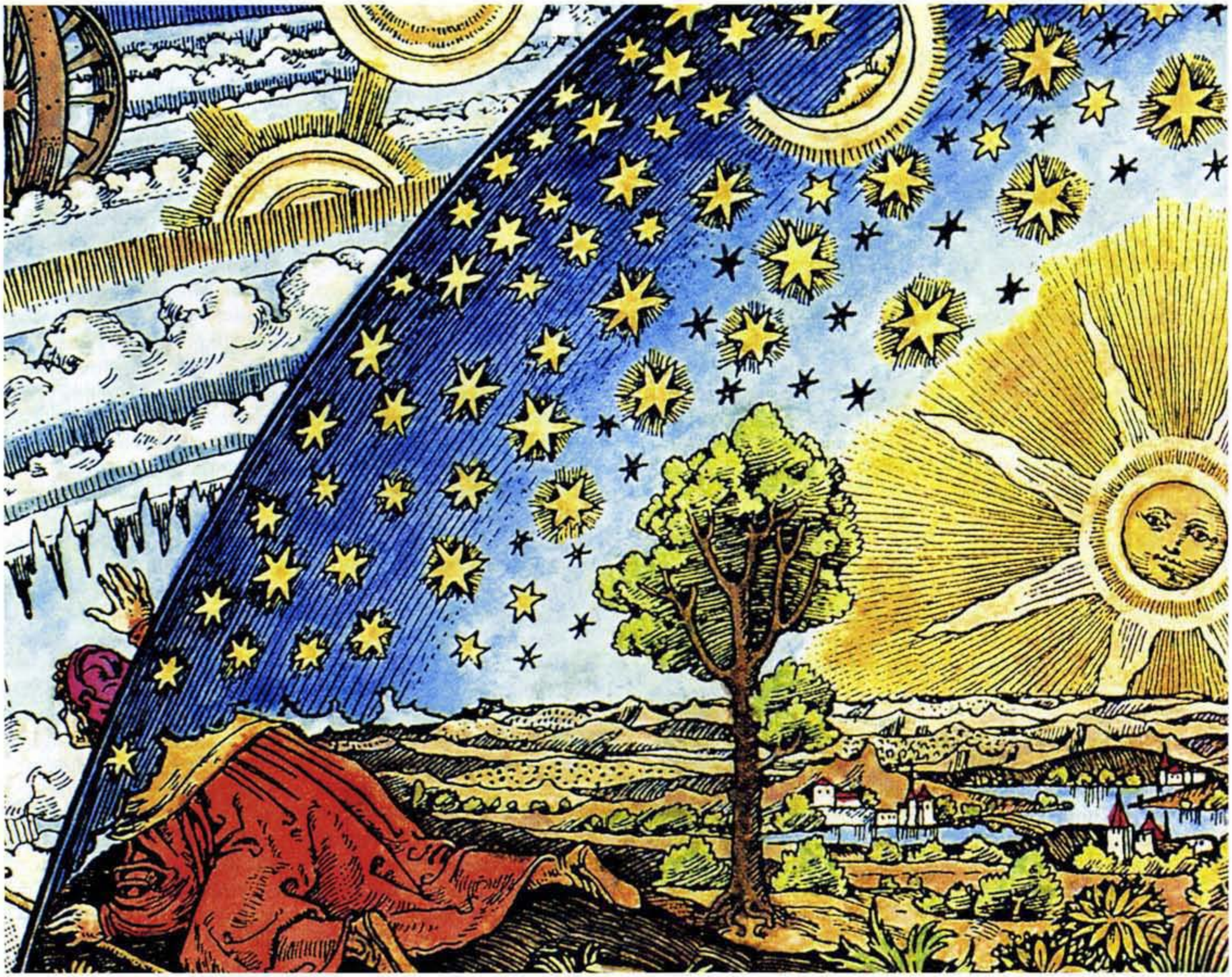
Participants include the Armory Center for the Arts, Art Center College of Design, Caltech, the Huntington Library, the Norton Simon Museum, One Colorado, the Pacific Asia Museum, and Southwest Chamber Music.

The Caltech contribution is a science-fiction film festival called "The Future of the Universe." Four films, chosen by Professor of History Robert Rosenstone, will launch an examination of the science that has inspired the science fiction, and perhaps the science fiction that has inspired the science. Each film will be followed by a panel discussion between scientists, science-fiction writers, humanists, and film-industry professionals. The series begins with *Contact* (1997) on Sunday, January 14, 2001, at 2:00 p.m. in Beckman Auditorium. The other films will be shown on Tuesdays at 7:30 p.m. in Baxter Lecture Hall, and include *Things to Come* (1936) on January 30, *The Day the Earth Stood Still* (1951) on February 13, and *Blade Runner* (1982) on February 27. Admission to all screenings is free; however, tickets will be required to see *Contact*, because of the anticipated demand. Tickets are available from the Office of Public Events at (626) 395-4652.

The Armory will be showcasing contemporary interpretations of space and the universe by American artists including Ed Ruscha, James Rosenquist, Dorothea Rockburne, Robert Rauschenberg, Rockne Krebs, Linda Connor, Carl Cheng, Vija Celmins, and Kim Abeles. Some of the works have been specially commissioned for this exhibition, including "a monumental outdoor night laser installation connecting important locations within the city of Pasadena." Art Center is presenting "The Universe from My Backyard," an installation by Russell Crotty featuring intricately rendered spheres representing the night sky. The Huntington will exhibit astronomical rare books, maps, and artifacts, from some 12th-century manuscripts that rarely go on display to a selection of Edwin Hubble's papers. The Norton Simon has chosen 60 masterpieces organized around the themes of the cosmic axis between heaven and earth; cosmic circles, including haloes; and the constellations. One Colorado will display photographs from the Hubble Space Telescope, including a 45-foot image of Harbig-Haro 47 (a jet ejected from a star, and perhaps a planetary system, aborning) stretched across Crate & Barrel. The Pacific Asia Museum is exploring how Hinduism, Jainism, Buddhism, and Daoism have expressed their conceptions of the cosmos through art, including a spectacular 10-foot-by-10-foot-by-10-foot Buddhist mandala recently built by one of the world's finest Tibetan artists. And Southwest Chamber Music will perform "Music of the Spheres," from medieval music up to John Cage's *Atlas Eclipticalis*, a contemporary score based on star charts.

For details, including all the workshops, children's activities, and other things not mentioned here, check the web at <www.pasadena-universe.org>. □

We have a clear view back to that moment in cosmic history when the universe turned transparent. By analogy to a human lifetime, this is about six hours after conception—before the zygote has divided for the first time.



An Ultrasound Portrait of the Embryonic Universe

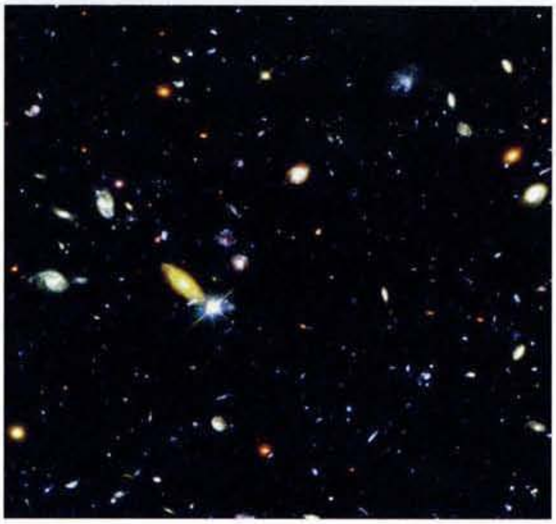
by Andrew E. Lange

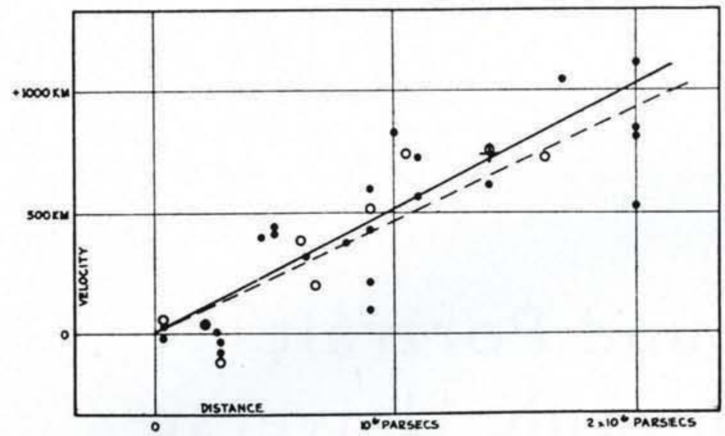
Left: What would we see if we could look beyond the visible heavens? Right: The Hubble Deep Field covers a one-arcminute speck of sky—about the size of a dime seen from 75 feet away, or 1/30th the diameter of the full moon—near the handle of the Big Dipper. This region was specifically chosen to exclude bright stars, nearby galaxies and galaxy clusters, and bright radio sources that might obscure the view of dimmer, more distant objects. The dimmest galaxies here are nearly four billion times fainter than the human eye can see.

I've been working with telescopes carried aloft by balloons since I was a graduate student. We'd launch them from Palestine, Texas, and my job was to drive like a bat out of hell all night long to Tuscaloosa, Alabama, to set up the downrange station. Then, when the balloon lost radio contact with Texas, I could receive the data in Alabama. And, as will not surprise my wife, I was frequently stopped for speeding—once in Louisiana, which is something you never, ever want to have happen to you. The sheriff, who looked a lot like Jackie Gleason, was actually wearing pearl-handled revolvers. He took me to the sheriff's station, and I was rambling on and on about how we were trying to take pictures of the early universe. He didn't say a word for quite a while. Then he looked me in the eye and said, "Now whadya want to do a thing like that for?" Well, I think that part of being human is a fundamental desire to look beyond the limit of our vision, because another very human instinct tells us that if we do (and this applies to the microscopic scale as well), we're going to find something wonderful. And the project I'm going to tell you about, called BOOMERANG, for Balloon Observations Of Millimetric Extragalactic Radiation ANd Geophysics, has done just that.

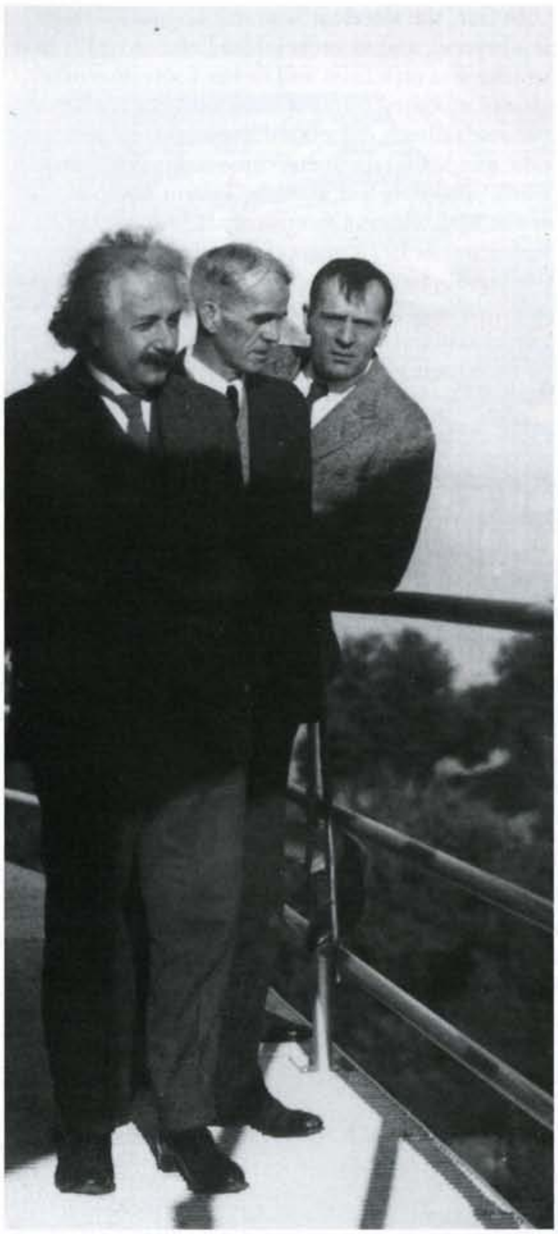
The artist who made the woodcut at left had the same idea—if we could somehow look beyond the stars, there would be some wonderful, magical world "outside." The most powerful equivalent of our eyes these days is the Hubble Space Telescope, which is sensitive to the same wavelengths we see. At right is a piece of the so-called Hubble Deep Field, in which the Hubble stared at a tiny corner of the sky for 10 days straight in order to see as far as it could possibly see. Of all the objects in this image, only two are stars—the rest are galaxies. But our artist would have been deeply disappointed by this picture, because if you look between the galaxies, it's just dark. There's no glowing, otherworldly "beyond" out there.

In fact, the woodcut is pretty accurate—there *is* a beyond, and in order to lead you to it, I'll have to take you on a brief and rather Caltech-centric tour of modern cosmology. (That's not hard to do, because Caltech has played a remarkably important role.) I'll talk about three seminal observations. The first was made by Edwin Hubble at the Mt. Wilson Observatory, which overlooks Pasadena, in 1929. Several people, notably Vesto Melvin Slipher, had noticed that the galaxies outside our immediate neighborhood are moving away from us at various speeds, but Hubble plotted their velocities as a function of their distance from us. He found that the farther away they are, the faster they are receding, so he concluded that the universe is expanding. Furthermore, we're not at the center of the expansion—there is no "center." The universe is expanding in all directions from every point. It's much like sitting on one raisin in a raisin bread as it bakes—no matter which raisin you choose, the others are moving away from you. His actual data





Hubble's data, as published in the *Proceedings of the National Academy of Sciences* (Volume 15, page 172). Distance equals time in cosmology, because the farther away something is, the longer its light takes to reach us. The oldest, farthest galaxies are also moving away from us the fastest, which implies that the average separation between galaxies—assuming our place in the universe is typical—is increasing over time. In a static universe, where the galaxies remain at fixed distances from one another, the line would be horizontal.



Photograph used with the kind permission of The Hebrew University of Jerusalem and The Roger Richman Agency, Inc.

Einstein (left); Walter Adams, director of the Mt. Wilson Observatory; and Hubble on the catwalk of the observatory's 100-inch Hooker telescope, at the time the world's largest, which Hubble used to measure galactic distances.

is shown above, and in cosmology, the way the points fit that straight line is considered perfect. You rarely get such a good correlation. The slope of that line is now called the Hubble constant, and it tells us the rate at which the universe is expanding. (The numerical value Hubble derived was off by about a factor of 10, but, being cosmology, that was OK too.)

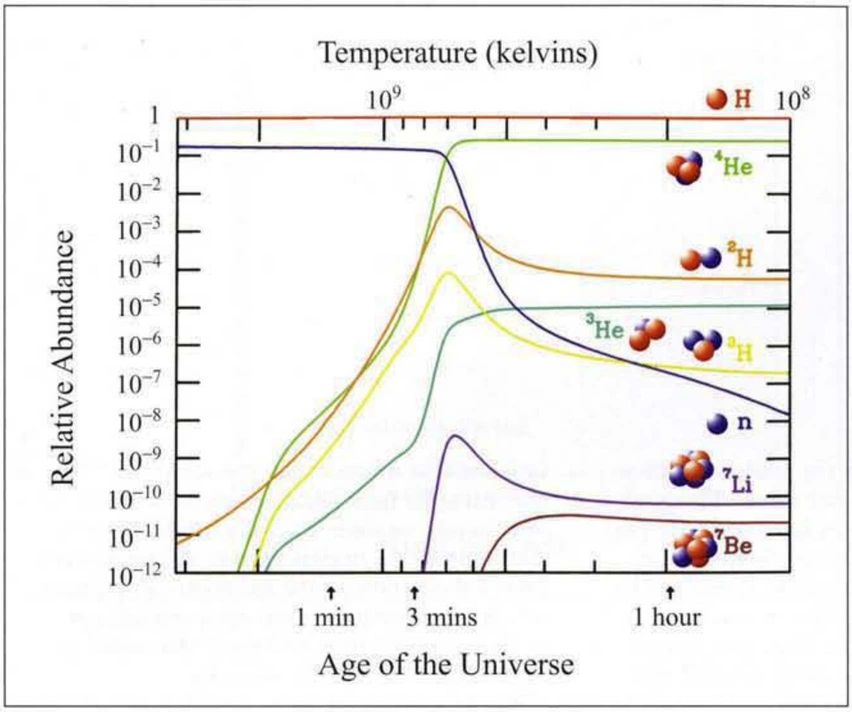
Before moving on to the next discovery, I have to tell you another thing about cosmology: nature is consistently more interesting than we can imagine. When Albert Einstein was working out his field-theory equations for general relativity 12 years before Hubble's discovery, they refused to agree with what Einstein's common sense told him—namely, that the universe had been around forever in pretty much the same form that it is today. He fixed that by sticking in a little thing called the cosmological constant, or Einstein's constant, such that when he plotted the separation between any two galaxies as a function of time, he got a horizontal line. But Hubble showed Einstein that his common sense was wrong. Einstein visited Caltech and met Hubble in 1931, and the campus was abuzz about whether Einstein would disavow his cosmological constant. He stayed mum while he was here, but he later called it the "greatest blunder of my life." More about that later; it's come back to haunt us in the last couple of years.

If the universe is expanding, it follows that it must have been smaller in the past, and that if you play the movie backward all the way to the beginning, it all collapses down to nothing. And now, if you run the movie forward again, you have the so-called Big Bang—the birth of the universe. So people speculated that the universe was much hotter when the matter was all crammed together, because if you let a gas expand, it cools. Our second major discovery was made at Caltech in the 1950s, when the late Nobel Laureate Willie Fowler (PhD '36) and others measured what atomic nuclei do in a very hot, dense environment. I won't go into detail, but at the very high temperatures and densities present in the early universe, protons and neutrons play a strange game of musical chairs from which come the light elements—hydrogen, deuterium, tritium, helium-3, helium, and tiny amounts of lithium and beryllium. (The heavier stuff gets made later, in stars and supernovas.) Each element emerges in a fixed proportion to the others—for example, about one helium atom for every 16 hydrogen atoms—and these ratios agree with what we see throughout the universe. That's a key reason why we believe in the Big Bang.

The third discovery was made in 1964 and involved a Caltech graduate, but it was not made at Caltech. It was made in Holmdel, New Jersey, which had not previously been known as a great astronomical site, at a big radio dish owned by Bell Labs. Nobel Laureates Arno Penzias and Robert Wilson (PhD '62) were working on the Telstar project, which was the first full-fledged communications satellite, and they found that wherever they looked, the sky was aglow with microwaves. This is now called the cosmic microwave background, or CMB, and it's the fossilized primeval fireball. These microwaves are literally the heat left over from the Big Bang. The total amount of energy emitted by all the stars that have ever burned in the whole history of the universe is tiny in comparison to the energy in the CMB.

We've just covered nearly a hundred years of cosmology, so it's okay if you feel a little dizzy. Now let me give you the abridged history of the universe, as told by physicists, that those three observations have led us to. We don't know exactly what happened in the first moments after the Big Bang, but at a time of one second, the observable universe was stuffed full of particles and antiparticles, and its radius was one ten-billionth of what it is today. It was a few light-years in diameter, or about the distance from our solar system to Proxima Centauri, the nearest star. As the universe expanded and cooled, most of that matter and antimatter annihilated each other, turning into energy. One minute after the Big Bang, pretty much everything was gone and all that was left was light. Very biblical. But for every billion antiprotons, there were roughly a billion and one protons, and we should be very, very thankful for that slight imbalance—otherwise we wouldn't be here. So for every proton in our bodies, there are a billion photons of light still echoing around the universe, as Penzias and Wilson discovered. And in the first few minutes after the Big Bang, those billion-and-first protons became Fowler's atomic nuclei.

For the next 300,000 years or so, the light and the residual matter were flinging one another around like professional wrestlers. The matter was an ionized plasma, like a candle flame, so the ions'



Musical chairs in the early universe. The vertical axis shows how many nuclei there are of the other light elements for every nucleus of hydrogen. The lines show how these relative abundances evolve over time. Before the graph begins, there's a seething fog of naked protons (red), which double as hydrogen nuclei; neutrons (blue); and electrons (not shown). The protons and neutrons promptly begin sticking to one another to make heavier nuclei such as deuterium, which has one of each. (Adapted from *The Early Universe*, by Edward Kolb and Michael Turner.)

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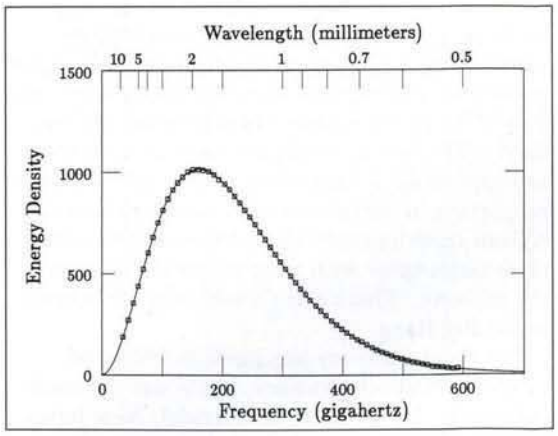
People seem to be fixated on breakfast metaphors—when that beautiful, elliptical COBE map was first published, at least one newspaper proclaimed, "Cosmologists discover early universe shaped like an egg."



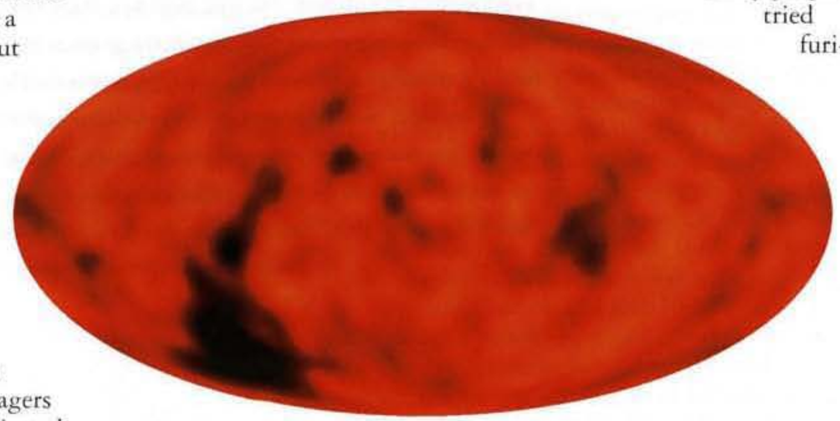
The CMB as measured by the Cosmic Background Explorer's Far Infrared Absolute Spectrometer. The data points are many times larger than the actual experimental error. (Adapted from *The Inflationary Universe*, by Alan Guth.)

electrical charges could grip the photons by their electromagnetic fields, and vice versa. That's why a candle flame is opaque—any light trying to pass through it gets scattered. But as the hot, foggy plasma of loose nuclei and electrons continued to expand and cool, it suddenly (on the cosmic time scale, that is) condensed into electrically neutral, crystal-clear atoms of mostly hydrogen and helium gas. The light finally escaped, and in the 15 billion years or so since, it hasn't interacted with anything. So when it hits our telescopes, we have a clear view back to that moment in cosmic history when the universe turned transparent. By analogy to a human lifetime, this is about six hours after conception—before the zygote has divided for the first time. BOOMERANG literally looks at the embryonic universe, whereas the Hubble Space Telescope typically looks back to the early adolescent universe—a time which, as those of you who have teenagers know, is much more complicated.

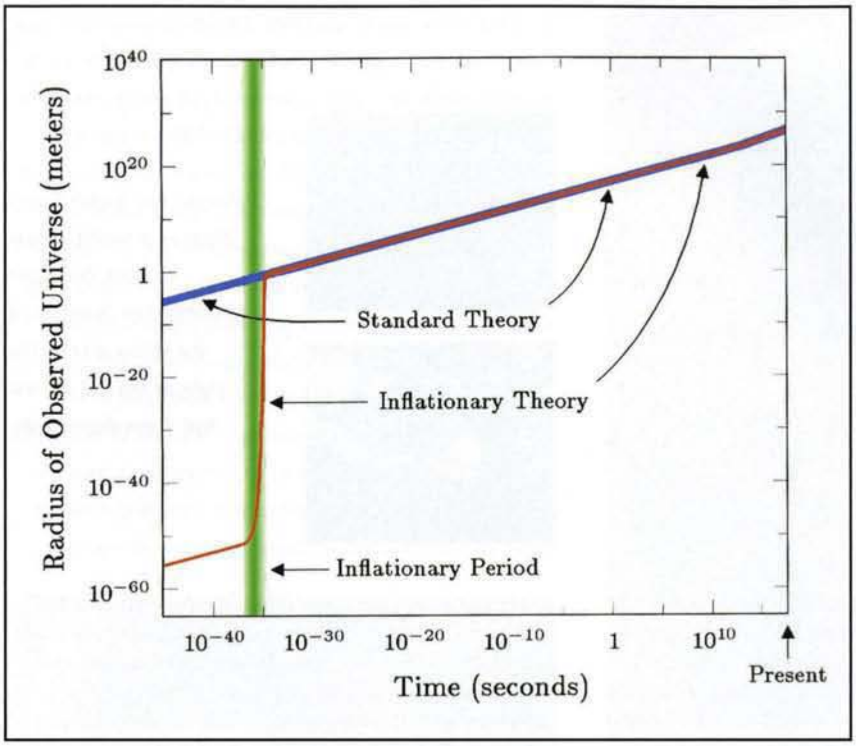
The Big Bang scenario predicts that the cooling universe should radiate a special distribution of colors called a black-body spectrum, which is the same kind of glow a spectrometer would measure from a red-hot stove. Above left is one of the most beautiful measurements ever made in physics—the brightness of the CMB across four orders of magnitude. The line is the theoretical black-body curve, which Max Planck derived in 1900, and the boxes are the data. The two match exactly. The temperature at which the embryonic universe teetered on the brink of transparency was 2,700 kelvins (K) or so, about half the surface temperature of the sun. The entire observable universe that we see today was roughly a thousand times smaller back then—about 30 million light-years across, or some 15 times the distance to Andromeda, the nearest galaxy. As the universe grew a thousandfold, the radiation's wavelength, which is proportional to its temperature, got stretched accordingly, and the CMB cooled to the chilly 2.7 K that we see today.

Any structures we see in the CMB would reflect the plasma's final state, and the hotter, denser regions would be the "seeds" from which galaxies eventually coalesced.

Many people tried furi-



Variations in the CMB were first detected by COBE's DMR (Differential Microwave Radiometers), which operated for four years. This map of the CMB over the entire sky shows what's left once the effects of our own galaxy's motion, interstellar dust, and other confounding factors have been subtracted. But although the DMR was very sensitive to temperature variations, its angular resolution was so broad that there are only 6,144 pixels in the entire map.



The universe gets bigger with time in both the standard and the inflationary model, and the two coincide when inflation ceases. The numbers along the axes are not to be taken as gospel: their exact values depend on the details of the Grand Unified Theory to which you subscribe. (Adapted from *The Inflationary Universe*.)

ously to map it, but success eluded them until the Cosmic Background Explorer, or COBE, satellite in 1992. The reason that it took so long is that there's really not much to see—the difference between the coldest and hottest points is only about one ten-thousandth of a kelvin. In other words, the fireball was exactly the same temperature to within 30 parts per million over the entire sky. But one end of the universe can't phone the other end to find out what it's wearing, because according to Einstein there's no way to send information faster than the speed of light. And the radiation from each end has traveled since the beginning of time and is just now reaching us, so it couldn't possibly have arrived at the other end already. So how do both ends know to be at the same temperature? This may not bother you, but it's the kind of thing that cosmologists lose sleep over.

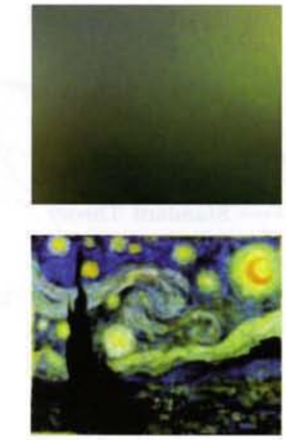
This and other problems have led to an amazing modification to the Big Bang model that solves everything in deus ex machina fashion. Solving so many problems with one idea is great, but the idea is so fantastic (in the sense of outlandish) that if you don't believe it, I don't blame you. Above is a plot of the universe's radius as a function of its age. This so-called log-log plot extends over 40 orders of magnitude on the horizontal axis and 100 on the vertical axis and is the kind of plot physicists love, because if you're right to within a factor of a thousand, you look great. In the standard Big Bang theory, plotted in blue, the universe gets bigger at a constant rate. In the modified theory (red), the universe grew placidly for the first 10^{-30} seconds or so, and then it did something extraordinary—it suddenly exploded in a violent expansion, which cosmologists in their understated way call "inflation." It grew from perhaps a ten-billionth of the size of a proton to about the size of a grapefruit at much faster than the speed of light, and then resumed its nice, gradual expansion. ("Hold on just a minute! Nothing can go faster than light!" you exclaim. Well, if you read the fine print in Einstein's equations, they say that no individual objects in the universe—including photons—can move faster than light in relation to one another. They don't say that the universe as a whole can't expand faster than light, taking all the objects within it with it.) So the microwave background can be the same temperature everywhere because, before the universe inflated, all its parts were in very close contact and would naturally equilibrate to the same temperature.

This has some really interesting implications. Galaxies today form clusters and superclusters—complex distributions of matter on the scale of millions and even billions of light-years. These could have originated as quantum fluctuations in the universe's density, which the inflationary process stretched large on the sky. This fantastic notion is very attractive to physicists, because it connects the largest and smallest scales, but it remains to be borne out. Furthermore, one can speculate that if our entire observable universe sprang from one bit of preinflationary primordial soup, it stands to reason that there could be lots of other bits. So there might be other inflationary bubbles that led to other universes outside our own. But that's perhaps best left (for now!) to the science-fiction writers.

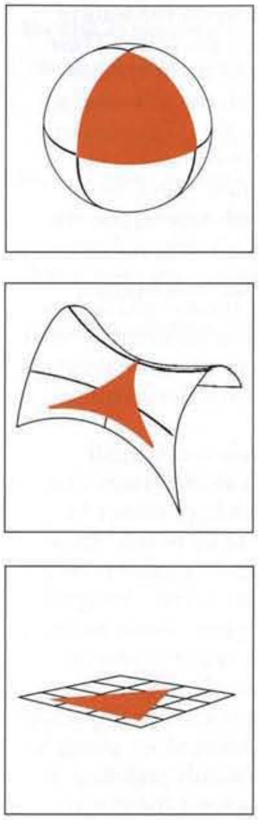
Inflation is not an intuitively comfortable process, and any theory that's so important that the basic observations of cosmology cannot be understood without it needs to be tested. Inflation makes only one really solid, testable prediction, which is that the universe is flat. Imagine standing on the surface of a sphere whose radius suddenly increases by, oh, 27 orders of magnitude—a billion billion billion. You may have been able to see that the sphere was curving underneath you beforehand, but afterward it's going to look real darn flat. You're instantly standing in the middle of Kansas. So whatever the initial geometry of the universe was, the inflationary epoch stretched it flat.

I don't mean that the universe is pancake-shaped, which was the headline in several newspapers when we published BOOMERANG's results. People seem to be fixated on breakfast metaphors—when that beautiful, elliptical COBE map was first published, at least one newspaper proclaimed, "Cosmologists discover early universe shaped like an egg." Here's what "flat" really means: Back in high school you learned that the internal angles of a triangle add up to 180 degrees. But this is only true on a flat surface—if you draw the same triangle on the surface of a sphere, you

Physicists love the early universe. It's uncluttered and easy to work with. Later on, when atoms form, suddenly we get nonlinear physics, chemistry, biology, economics... it all goes to hell in a hurry.



Vincent van Gogh's *Starry Night* as it would appear to COBE (top) and BOOMERANG (bottom), if the yellow star to the right of the tall cypress had a one-degree halo.



Depending on the surface on which you draw it, the three angles of a triangle can add up to more or less than 180 degrees.

will get a number greater than 180 degrees whose exact value depends on the triangle's area. And if you draw it on a funny, saddle-shaped surface called a hyperbolic surface, you'll get less than 180 degrees. Furthermore, on a flat surface, two parallel lines (or rays of light) never meet. That's what parallel means. But on a sphere, if you send two parallel rays of light due north from different points on the equator, they'll cross each other at the North Pole. Similarly, parallel lines on a hyperbolic surface diverge. The equivalent is also true in three dimensions, and because Einstein showed that matter bends space, only if the amount of matter in the universe is just right will parallel light rays stay "parallel." If there is more or less matter than that magic amount, the rays will either converge or diverge. Cosmologists refer to the average density of matter in the universe as "omega." If omega is greater than one, the universe is closed, like the surface of a sphere, and if I set off in any direction in a straight line, I'll eventually end up back where I started. If omega is less than one, the universe is open and infinite, like the hyperbolic surface. If omega is exactly one, we have a flat universe that is also infinite.

So in order to measure the universe's geometry and calculate its total cargo of matter, while at the same time testing the inflationary model, all we have to do is measure the sum of the angles of a triangle. That sounds pretty simple, but the triangle has to be really big. If we look as far back as we can, all the way to the embryonic universe, and hope that someone way out there is holding up a meter stick, we've made a triangle with two legs that are each 15 billion light-years long. And we don't actually have to measure all three angles, because if we know the length of two legs and the angle between them, we can calculate the rest, using the laws of sines and cosines. If the numbers don't add up, it shows that the universe isn't flat.

There is no meter stick out there, but there is a physical process we can exploit to measure the angle between the legs. The dense plasma of the embryonic universe was trying to collapse on itself due to its incredibly intense gravitation, but the equally intense radiation pressure from all the photons kept it propped up. The slightly denser regions caused by those fluctuations I mentioned earlier—the ones that got writ large on the sky during inflation—would have been collapsing slightly faster, churning up sound waves that propagated through the embryonic universe. These are exactly analogous to the ripples that are seen on the surface of the sun (in fact, the early universe would have looked very much like the sun), except that we're seeing them from within. (The discovery of the solar ripples and subsequent deduction that the sun's interior is resonating like an organ pipe has spawned an entire field called helioseismology, but that's another Caltech-centric story.)

Theorists, including Caltech's Marc Kamionkowski, professor of theoretical physics and astrophysics, have calculated the average size the ripples should have for universes with varying amounts of curvature. Physicists love the early universe. It's uncluttered and easy to work with. Later on, when atoms form, suddenly we get nonlinear physics, chemistry, biology, economics... it all goes to hell in a hurry. Physicists don't even want to try calculating that stuff, but the infant universe is good. It turns out that if the universe is flat, the characteristic diameter of the fluctuations is about one degree, or roughly twice the diameter of the full moon. Unfortunately, COBE couldn't see that sharply. Its angular resolution—the smallest shape it could make out—was seven degrees in diameter, or 14 moons' worth. So BOOMERANG was designed to spot things one-third the size of the full moon. Vincent van Gogh's *Starry Night* also has structures of a characteristic angular scale, so to give you a better idea of what this all means, I've reproduced the painting as COBE and BOOMERANG would

Each bolometer spiderweb (bottom), shown seven times its actual size, is a delicate tracery floating over a cavity from which the silicon has been eaten away. The bolometers are mounted in BOOMERANG's focal-plane assembly (below). The assembly, seen here with Silvia Masi of the University of Rome, is made largely of copper for best heat dissipation. The sphere is the helium-3 reservoir. The assembly, in turn, goes into the bottom of the liquid-nitrogen dewar (right), which one might think was worshipped as a cult object. The devotees are, clockwise, Caltech postdoc Barth Netterfield (seated, wearing black sweater), now at the University of Toronto; Francesco Piacentini of the University of Rome; an anonymous pair of legs; Caltech grad student Brendan Crill; John Ruhl, a professor at UC Santa Barbara; and Armando Iacoangeli, of the University of Rome.

see it. We can't see the brush strokes yet, but the swirls are clearly visible.

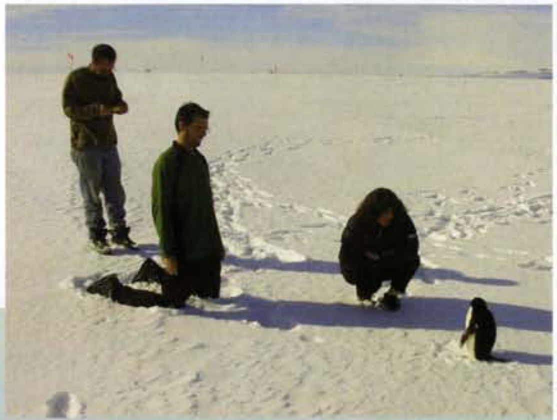
BOOMERANG's detector uses a fantastic new technology developed by Jamie Bock and his group up at the Jet Propulsion Laboratory, or JPL, which Caltech runs for NASA. You can tell whether the sun is shining when you're blindfolded by feeling the heat on your face, and the detector works the same way. Called a bolometer, it's a button-sized, freestanding spider web micromachined on a silicon wafer. The web's mesh is larger than the wavelengths of cosmic rays and other things we aren't interested in, so they fly right through, but it's smaller than the millimeter-sized microwaves from the Big Bang. They get absorbed by the web as if it were a solid surface, and a tiny thermometer in the middle of the web measures how much it heats up with a precision of better than a millionth of a kelvin.

BOOMERANG would not have been possible without the very close contact that exists between Caltech and JPL. Nor would it have been possible without the vision of JPL's Director of Space and Earth Science Programs, Charles Elachi (MS '69, PhD '71). When Jamie and I wandered down from Berkeley some years ago and said, "Hi! You don't know us, but we'd kind of like some money and lab space to build this idea we have," he talked to us for a while and said, "Great! You got it!" And he has supported us in many ways ever since.

It's a basic fact of life that your detector has to be colder than the thing you're trying to see; otherwise, you're mostly going to see the detector. The CMB is 2.73 K, less than three degrees above absolute zero, so our array of 16 detectors was kept chilled to 0.28 K by liquid helium-3. The cryogenic system, which holds 60 liters of helium-4 to cool the helium-3, and 60 liters of liquid nitrogen to cool the helium-4, was developed by Professor Paolo de Bernardis's team at the University of Rome. They also built the 1.2-meter microwave mirror system that focuses the CMB onto the spiderwebs.

Furthermore, measuring a difference of a few millionths K in the presence of our sun's 5,000 K is no mean feat. If the sun, the earth, or even the balloon had gotten near the field of view, they would have cast a glint of light onto the image and ruined it. The mirror and the entire optical path had to be very carefully shielded from stray light, so the telescope was enshrouded in an elaborate system of enormous baffles built from aluminized Mylar.

So what with the dewars and the shielding and the computers and the solar panels and all, the final package wound up weighing 1,400 kilograms. And we needed to get this massive thing above as much of the earth's atmosphere as possible, but the heavier something is, the more it costs to put it in orbit. So we used a poor man's satellite—a balloon that flies about 37 kilometers



What would an Antarctic travelogue be without a few tourist postcards? At top, an Adélie penguin provides a photo op for (from left) Tom Montroy, a grad student at UCSB; Crill; and Masi. In the bottom picture, the wreck of a Pegasus supply plane is now the local jungle gym. From left: de Bernardis; Piacentini; Andrea Boscaleri of IROE (Istituto di Ricerca sulle Onde Elettromagnetiche), Florence; and Francesco Pongetti of ING (Istituto Nazionale di Geofisica), Rome.

high. At that altitude, 99 percent of the atmosphere is below us, and the balloon inflates to about the size of the Rose Bowl. A balloon flight out of Texas typically lasts just a few hours, but about a decade ago, someone discovered that if you launch from the coast of Antarctica at just the right time of year, the winds will carry you around the continent in a big circle. You get a flight time of a week or two before returning to where you took off. Since then, about a dozen balloon flights have been made this way.

The summer of 1998 saw us assembling and testing BOOMERANG back in Palestine, Texas, and by mid-October BOOMERANG had been taken apart again and carefully crated for shipment to NASA's National Scientific Balloon Facility at McMurdo Station, Antarctica. By the first week of November, there were 13 team members down there (including Caltech grad student Brendan Crill, postdoc Barth Netterfield, and Pete Mason (BS '51, MS '52, PhD '62), a retired senior member of the technical staff at JPL) reassembling and retesting the apparatus. I had classes to teach, so I got to stay back in my office in Pasadena and worry. I did manage to get down there on December 11, but was unable to stay long.

Antarctica is a beautiful place, so beautiful that there are very few people who've been there just once. Everyone wants to go back. As Brendan is fond of saying, the weather is "sunny and dry, just like L.A., just 40 degrees Celsius colder." The NASA folks gave us the use of a hangar, which they call a high bay, out at the Williams Field airstrip, which is about six miles from McMurdo. The "road" across the ice shelf to the field is marked by a series of flags on stakes and precious little else, which makes driving interesting when the wind kicks up and the blowing snow cuts your visibility way down. McMurdo is quite plush; Williams Field somewhat less so—our high bay had a canvas door and an outhouse. Phil Farese, a grad student at UC Santa Barbara, cut an insulated toilet-seat liner from a sheet of Styrofoam, which helped enormously.

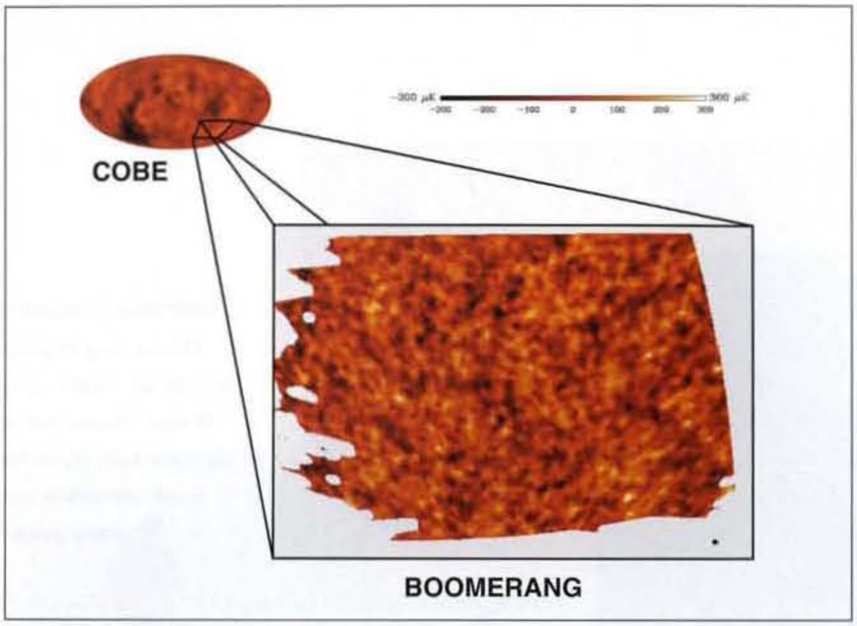
The sun never sets at that time of year, which made it easier to work two shifts, and sometimes around the clock, getting ready for launch. Even so, it took nearly two months. The team got everything back together and operating in a couple of weeks, but the tests and calibrations took a month and a half. It wasn't all grind, grind, grind, though—they worked in a lot of skiing and mountain biking on their off hours, as well as touring the local ice caves, Scott's cabin from his ill-fated polar expedition of 1911, and a nearby plane wreck from the 1960s. We had hoped to launch on Christmas—that would have been the best present ever!—but the launch was scrubbed by high winds.

We lifted off on December 28, 1998, Pasadena time—McMurdo Station is just across the International Date Line, so it was the 29th over there. At the top of the next page is the balloon's actual

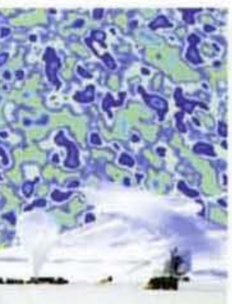
BOOMERANG one-upped Phineas Fogg by going around the world in only 10 days. The red line is the flight path; the arrow marks the takeoff and landing points.

track, which roughly followed 79° south latitude. You don't always get this lucky. When one of my friends at JPL saw this, he said, "Wow! What kind of propulsion system did you use?" In fact, we didn't even tinker with the balloon's altitude to try to steer it. We just let it go, and sat by the computer watching the track as it evolved. We got worried a few times when the balloon started going astray, but it always came back on course, and after an 8,000-kilometer journey, it landed 50 kilometers from the launch site. Most importantly, the landing was 50 kilometers inland across the ice shelf, not 50 kilometers out to sea! The air is so clear down there that the balloon actually came back into view from Williams Field, and the entire landing was visible from the launch site. The landing sequence is radio-controlled (from an airplane—we had assumed we'd have to fly some distance to intercept the balloon), and BOOMERANG parachuted reasonably gently to earth, taking data all the way down. The solar panels crumpled on impact, but as they say, any landing you can walk away from is a good one—the dewar was still under vacuum with helium to spare, and the hard drives were fine. The hard drives were for backup, in case BOOMERANG couldn't transmit the data while

Above: Sun-sensor calibration. In flight, BOOMERANG faces away from the sun. The Mylar wings keep stray light out, as will an inverted Mylar snout. The complete craft looked like a three-story teapot. Right: Launch. Mt. Erebus, behind the balloon, is an active volcano 40 km off.



Above: The BOOMERANG data covers approximately 1,800 square degrees, or 2.5 percent, of the southern sky, as shown in relation to the COBE all-sky map above it. The small black circle in the lower right corner of the BOOMERANG data is the size of the full moon. Below: Although the variations are very faint, they are quite large. Here the CMB, in a more suitably Antarctic color scheme, has been inserted to scale behind the launch preparations.



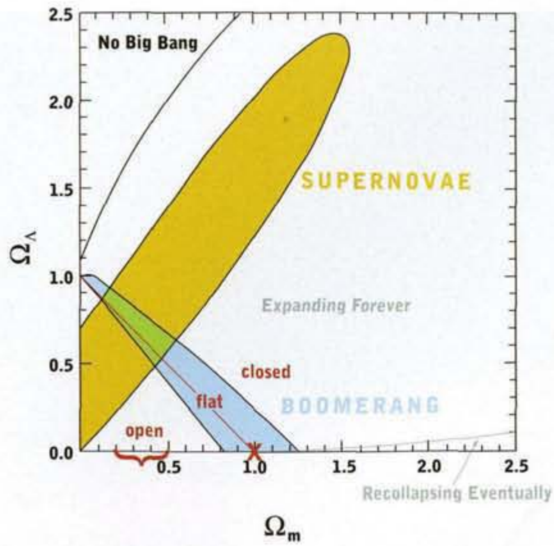
aloft. There's very poor cell-phone coverage in the Antarctic, especially now that the Iridium global wireless network has gone bankrupt. (Iridium was just coming on line back then, and I called them and asked, "How many cell-phone numbers will we have to buy to get all the data down through your system?" The 10-day flight would have cost us $1.5 million in phone charges. No wonder they went out of business.) So BOOMERANG sent all its data to a NASA satellite, which relayed it back to us. And, as it happened, that worked just fine.

The collaboration, including Caltech postdoc Eric Hivon and senior engineer Viktor Hristov, has fully analyzed only 5 percent of the data so far, but here's the punch line. The BOOMERANG map above is different from the COBE map above it in two important respects. First of all, every feature is real. The COBE instrument was operating near the limit of its sensitivity, so there is a lot of noise mixed in with its data. BOOMERANG had much higher sensitivity, and produced a map with relatively little noise in it. We mapped the entire sky once a day for 10 days, and the same structures appeared every day. We observed the microwave background at three different wavelengths, and the same structures appear at all three wavelengths. (We also used a fourth wavelength to look for faint emissions from the dust in our own galaxy.) So we can now put our finger on some point in the sky and say, you know, that really *is* a cold spot. Second, the structures are typically larger than BOOMERANG's angular resolution, so we can, for the first time, get an accurate measure of how big they are. The BOOMERANG map shows structures that are the right size to have evolved into galactic superclusters, so for the first time there's a visible link between the embryonic universe and the present universe. That's very, very exciting.

I failed to mention earlier that if the universe is closed, it becomes more and more closed as it evolves, and if it's open, it becomes more and more open—only if it is exactly flat does it stay flat. But we know from several lines of evidence that the universe is within a factor of 10 of being flat, and why this should be so is a big mystery—it should have gone off in one direction or the other long since. The "baryonic" matter that you and I and planets and stars are made of gives us an omega of a few percent (about 0.03–0.05), and the so-called "dark matter" that cosmologists assume exists—because without it all the galaxies we see would have long since flung themselves apart—brings omega up to between 0.1 and 0.3. As I've said before, being off by a factor of 10 in cosmology is the same as being dead on, so theorists have therefore predicted that the universe must be exactly flat; that is, omega must equal one.

But a couple of years ago, observations of extremely distant supernovae indicated something very unsettling, even to cosmologists—the expansion of the universe is accelerating. To go back to the raisin-bread analogy for a moment (where would we be without our breakfast metaphors?), the loaf of bread is rising at an ever-increasing rate. Nobody knows why. The current thinking is, darn that Einstein, he was right after all. There appears to be a second type of matter-energy density that can be expressed by Einstein's cosmological constant. This idea is so new that we haven't even agreed on a name for it. The favorite so far appears to be "dark energy," which has the potential to be misleading in the popular mind—this stuff is not related to dark matter the way that ordinary matter and energy are related by $E = mc^2$. It's also called "quintessence," but by far the most sophisticated name I've heard is "the 'funny energy' density." Whatever we call it, if we plot it versus various calculated values for the amount of matter in the universe (above right), the supernovae results lie within the yellow region. The BOOMERANG results put us in the blue region. The overlap between the two pins us down squarely in the little green zone. This tells us that there is not enough matter—in all forms, visible and dark—to make the universe flat, but if we add in the dark energy as well, omega comes to within a few percent of being exactly one. This eliminates a lot of theoretical models of the universe that cosmologists have been tossing around. It's also the ultimate Copernican revolution—we've come from not being at the center of the universe to becoming a 10 to 20 percent minority constituent of the dark matter, which has now in turn become a mere one-third of the total matter-energy density in the universe. And we have even less of a clue about what the other two-thirds are than we do about ordinary dark matter. That's great progress, isn't it?

Since our results appeared in *Nature*, there has been a slew of theoretical papers interpreting

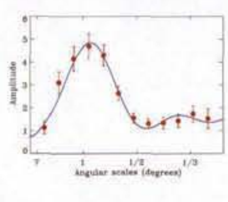


For the last 20 years or so, cosmologists have assumed for a variety of reasons that omega equals one, putting us where the red X is on the graph. Unfortunately, the measurements of all the matter in the universe, including the dark matter, all lie within the red bracket. But if there are really two dimensions to omega, the problem can be resolved. In this graph, Ω_m is the contribution from ordinary matter, and Ω_Λ is the new "dark energy." The sum of the two omegas is one (the red line), and the supernova and the BOOMERANG results intersect above the bracket.

them. People have invoked new neutrino physics, topological defects, leptonic asymmetry, delayed recombination—all kinds of things. We thought our experiment would pin those squirmy theorists down. So far, we've failed badly. It's like the seven blind men and the elephant.

Now at this point, you're thinking, "Sheesh! They went all the way to the Antarctic to make this fuzzy picture?! Cosmologists must be *really* starved for data!" Well, in fact cosmologists *are* really starved for data, but there's more here than meets the eye. Buried in the blotches is a wealth of information, which is extracted mathematically in exactly the way that the graphic equalizer on your stereo system works. As you watch those little lights wiggling up and down, the graphic equalizer is sorting the tones into bass notes and treble notes. In fact, it sorts them into several different bins, or frequency ranges, and the lights tell you how much sound energy is going into each bin. Similarly, you can ask what the distribution in the BOOMERANG data is of large angular scales, corresponding to bass notes, versus small angular scales, which are treble notes. For those of you who are Caltech graduates, we take a Fourier transform of this map to get its power spectrum. This is what I call the music of the spheres, because the sky is ringing with a very characteristic tone—our one-degree angular scale.

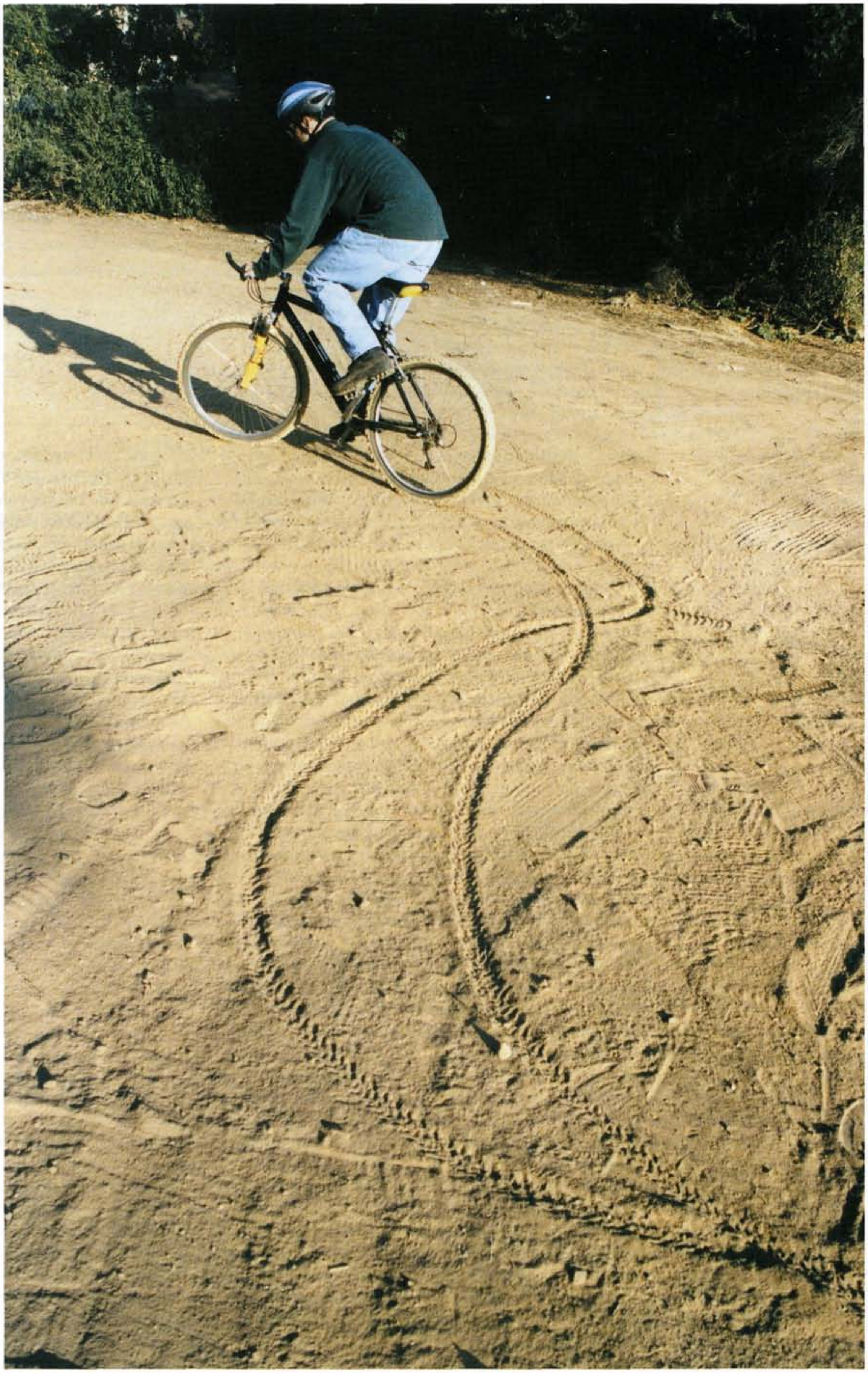
Cosmologists are eager to find out if that tone is being played on a trumpet or a violin. In other words, what are the overtones? The harmonics? The higher frequencies, or in our case the smaller angular scales, are what makes a trumpet sound different from a violin when both are playing the same note. And that's where all the excitement is going to be in the coming months and years. The sound waves that resulted from the pre-inflation fluctuations amplified them and processed them to create a spectrum that will have peaks at higher frequencies, and the hope is that if we can understand that spectrum well enough, we will be able to work backward from it to reveal the original quantum fluctuations through a mathematical process called deconvolution. We hope that we can push BOOMERANG's data out to a little beyond one-third of a degree, which will indicate more precisely what the overtones look like. And Rawn Professor of Astronomy Tony Readhead's group is in Chile with a fantastic machine called the CBI, or Cosmic Background Imager [see *E&S* 1999, No. 3], which was built here at Caltech and will extend our vision out to less than one-tenth of a degree—sufficient to see the seeds of clusters of galaxies as well as superclusters. The combination of these two experiments will really reveal what the music of the spheres sounds like. □



In this plot of the CMB's harmonics, the BOOMERANG data and its error bars are shown in red. The blue line is predicted by various cosmological arguments. The BOOMERANG data at scales less than half a degree is consistent with the wavy line, but could fit a straight line just as easily; future observations will tell the tale.

BOOMERANG is a collaboration of 36 scientists at 16 institutions in four nations. Andrew Lange, professor of physics at Caltech, is the leader of the U.S. contingent. This article was adapted from a Watson lecture given by Lange on May 3, six days after BOOMERANG's results made the cover of Nature.

Lange earned his BA and PhD, both in physics, at Princeton in 1980 and Berkeley in 1987, respectively. He came to Caltech as a Visiting Associate in 1993, and stayed on as a professor of physics the following year, having married Frances Arnold, Dickinson Professor of Chemical Engineering and Biochemistry. (An article on Arnold's research appears in E&S *1/2, 1999.)*



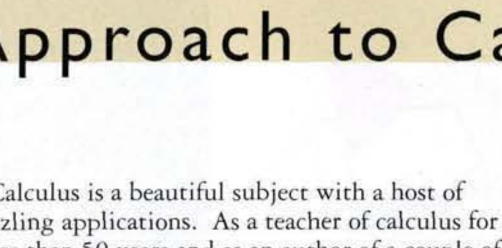
You might think you need calculus to determine the area between the tire tracks made by this bike, ridden by Jason McIlhaney, BS 2000. Surprisingly, geometry offers another way of solving it—without formulas.

A Visual Approach to Calculus Problems

by Tom M. Apostol

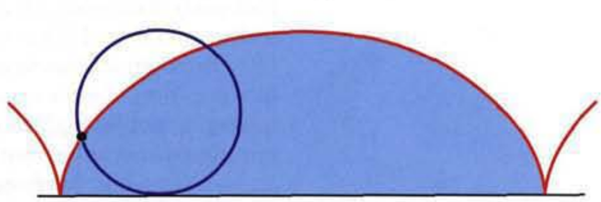
Calculus is a beautiful subject with a host of dazzling applications. As a teacher of calculus for more than 50 years and as an author of a couple of textbooks on the subject, I was stunned to learn that many standard problems in calculus can be easily solved by an innovative visual approach that makes no use of formulas. Here's a sample of three such problems:

Problem 1. Find the area of the region under an exponential curve. In the graph of the exponential function $y = e^x$, below, we want the area of the blue region between the curve and the x-axis and along the interval from minus infinity up to any point x. Integral calculus reveals that the answer is e^x. And if the equation of the curve is $y = e^{x/b}$, where b is any positive constant, integration tells us the area is b times $e^{x/b}$.



Problem 2. Find the area of a parabolic segment (left)—the purple region below the graph of the parabola $y = x^2$ from 0 to x. The area of the parabolic segment was first calculated by Archimedes more than 2000 years ago by a method that laid the foundations for integral calculus. Today, every freshman calculus student can solve this problem: Integration of x^2 gives $x^3/3$.

Problem 3. Find the area of the region under one arch of a cycloid (next column). A cycloid is the path traced out by a fixed point on the boundary of a circular disk that rolls along a horizontal line, and we want the area of the region shown in blue. This problem can also be done by calculus but it is more difficult than the first two. First, you have to find an equation for the cycloid, which is not exactly trivial. Then you have to integrate this to get the required area. The answer is three times the area of the rolling circular disk.

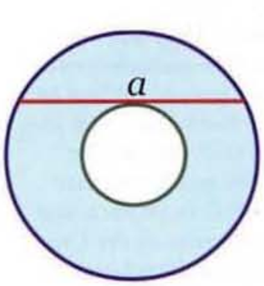


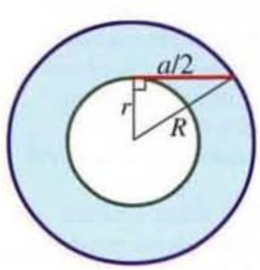
These classic problems can also be solved by a new method that relies on geometric intuition and is easily understood even by very young students. You don't need any equations. Moreover, the new method also solves some problems that can't be done *with* calculus.

The method was conceived in 1959 by Mamikon A. Mnatsakanian, then an undergraduate at Yerevan University in Armenia. When he showed his method to Soviet mathematicians they dismissed it out of hand and said, "It can't be right—you can't solve calculus problems that easily." He went on to get a PhD in physics, was appointed a professor of astrophysics at the University of Yerevan, and became an international expert in radiative transfer theory. He also continued to develop his powerful geometric methods. He eventually published a paper outlining them in 1981, but it seems to have escaped notice, probably because it appeared in Russian in an Armenian journal with limited circulation (*Proceedings of the Armenian Academy of Sciences*, vol. 73, no. 2, pages 97–102).

Mamikon came to California about a decade ago to work on an earthquake-preparedness program for Armenia, and when the Soviet government collapsed, he was stranded in the United States without a visa. With the help of a few mathematicians in Sacramento and at UC Davis, he was granted status as an "alien of extraordinary ability." While working for the California Department of Education and at UC Davis, he further developed his methods into a universal teaching tool using hands-on and computer activities, as well as pictures. He has taught these methods at UC Davis and in Northern California classrooms, ranging from Montessori elementary schools to inner-city public high schools, and he has demonstrated them at teacher conferences. Students and teachers alike have responded enthusiastically, because the methods are vivid and dynamic and don't require the algebraic formalism of trigonometry or calculus.

About four years ago, Mamikon showed up at *Project MATHEMATICS!* headquarters and convinced me that his methods have the potential to make a significant impact on mathematics education, especially if they are combined with visualization tools of modern technology. Since then we have published several joint papers on innovative ideas in elementary mathematics.

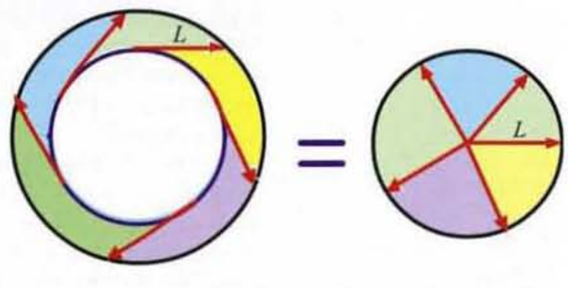




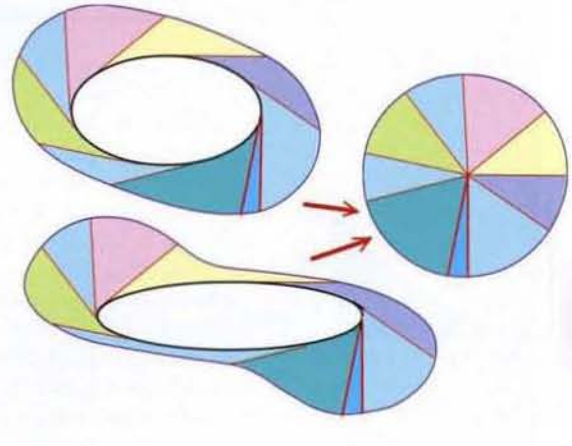
Like all great discoveries, the method is based on a simple idea. It started when young Mamikon was presented with the classical geometry problem, involving two concentric circles with a chord of the outer circle tangent to the inner one, illustrated at left. The chord has length a, and the problem is: Find the area of the ring between the circles. As the late Paul Erdös would have said, any baby can solve this problem. Now look at the diagram below it. If the inner circle has radius r its area is πr^2, and if the outer circle has radius R, its area is πR^2, so the area of the ring is equal to $\pi R^2 - \pi r^2 = \pi(R^2 - r^2)$. But the two radii and the tangent form a right triangle with legs r and $a/2$ and hypotenuse R, so by the Pythagorean Theorem, $R^2 - r^2 = (a/2)^2$, hence the ring has the area $\pi a^2/4$. Note that the final answer depends only on a and not on the radii of the two circles.

If we knew in advance that the answer depends only on a, we could find it another way: Shrink the inner circle to a point, and the ring collapses to a disk of diameter a, with an area equal to $\pi a^2/4$.

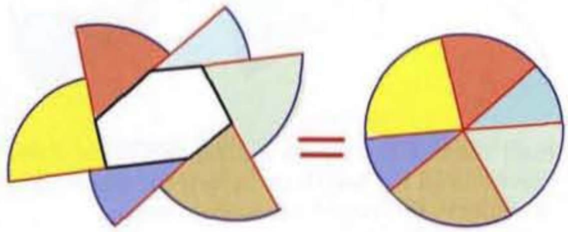
Mamikon wondered if there was a way to see why the answer depends only on the length of the chord. Then he thought of formulating the problem in a dynamic way. Take half the chord and think of it as a vector of length L tangent to the inner circle. By moving this tangent vector around the inner circle, we see that it sweeps out the ring between the two circles. (But it's obvious that the area is being swept due to pure rotation.) Now, translate each tangent vector parallel to itself so that the point of tangency is brought to a common point. As the tangent vector moves around the inner circle, the translated vector rotates once around this common point and traces out a circular disk of radius L. So the tangent vectors sweep out a circular disk as though they were all centered at the same point, as illustrated below. And this disk has the same area as the ring.



Mamikon realized that this dynamic approach would also work if the inner circle was replaced by an arbitrary oval curve. Below you can see the same idea applied to two different ellipses. As the tangent segment of constant length moves once around each ellipse, it sweeps out a more general annular shape that we call an oval ring.



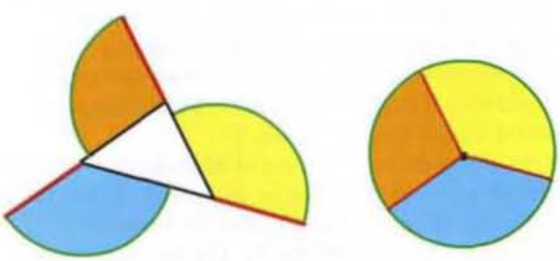
Left: Students at the Southland Park Montessori Elementary School in Sacramento play with magnetic manipulative wedges, shaping them into a circular disk. Pushing with your finger in the center can turn it into an oval ring of any shape.



Again, we can translate each tangent segment parallel to itself so that the point of tangency is brought to a common point. As the tangent moves around the oval, the translated segments trace out a circular disk whose radius is that constant length. So, the area of the oval ring should be the area of the circular disk.

The Pythagorean Theorem can't help you find the areas for these oval rings. If the inner oval is an ellipse, you can calculate the areas by integral calculus (which is not a trivial task); if you do so, you'll find that all of these oval rings have equal areas depending only on the length of the tangent segment.

Is it possible that the same is true for any convex simple closed curve? The diagram below illustrates the idea for a triangle.

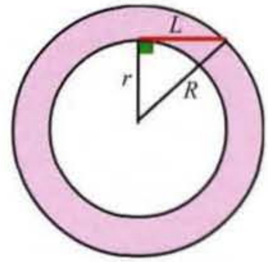


As the tangent segment moves along an edge, it doesn't change direction so it doesn't sweep out any area. As it moves around a vertex from one edge to the next, it sweeps out part of a circular sector. And as it goes around the entire triangle, it sweeps out three circular sectors that, together, fill out a circular disk, as shown to the right.

The same is true for any convex polygon, as illustrated above.

The area of the region swept out by a tangent segment of given length moving around any convex polygon is equal to the area of a circular disk whose radius is that length. Therefore the same is true for any convex curve that is a limit of convex polygons. This leads us to

Mamikon's Theorem for Oval Rings: *All oval rings swept out by a line segment of given length with one endpoint tangent to a smooth closed plane curve have equal areas, regardless of the size or shape of the inner curve. Moreover, the area depends only on the length L of the tangent segment and is equal to πL^2, the area of a disk of radius L, as if the tangent segment was rotated about its endpoint.*

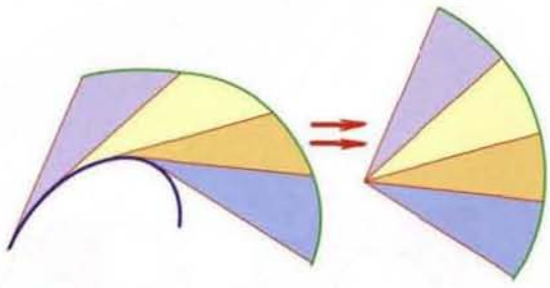


Incidentally, Mamikon's theorem for oval rings provides a new proof of the Pythagorean Theorem, as illustrated at right.

If the inner curve is a circle of radius r, the outer curve will also be a circle (of radius R, say), so the area of the oval ring will be equal to the difference $\pi R^2 - \pi r^2$. But by Mamikon's theorem, the area of the oval ring is also equal to πL^2, where L is the constant length of the tangent segments. By equating areas we find $R^2 - r^2 = L^2$, from which we get $R^2 = r^2 + L^2$, the Pythagorean Theorem.

Now we can illustrate a generalized version of Mamikon's theorem. The lower curve in the diagram at the top of the next page is a more or less arbitrary smooth curve. The set of all tangent segments of constant length defines a region that is bounded by the lower curve and an upper curve traced out by the segment's other extremity. The

Right: Mamikon helps children at the Montessori School trace a tractrix with a bicycle.



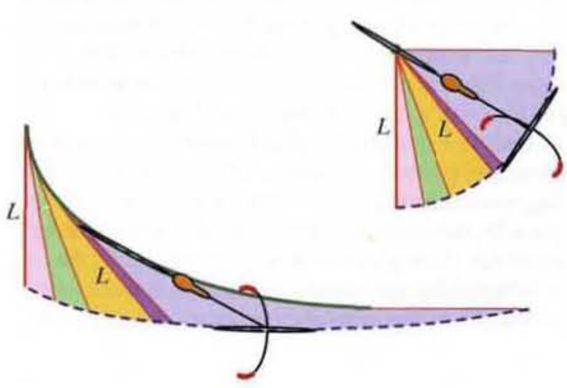
exact shape of this region will depend on the lower curve and on the length of the tangent segments. We refer to this region as a *tangent sweep*.

When each segment is translated to bring the points of tangency together as before, as shown in the right-hand diagram above, the set of translated segments is called the *tangent cluster*. When the tangent segments have constant length, as in this figure, the tangent cluster is a circular sector whose radius is that constant length.

By the way, we could also translate the segments so that the *other* endpoints are brought to a common point. The resulting tangent cluster would be a symmetric version of the cluster in the right-hand figure. Now we can state

Mamikon's Theorem: *The area of a tangent sweep is equal to the area of its tangent cluster, regardless of the shape of the original curve.*

You can see this in a real-world illustration when a bicycle's front wheel traces out one curve while the rear wheel (at constant distance from the front wheel) traces out another curve, as below. To find the area of the region between the two curves with calculus, you would need equations for both curves, but we don't need any here. The area of the tangent sweep is equal to the area of a circular sector depending only on the length of the bicycle and the change in angle from its initial position to its final position, as shown in the tangent cluster to the right. The shape of the bike's path does not matter.



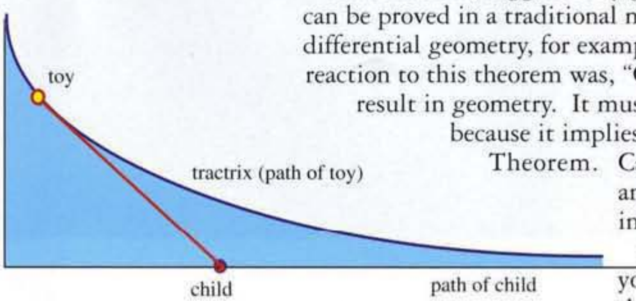
The next diagram illustrates the same idea in a more general setting. The only difference is that the tangent segments to the lower curve need not have constant length. We still have the tangent sweep (left) and the tangent cluster.

Mamikon's theorem, which seems intuitively obvious by now, is that the area of the tangent cluster is equal to the area of the tangent sweep. (To convince yourself, consider corresponding equal tiny triangles translated from the tangent sweep to the tangent cluster.)

In the most general form of Mamikon's theorem the given curve need not lie in a plane. It can be any smooth curve in space, and the tangent segments can vary in length. The tangent sweep will lie on a developable surface, one that can be rolled out flat onto a plane without distortion. The shape of the tangent sweep depends on how the lengths and directions of the tangent segments change along the curve; the tangent cluster lies on a conical surface whose vertex is the common point. Mamikon's general theorem equates the area of the tangent sweep with that of its tangent cluster.

General Form of Mamikon's Theorem: *The area of a tangent sweep to a space curve is equal to the area of its tangent cluster.*

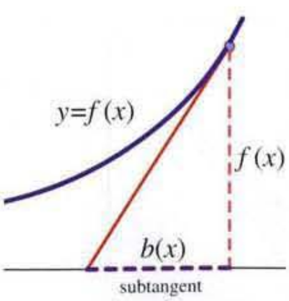
This theorem, suggested by geometric intuition, can be proved in a traditional manner—by using differential geometry, for example. My first reaction to this theorem was, "OK, that's a cool result in geometry. It must have some depth because it implies the Pythagorean Theorem. Can you use it to do anything else that's interesting?"



It turns out that you can apply this theorem in all sorts of interesting ways. As already mentioned, curves swept out by tangent segments of constant length include oval rings and the bicycle-tire tracks. Another such example is the tractrix, the trajectory of a toy on a taut string being pulled by a child walking in a straight line, as shown above. To find the area of the region between the tractrix and the x-axis using calculus, you have to find the equation of the tractrix. This in itself is rather challenging—it requires solving a differential equation. Once you have the equation of the tractrix, you have to integrate it to get the area. This also can be done, but the calculation is somewhat demanding; the final answer is simply $\pi L^2/4$, where L is the length of the string. But we can see that the tractrix is a particular case of the "bicyclix," so its swept area is given by a circular sector, and its full area is a quarter of a circular disk.

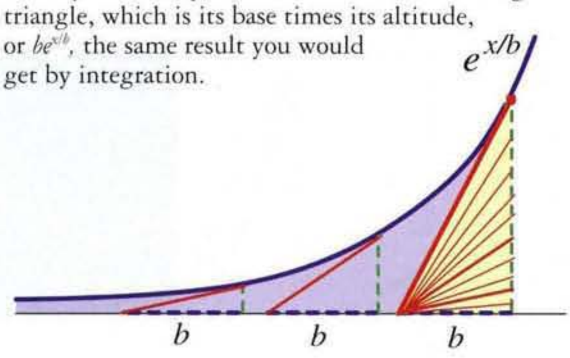
All the examples with tangents of constant length reveal the striking property that the area of the tangent cluster can be expressed in terms of the area of a circular sector without using any of the formal machinery of traditional calculus.

But the most striking applications are to examples in which the tangent segments are of variable length. These examples reveal the true power of Mamikon's method. This brings us to Problem 1: exponential curves. Exponential functions are ubiquitous in the applications of mathematics. They occur in problems concerning population growth, radioactive decay, heat flow, and other physical situations where the rate of growth of a quantity is proportional to the amount present. Geometrically, this means that the slope of the tangent line at each point of an exponential curve is proportional to the height of the curve at that point. An exponential curve can also be described by its subtangent, which is the projection of the tangent on the x-axis. The diagram at the bottom of the left-hand column shows a general curve with a tangent line and the subtangent. The slope of the tangent is the height divided by the length of the subtangent. So, the slope is proportional to the height if and only if the subtangent is constant.



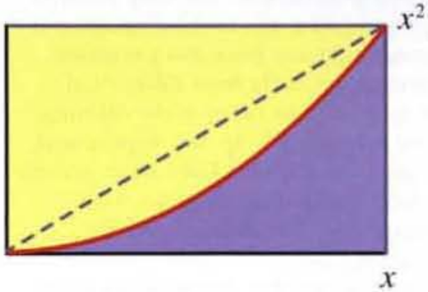
The next diagram, at the bottom of this column, shows the graph of an exponential curve $y = e^{x/b}$, where b is a positive constant. The only property of this curve that plays a role in this discussion is that the subtangent at any point has a constant length b. This follows easily from differential calculus, but it can also be taken as the defining property of the exponential. In fact, exponential curves were first introduced in 1684 when Leibniz posed the problem of finding all curves with constant subtangents. The solutions are the exponential curves.

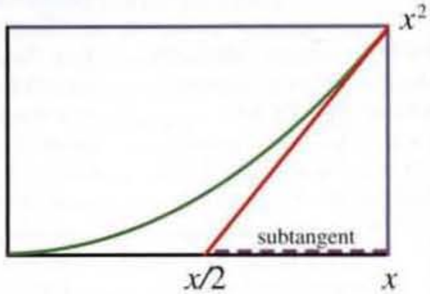
By exploiting the fact that exponential curves have constant subtangents, we can use Mamikon's theorem to find the area of the region under an exponential curve without using integral calculus. The diagram below shows the graph of the exponential curve $y = e^{x/b}$ together with its tangent sweep as the tangent segments, cut off by the x-axis, move to the left, from x all the way to minus infinity. The corresponding tangent cluster is obtained by translating each tangent segment to the right so that the endpoint on the x-axis is brought to a common point, in this case, the lower vertex of the right triangle of base b and altitude $e^{x/b}$. The resulting tangent cluster is the triangle of base b and altitude $e^{x/b}$. Therefore the area of the purple region is equal to the area of the yellow right triangle, so the area of the region between the exponential curve and the interval (from minus infinity to x) is equal to twice the area of this right triangle, which is its base times its altitude, or $be^{x/b}$, the same result you would get by integration.



This yields the astonishing result that the area of the region under an exponential curve can be determined in an elementary geometric way without the formal machinery of integral calculus.

We turn now to our second problem, perhaps the oldest calculus problem in history—finding the area of a parabolic segment, the purple region at left, below. The parabolic segment is inscribed in a rectangle of base x and altitude x^2. The area of the rectangle is x^3. From the figure we see that the area of the parabolic segment is less than half that of the rectangle in which it is inscribed. Archimedes made the stunning discovery that the area is exactly one-third that of the rectangle. Now we will use Mamikon's theorem to obtain the same result by a method that is not only simpler than the original treatment by Archimedes but also more powerful because it can be generalized to higher powers.



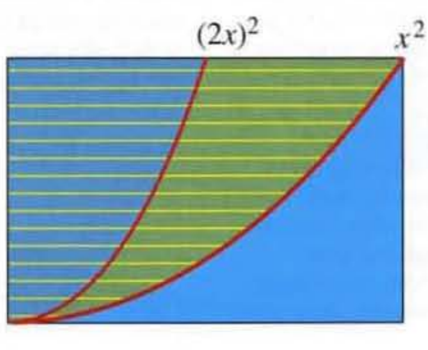


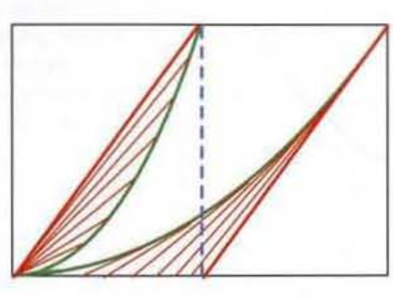
This parabola has the equation $y = x^2$, but we shall not need this formula in our analysis. We use only the fact that the tangent line above any point x cuts off a subtangent of length $x/2$, as indicated in the lower diagram. The slope of the tangent is x^2 divided by $x/2$, or $2x$.

To calculate the area of the parabolic segment we look at the next figure in which another parabola $y = (2x)^2$ has been drawn, exactly half as wide as the given parabola. It is formed by bisecting each horizontal segment between the original parabola and the y axis. The two parabolas divide the rectangle into three regions, and our strategy is to show that all three regions have equal area. If we do this, then each has an area one-third that of the circumscribing rectangle, as required.

The two shaded regions formed by the bisecting parabola obviously have equal areas, so to complete the proof we need only show that the region above the bisecting parabola has the same area as the parabolic segment below the original parabola. To do this, let's look at the next diagram, below. The right triangles here have equal areas (they have the same altitude and equal bases). Therefore the problem reduces to showing that the two shaded regions in this diagram have equal areas. Here's where we use Mamikon's theorem.

The shaded portion under the parabola $y = x^2$ is the tangent sweep obtained by drawing all the





With Mamikon's help, the Montessori schoolchildren built this 60-foot-long suspension bridge. Using themselves as weight, they are illustrating how heavy loading changes the shape of the cable from a catenary (the curve normally formed by hanging a chain from both ends) to a parabola. Such a "breakdown" occurred during the 50th-anniversary celebration of the Golden Gate Bridge in 1987.

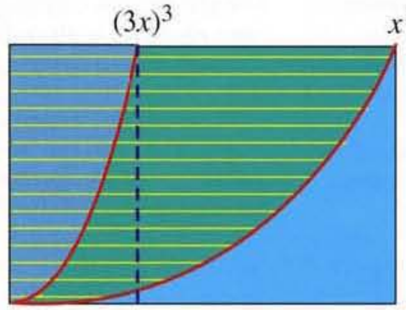
tangent lines to the parabola and cutting them off at the x-axis. And the other shaded portion is its tangent cluster, with each tangent segment translated so its point of intersection with the x axis is brought to a common point, the origin.

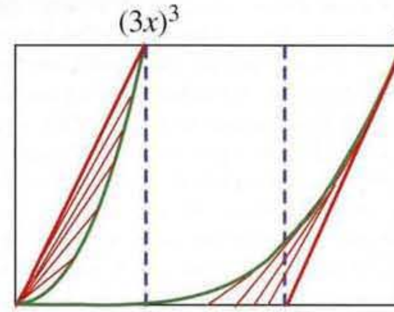
At a typical point (t, t^2) on the lower parabola, the tangent intersects the x-axis at $t/2$. Therefore, if the tangent segment from $(t/2, 0)$ to (t, t^2) is translated left by the amount $t/2$, the translated segment joins the origin and the point $(t/2, t^2)$ on the curve $y = (2x)^2$. So the tangent cluster of the tangent sweep is the shaded region above the curve $y = (2x)^2$, and by Mamikon's theorem the two shaded regions have equal areas, as required. So we have shown that the area of the parabolic segment is exactly one-third that of the circumscribing rectangle, the same result obtained by Archimedes.

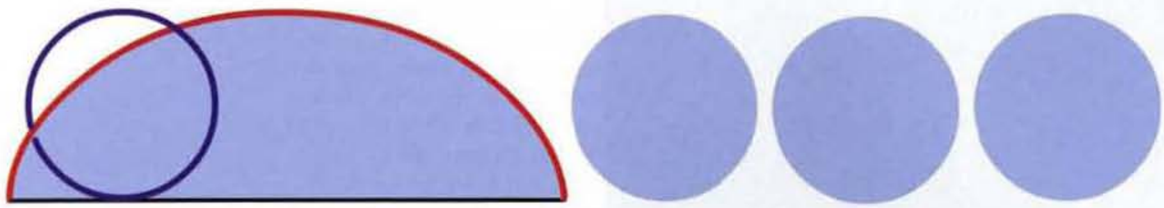
The argument used to derive the area of a parabolic segment also extends to generalized parabolic segments, in which x^2 is replaced by higher powers. The graphs of $y = x^3$ and $y = (3x)^3$ at left divide the rectangle of area x^4 into three regions. The curve $y = (3x)^3$ *trisects* each horizontal segment in the figure, hence the area of the region above this curve is half that of the region between the two curves. In this case we will show that the area of the region above the trisecting curve is equal to that below the original curve, which means that each region has an area one-fourth that of the circumscribing rectangle.

To do this we use the fact that the subtangent is now one-third the length of the base, as shown below. One shaded region is the tangent sweep of the original curve, and the other is the corresponding tangent cluster, so they have equal areas. The right triangles are congruent, so they have equal areas. Therefore the region above the trisecting curve has the same area as the region below the curve $y = x^3$, and each is one-fourth that of the rectangle, or $x^4/4$. The argument also extends to all higher powers, a property not shared by Archimedes' treatment of the parabolic segment. For the curve $y = x^n$ we use the fact that the subtangent at x has length x/n.

We turn next to our third standard calculus



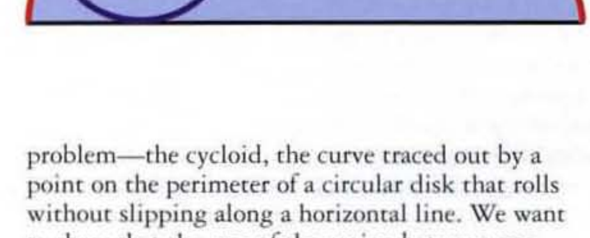




problem—the cycloid, the curve traced out by a point on the perimeter of a circular disk that rolls without slipping along a horizontal line. We want to show that the area of the region between one arch of the cycloid and the horizontal line is three times the area of the rolling disk (above), without deriving an equation for the cycloid or using integral calculus.

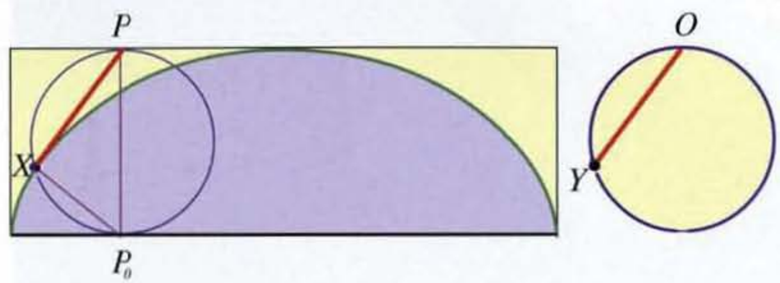
Below is a cycloidal arch inscribed inside a rectangle whose altitude is the diameter d of the disk and whose base is the disk's circumference, πd. The area of the circumscribing rectangle is πd^2, which is four times the area of the disk. So it suffices to show that the unshaded region above the arch and inside the rectangle has an area equal to that of the disk.

To do this, we show that the unshaded region is



the tangent sweep of the cycloid, and that the corresponding tangent cluster is a circular disk of diameter d. By Mamikon's theorem, this disk has the same area as the tangent sweep. Because the area of the disk is one-fourth the area of the rectangle, the area of the region below the arch must be three-fourths that of the rectangle, or three times that of the rolling disk.

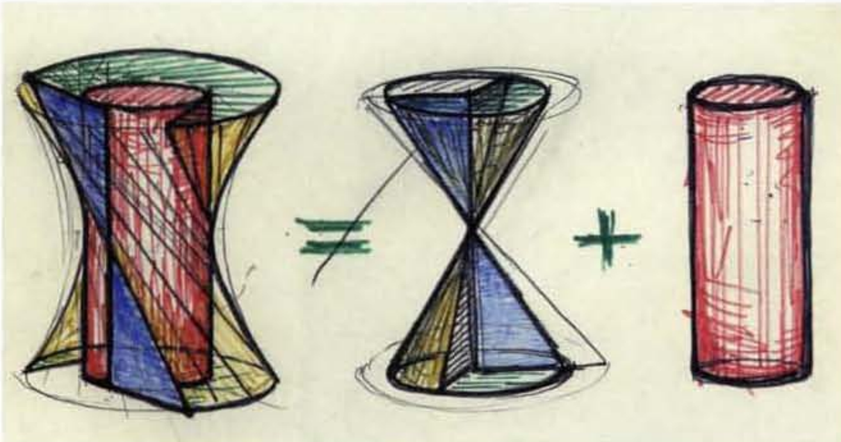
It remains to show that the tangent cluster of the unshaded region is a circular disk, as asserted. As the disk rolls along the base it is always tangent to the upper and lower boundaries of the circumscribing rectangle. If we denote the upper point of tangency by P and the lower point of

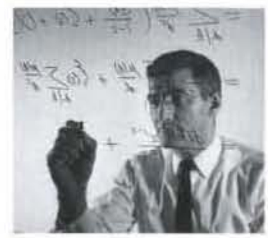


tangency by P_0, as in the diagram above, the diameter PP_0 divides the rolling circle into two semicircles, and any triangle inscribed in these semicircles must be a right triangle. The disk undergoes instantaneous rotation about P_0, so the tangent to the cycloid at any point X is perpendicular to the instantaneous radius of rotation and therefore must be a vertex of a right triangle inscribed in the semicircle with diameter PP_0. Consequently, the chord XP of the rolling disk is always tangent to the cycloid.

Extend the upper boundary of the circumscribing rectangle beyond the arch and choose a fixed point O on this extended boundary. Translate each chord parallel to itself so that point P is moved horizontally to the fixed point O. Then the other extremity X moves to a point Y such that segment OY is equal in length and parallel to PX. Consequently, Y traces out the boundary of a circular disk of the same diameter, with OY being a chord equal in length and parallel to chord PX. Therefore the tangent cluster is a circular disk of the same diameter as the rolling disk, and Mamikon's theorem tells us that its area is equal to that of the disk.

These examples display a wide canvas of geometric ideas that can be treated with Mamikon's methods, but seeing them static on a printed page leaves something to be desired. Animation, clearly, is a better way to show how the method works. So we plan to use these examples in the first of a series of contemplated videotapes under





One of Mamikon's 1959 hand sketches illustrates how the volume of a hyperboloid can be seen as disected into an inscribed cylinder and a "tangential" cone (the tangents to the cylinder). Right: Apostol in 1977.

the umbrella of *Project MATHEMATICS!* Like all videotapes produced by *Project MATHEMATICS!*, the emphasis will be on dynamic visual images presented with the use of motion, color, and special effects that employ the full power of television to convey important geometric ideas with a minimal use of formulas. The animated sequences will illustrate how tangent sweeps are generated by moving tangent segments, and how the tangent segments can be translated to form tangent clusters. They will also show how many classical curves are naturally derived from their intrinsic geometric and mechanical properties.

Mamikon's methods are also applicable to many plane curves not mentioned above. In subsequent videotapes we plan to find full and partial areas of the ellipse, hyperbola, catenary, logarithm, cardioid, epicycloids, hypocycloids, involutes, evolutes, Archimedean spiral, Bernoulli lemniscate, and sines and cosines. And we can find the volumes of three-dimensional figures such as the ellipsoid, the paraboloid, three types of hyperboloids, the catenoid, the pseudosphere, the torus, and other solids of revolution.

I'll conclude with a small philosophical remark: Newton and Leibniz are generally regarded as the discoverers of integral calculus. Their great contribution was to unify work done by many other pioneers and to relate the process of integration with the process of differentiation. Mamikon's method has some of the same ingredients, because it relates moving tangent segments with the areas of the regions swept out by those tangent segments. So the relation between differentiation and integration is also embedded in Mamikon's method. □

Samples of the computer animation of the problems shown in this article can be viewed at http://www.its.caltech.edu/~mamikon/calculus.html

Professor of Mathematics, Emeritus, Tom Apostol joined the Caltech faculty in 1950. On October 4, 2000, a special mathematics colloquium was held in honor of his 50 years at Caltech. On that occasion he delivered the talk that's adapted here. (Mamikon Mnatsakanian was also on hand to show his computer animations.)

Apostol earned his BS in chemical engineering (1944) and MS in mathematics (1946) from the University of Washington. His PhD, with a thesis in analytic number theory, is from UC Berkeley (1948). Before beginning his 50 years at Caltech, he spent a year each at Berkeley and MIT.

Apostol should know everything there is to know about teaching calculus, even though he admits he was surprised by this new approach. For nearly four decades Caltech undergraduates (as well as a couple of generations of mathematics students all over the country) have learned calculus from his two-volume text, often referred to as "Tommy 1" and "Tommy 2." These and his other textbooks in mathematical analysis and analytic number theory have been translated into Greek, Italian, Spanish, Portuguese, and Farsi.

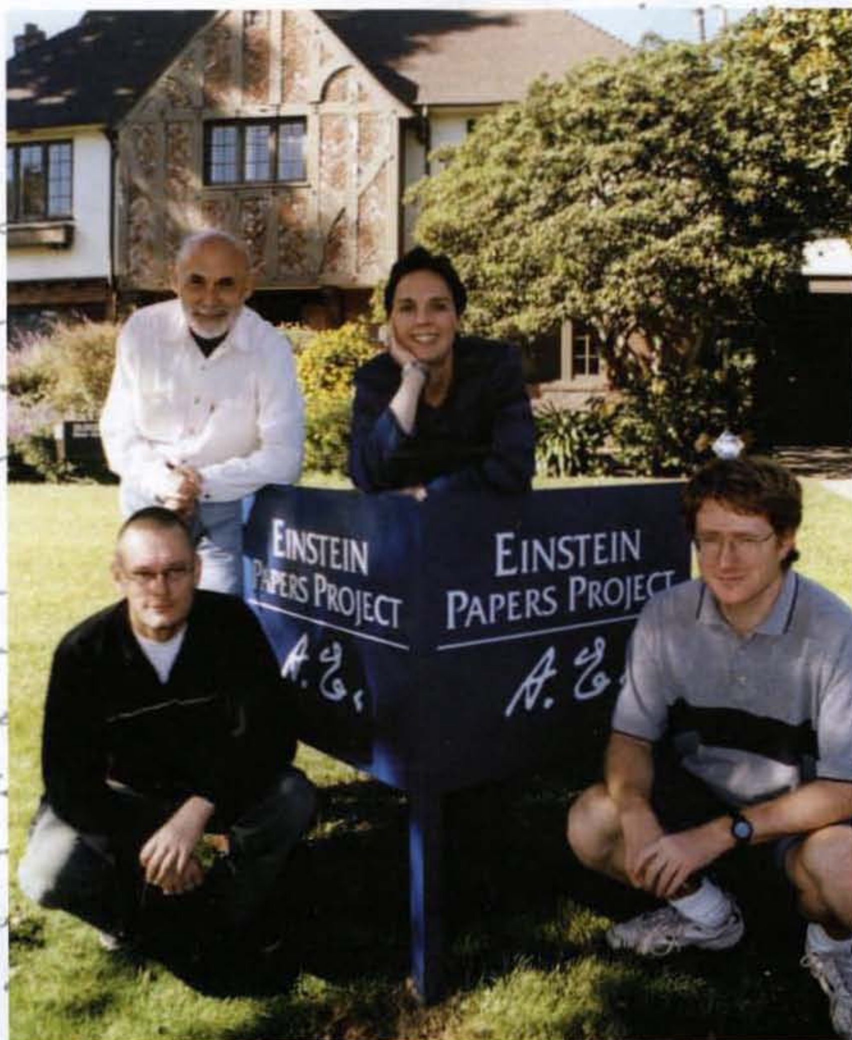
Although known nationally and internationally for his written textbooks, Apostol turned to the visual media in the 1980s as a member of the Caltech team that produced The Mechanical Universe . . . and Beyond, *a 52-episode telecourse in college physics. And he never looked back. He's currently creator, director, and producer of* Project MATHEMATICS!, *a series of award-winning, computer-animated videotapes that are used nationwide and abroad as support material in high-school and community-college classrooms.*

Autogr. I/178

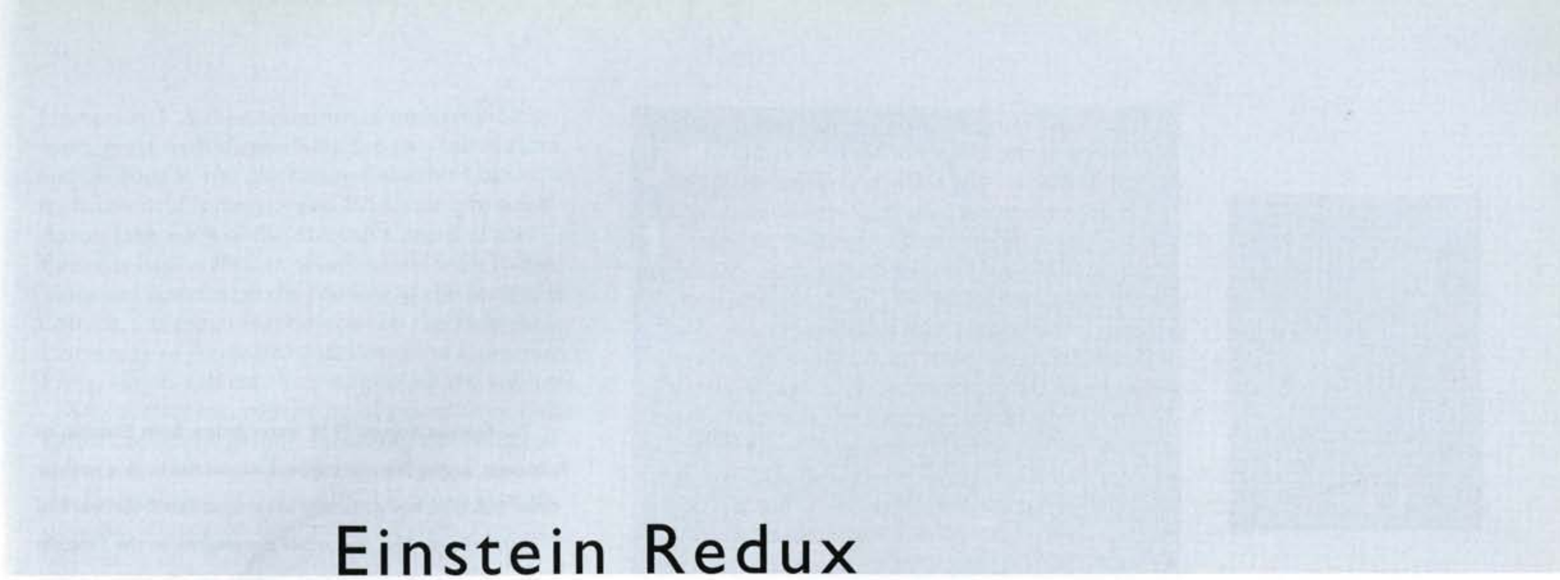
Pasadena ...

Liebe Lebachs!

Nach ... ist heute
endlich ein ... mal schreiben
kann. Diese ... Erkäl-
tung mit ... Weise
in dem ... es ist aber
eine ganz ... hatte
ich ... und
Landschaft. ... ordentlich,
das südliche ... ich hatte
ich von der ... ichtig was
auszuhalten ... sprechen
u.s.w. Es gi... önsten
was dann ... Tropen-
stadt im sp... gerade
Revolution, ... kurz



nach unserer ... ehemaligen
Studien-Kollege vom Züricher Polytechnikum,
wurde bei dieser Gelegenheit abgesetzt. Hier
in Pasadena hat es Ähnlichkeit mit dem Paradies.
Immer Sonne und klare Luft, Gärten mit Palmen
und Pfefferbäumen und freundliche Leute, die
einen alle anlächeln und um Autogramme bitten.
Wissenschaftlich ist es sehr interessant, und
die Kollegen sind wunderbar zu mir. Mich aber



Einstein Redux

by Jane Dietrich

Left: Diana Barkan, director and general editor of the Einstein Papers Project, with three of the editors (counterclockwise from left, József Illy, Christoph Lehner, and David Kennefick) in front of the project's new home. They're superimposed over a letter Einstein wrote to family friends in Germany on January 16, 1931, during his first visit to Pasadena. Toward the bottom of the page he writes: "Here in Pasadena it is like Paradise. Always sunshine and clear air, gardens with palms and peppertrees and friendly people who smile at you and ask for autographs. Scientifically it is very interesting and my colleagues are wonderful to me." On the second page, though, he goes on to say how much he longs for Germany. Right: Einstein and Millikan during the same visit.

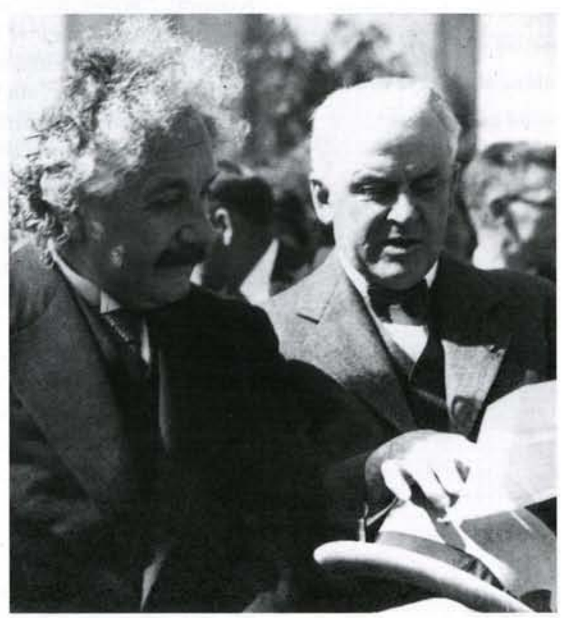
Einstein has returned to Caltech. Not literally, but literarily.

Although the abundance of photographs of the great physicist on campus (see page 12) has left the impression that he was at some time a member of the Caltech faculty, he wasn't. Three sojourns of several months each as a visiting scientist occurred in 1931, 1932, and 1933, with Albert Einstein returning to Germany each time except the last—when he moved permanently to Princeton.

Why Princeton? Why not just stay at Caltech, where he found the science very exciting? It almost happened. In her 1991 book, *Millikan's School*, Archivist Judith Goodstein lays the failure to catch Einstein at Robert Millikan's parsimonious feet. She relates that, in 1931, Trustee Arthur Fleming had offered Einstein $20,000 for a 10-week stay. The trustees agreed that they would have to back up this overly generous offer if Einstein indeed considered it a commitment, but they sent Millikan off to Berlin to sound out $15,000 instead. Millikan eventually obtained Einstein's agreement to come for $7,000, because Mrs. Einstein was eager to spend the winter in Southern California. "The penny-pinching Millikan had saved Caltech a tidy sum of money, and coincidentally lost a permanent faculty member," writes Goodstein.

A later article, "Albert Einstein at Caltech," by Abraham Hoffman, in the Winter 1997/98 issue of *California History*, paints Einstein as less greedy about his own salary and more anxious about a position for his assistant, Walther Mayer. According to Hoffman, Princeton's Abraham Flexner, director of the newly founded Institute for Advanced Study, put a full-court press on Einstein in 1932, offering a permanent position at the Institute and a place for Mayer. Millikan pleaded with Flexner to at least share Einstein with Caltech in a continuing visiting arrangement but came up with nothing for Mayer. Princeton said no to sharing. Einstein, knowing as he sat in Pasadena in the winter of 1933 that he could no longer return to Germany, was concerned about the security of his future, and Princeton was clearly the better deal. Could Millikan have tried harder? Probably.

Now, nearly 70 years later, and 45 years after Einstein's death, Caltech has gotten another chance to do the right thing by offering generous support to the Einstein Papers Project. And Caltech and Princeton are again linked over Einstein, but in cooperation, not competition. The Einstein Papers Project is researching, selecting, editing, and annotating *The Collected Papers of Albert Einstein*, which is expected to run to 29 volumes containing 14,000 documents—*the* most ambitious publishing venture in the history of 20th-century science. The only thing comparable in scope, according to Associate Professor of History Diana Kormos Barkan, might be the 22 volumes



Photograph used with the kind permission of The Hebrew University of Jerusalem and The Roger Richman Agency, Inc.

of Christiaan Huygens' work, collected at the beginning of the 20th century by a group of Dutch scientists. Or Darwin's collected papers; but that publication (just his correspondence) is not as comprehensive as the Einstein project, which includes 40,000 documents from the original Einstein archive, as well as 15,000 more unearthed later by the project editors.

Barkan, a historian of science and a member of the Caltech faculty since 1989, was appointed director and general editor of the Einstein project last spring. (Her research interests include the modern history of the physical sciences and European intellectual history; her book, *Walther Nernst and the Transition to Modern Physical Science,* was reviewed in *E&S*, No. 1/2, 1999.) Barkan was also offered a faculty position at Boston University, where the collection had resided since 1984 in quasi exile from Princeton, more or less the result of historical accident. The question then arose whether Barkan would move to Boston to join the papers, or whether the papers might find a congenial home in Pasadena instead.

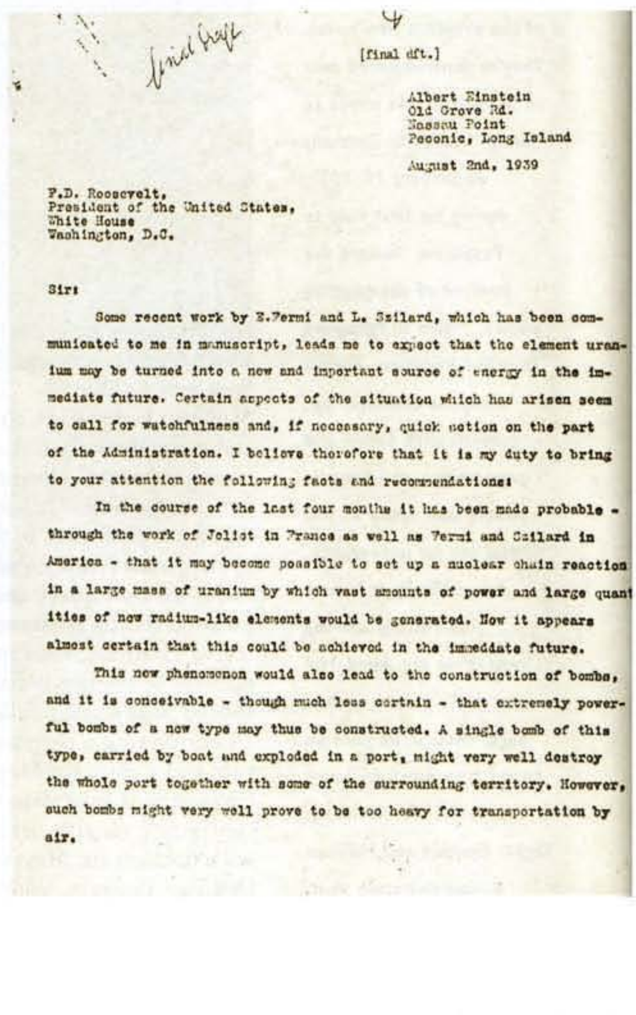
Caltech warmly embraced the idea of housing the project, as did Princeton University Press, the papers' publisher. The choice of Caltech was a good one, partly for historical and partly for sentimental reasons, according to Martin Klein, professor emeritus of physics and the history of science at Yale, and formerly a senior editor of the papers. Caltech has "genuine experts in general relativity in its post-Einsteinian development," says Klein.

President David Baltimore and Provost Steve Koonin greeted the prospect of housing the Einstein papers with more enthusiasm than Millikan had once proffered to the man himself. "Einstein had a very visible and productive relationship with this institution in the '30s," says Koonin. "It's exciting to have the papers here. In a sense, it's as if they've come home." This is particularly true, he adds, because some of the ongoing research here, such as the search for gravitational radiation in which Caltech has been a leader, has come out of work that Einstein began. "And it's a very nice way for the humanities and sciences to interact."

It also raises Caltech's profile in the history of science. "With the arrival on campus of the Einstein Papers Project, coupled with the hiring of Adrian Johns [associate professor of history] and Jed Buchwald [the Dreyfuss Professor of History], our small but powerful history of science group has confirmed it is one of the best in the world," claims John Ledyard, chair of the Division of the Humanities and Social Sciences. "This is as it should be at Caltech."

"Caltech is just a terrific place for the papers," says Walter Lippincott, director of Princeton University Press. "I'm thrilled that the project is housed at Caltech, because of the Einstein connection." (Einstein had no connection to Boston

The famous August 1939 letter below from Einstein to Roosevelt, urging him to support experiments in a nuclear chain reaction, has generally been considered the work of Leo Szilard. This and other documents in the Einstein papers show, however, that Szilard and Einstein were in close correspondence that summer and indeed composed the German text together (there were at least two drafts), which Szilard then translated into English. The corrrespondence also reveals that they considered asking Charles Lindbergh to be the bearer of the letter to the president, but changed their minds, probably upon hearing of Lindbergh's pro-German remarks. Banker Alexander Sachs finally carried the letter to FDR in mid-October, after Hitler had invaded Poland. The president reacted swiftly; the rest is history.



final draft

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[final dft.]

Albert Einstein
Old Grove Rd.
Nassau Point
Peconic, Long Island

August 2nd, 1939

F.D. Roosevelt,
President of the United States,
White House
Washington, D.C.

Sir:

Some recent work by E.Fermi and L. Szilard, which has been communicated to me in manuscript, leads me to expect that the element uranium may be turned into a new and important source of energy in the immediate future. Certain aspects of the situation which has arisen seem to call for watchfulness and, if necessary, quick action on the part of the Administration. I believe therefore that it is my duty to bring to your attention the following facts and recommendations:

In the course of the last four months it has been made probable - through the work of Joliot in France as well as Fermi and Szilard in America - that it may become possible to set up a nuclear chain reaction in a large mass of uranium by which vast amounts of power and large quantities of new radium-like elements would be generated. Now it appears almost certain that this could be achieved in the immediate future.

This new phenomenon would also lead to the construction of bombs, and it is conceivable - though much less certain - that extremely powerful bombs of a new type may thus be constructed. A single bomb of this type, carried by boat and exploded in a port, might very well destroy the whole port together with some of the surrounding territory. However, such bombs might very well prove to be too heavy for transportation by air.

University.) A memorandum of understanding was signed with dispatch by the two institutions, and on June 8, the day before Caltech's Commencement, Lippincott and Princeton physicist Aaron Lemonick of the executive board of the Einstein Papers Project shook hands with Baltimore and Koonin on the transfer of the project to Caltech. It remains sponsored by the Hebrew University of Jerusalem and Princeton University Press, which will continue to publish the volumes.

An endowment, consisting of grants from individuals and foundations, including the National Science Foundation, the National Endowment for the Humanities, and the Alfred P. Sloan Foundation, has supported the Einstein Papers Project from early on. Caltech will be providing additional support as well as space.

On August 4, the Einstein papers, in seven large filing cabinets, moved into newly refurbished second-story offices (described by former editors familiar with previous quarters as "elegant" and "luxurious," although Barkan put much of the furniture together herself) in a house on Hill Avenue, next door to the Alumni House. It was once the home of the vice president for institute relations and, before that, the temporary home of then-President and Mrs. Tom Everhart. But it was determined at the last minute that the floor of the upstairs offices, originally designed to support

-2-

The United States has only very poor ores of uranium in moderate quantities. There is some good ore in Canada and the former Czechoslovakia, while the most important source of uranium is Belgian Congo.

In view of this situation you may think it desirable to have some permanent contact maintained between the Administration and the group of physicists working on chain reactions in America. One possible way of achieving this might be for you to entrust with this task a person who has your confidence and who could perhaps serve in an inofficial capacity. His task might comprise the following:

a) to approach Government Departments, keep them informed of the further development, and put forward recommendations for Government action, giving particular attention to the problem of securing a supply of uranium ore for the United States;

b) to speed up the experimental work, which is at present being carried on within the limits of the budgets of University laboratories, by providing funds, if such funds be required, through his contacts with private persons who are willing to make contributions for this cause, and perhaps also by obtaining the co-operation of industrial laboratories which have the necessary equipment.

I understand that Germany has actually stopped the sale of uranium from the Czechoslovakian mines which she has taken over. That she should have taken such early action might perhaps be understood on the ground that the son of the German Under-Secretary of State, von Weizsäcker, is attached to the Kaiser-Wilhelm-Institut in Berlin where some of the American work on uranium is now being repeated.

Yours very truly,

(Albert Einstein)

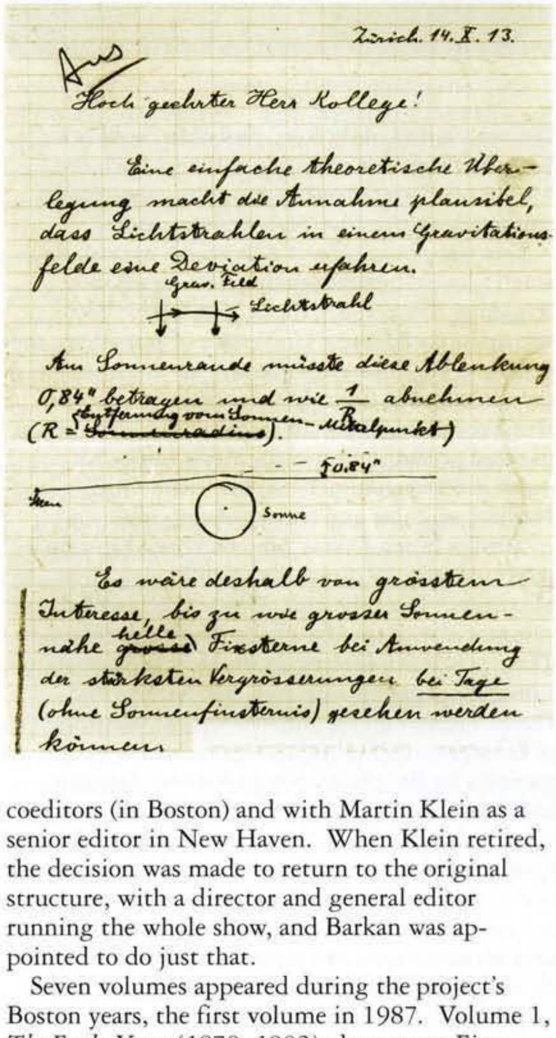
beds and chests of drawers, probably could not bear the burden of the filing cabinets, each the weight of a large grand piano. They were unceremoniously moved to the basement instead.

This was not as callous as it might appear: the seven filing cabinets contain photocopies, not originals. Since 1982, the originals have been housed at the Hebrew University of Jerusalem, the beneficiary of Einstein's literary estate (although the collection at Caltech is the more comprehensive, containing copies of thousands of documents in other private collections). After Einstein's death in Princeton in 1955, his friend Otto Nathan, executor and trustee of the estate, and co-trustee Helen Dukas, who had been Einstein's secretary since 1928, set about collecting all of his papers. Over the next 25 years they added substantially to the size of the existing archives. There was much interest at the time in publishing Einstein's scientific writings, but Nathan and Dukas insisted on the importance of publishing *all* of Einstein—including his letters, writings, and speeches on the philosophy of science, Zionism, pacifism, civil liberties, and other humanistic and social issues. In 1971 Princeton University Press agreed to take on the massive publishing project, which continued to be plagued by delays. John Stachel of Boston University was appointed the first general editor and moved to the Institute for Advanced Study in 1977, temporarily on leave from Boston. Disagreements between the press and the Einstein estate held up work and funding until the case was decided by arbitration in 1980, and Stachel was finally granted access to the papers.

By that time the project was housed in cramped quarters at Princeton University Press, and when Stachel decided to return in 1984 to Boston University, which was willing to grant office space, the massive photocopy collection was moved there. When Stachel left the project in 1988, it continued with Robert Schulmann and Jürgen Renn as

The Einstein papers arrived at Caltech in seven large filing cabinets (top left), each weighing 950 pounds. While the regular office files could be hoisted up the elegant staircase to the second-floor offices with little difficulty (top), the heavy files containing the heart of the project had to be lowered to the basement on an electric dolly.

In another famous letter, this one to George Ellery Hale in 1913, Einstein suggests that starlight might bend in the presence of a gravitational field around the sun, a key ingredient in his general theory of relativity, which he was to complete in 1915. The original of this letter is not in the archive at the Hebrew University of Jerusalem; it never left the Pasadena area and resides with Hale's papers in the Huntington Library in San Marino. (Used with the kind permission of the Huntington Library.)



Ans

Zürich. 14. X. 13.

Hoch geehrter Herr Kollege!

Eine einfache theoretische Überlegung macht die Annahme plausibel, dass Lichtstrahlen in einem Gravitationsfelde eine Deviation erfahren.

Grav. Feld

Lichtstrahl

Am Sonnenrande müsste diese Ablenkung 0,84" betragen und wie $\frac{1}{R}$ abnehmen (R = ~~Sonnenradius~~ Entfernung vom Sonnen-Mittelpunkt).

0,84"

Sonne

Es wäre deshalb von grösstem Interesse, bis zu wie grosser Sonnennähe ~~grosse~~ helle Fixsterne bei Anwendung der stärksten Vergrösserungen bei Tage (ohne Sonnenfinsternis) gesehen werden können.

coeditors (in Boston) and with Martin Klein as a senior editor in New Haven. When Klein retired, the decision was made to return to the original structure, with a director and general editor running the whole show, and Barkan was appointed to do just that.

Seven volumes appeared during the project's Boston years, the first volume in 1987. Volume 1, *The Early Years (1879–1902)*, documents Einstein's youth up until the time he began work for the Swiss patent office. About two-thirds of the 142 documents reproduced in the first volume were discovered by the project editors and had not been published previously. Among these were 52 letters exchanged with Mileva Maric, who would become Einstein's first wife, letters that, since their publication, have spawned several books about Einstein's love life.

The subsequent 28 volumes fall into three periods: the Swiss years (1900–1914), the Berlin years (1914–1933), and the Princeton years (1933-1955); these will all contain several volumes—11, for example, for the Berlin period. The volumes are divided into two series: "writings" (books, published and unpublished articles, lecture notes, research notebooks, book reviews, reliable records of speeches and interviews) and "correspondence" (letters written to and from Einstein, as well as selected third-party letters about him). This interleaving and cross-referencing of the writings and correspondence is one of the project's unique features. The volumes are being published in chronological order.

Volume 2, *The Swiss Years: Writings, 1900–1909*, covers the first decade of Einstein's career. His published scientific work at this time includes "some of the most significant achievements of 20th-century physics"—his seminal papers of 1905, the third of which set forth the special theory of relativity. By Volume 3, *The Swiss Years: Writings, 1909–1911*, Einstein has left the patent office and begun his academic career, first at the University of Zurich, then at the German University of Prague. Almost half of this book consists of previously unpublished notes for his lectures on mechanics, on electricity and magnetism, and on kinetic theory and statistical mechanics. The volume also documents his continuing interest in the problems of radiation and quantum theory and concludes with his report to the first Solvay Conference, the first international meeting devoted to these problems. The Swiss years end in Volume 4—*Writings, 1912–1914*—more than half of which traces his struggle to construct the general theory of relativity. It contains the first joint paper with Marcel Grossmann on general relativity, as well as an unpublished manuscript on relativity and electrodynamics, and the previously unknown Einstein-Besso calculations on the perihelion motion of Mercury. Volume 5, covering the whole Swiss period, contains the *Correspondence, 1902–1914*. Most of the 520 letters had not been published before and present a rich picture of Einstein in his 20s and early 30s in his relationship to his family, friends, and contemporaries in physics.

In 1914, Einstein moved to Berlin to join the Prussian Academy of Sciences. In Volume 6, *The Berlin Years: Writings 1914–1917*, he completes the general theory of relativity, returns to the puzzles of quantum theory, and, as World War I begins, publicly expresses his views on nonscientific subjects for the first time by signing a "Manifesto to Europeans," urging unity and an end to hostilities. Volume 8, *The Berlin Years: Correspondence, 1914–1918*, is really two volumes, which comprise almost 700 letters, many of them only recently discovered by the editors. They cover his scientific discussions with colleagues, his sense of moral urgency about the war, and the breakup of his first marriage.

Eight books of *The Collected Papers of Albert Einstein* have been published so far; actually Volume 7 is missing—but Volume 8 comes in two parts. Below: In the papers' basement sanctuary, Barkan and Kennefick look over an interesting file with Susan Davis, division administrator for the humanities and social sciences, who was instrumental in the logistics of bringing the project to Caltech.

Volume 7, *The Berlin Years: Writings, 1918–1921*, slightly out of order, will be the first book to appear from Caltech. Covering a particularly interesting period of Einstein's life, the book contains detailed annotations to his lectures and notes on the general theory of relativity. It was a time when he began to reexamine both the mathematics and the physics of his theory and to ponder its philosophical implications. Eddington's 1919 eclipse expedition confirmed Einstein's prediction that the sun's gravitational field would bend starlight. Einstein made his first trip to the U.S. in 1921—primarily to raise funds for the Hebrew University of Jerusalem with Chaim Weizmann, but he also gave a series of lectures on the theory of relativity, included in this volume, at Princeton.

One of the more interesting accounts in Volume 7, according to Barkan, is the growing anti-relativity movement among some scientists in Germany, the increasing anti-Semitic outbursts at the University of Berlin, and the complex relationship between the two. A number of documents pertain to Einstein's surprising skills on a wide range of patent disputes for which he served as an expert witness. "Throughout his life, he continued to derive great pleasure from examining devices and gadgets, especially electrical ones," says Barkan.

Editors of Volume 7 are Robert Schulmann, Michel Janssen, József Illy, and Christoph Lehner. Schulmann, now in Washington, D.C., has been with the project since 1981 and an editor on all the volumes; Janssen is assistant professor at the University of Minnesota; Illy, a visiting editor from Hungary, will now visit in Pasadena instead of Boston; and Lehner, senior assistant editor, moved with the papers from Boston to Pasadena quite literally—he packed them up on one end and unpacked them at the other. He will also hold the position of senior research fellow in the humanities at Caltech. Joining the staff as a junior editor in January will be Daniel Kennefick, PhD '97, Caltech's first doctoral student in both physics and the history of science and winner of the Clauser Prize for the dissertation showing the most originality and ingenuity.

For those who are eager to follow Einstein's thought processes as he struggled with relativity, to read what he and H. A. Lorentz or Max Planck had to write to each other, or merely to romp through Albert and Mileva's love letters, be advised that everything is published in its original language, which is almost always, at least in the early volumes, German. The annotations and editorial commentaries are in English, however, and Princeton University Press has been publishing companion volumes with translations into English of all previously untranslated material. (And the Mileva letters have been translated and published in their own book.) The translation project is separately funded by the National Science Foundation and has remained at Princeton until now, but it too falls under Barkan's editorial responsibilities.

The filing cabinets on Hill Avenue are only for the use of the project staff, but a duplicate copy of the collection will be made available to scholars and researchers in the Caltech Archives. (Similar copies have been deposited in the project's former institutional homes, Princeton and Boston University, and at the Swiss Federal Institute of Technology, Einstein's alma mater.) The campus community also has the opportunity to attend four seminars on Einsteinian themes throughout the year. The first, "Lorentz vs. Einstein: The Special Theory of Relativity in Historical Context," was held on October 5 by A. J. Kox, the Pieter Zeeman Professor of History of Physics at the University of Amsterdam. Kox was also an editor of Volume 2 through Volume 8 of the collected papers.

Several members of the Caltech faculty will serve on an advisory committee to the general editor: Judith Goodstein, university archivist and faculty associate in history; Christopher Hitchcock, associate professor of philosophy; Mac Pigman, professor of literature; and Robbie Vogt, Avery Distinguished Service Professor and professor of physics. Representing Caltech on the advisory board to Princeton University Press is Kip Thorne, the Feynman Professor of Theoretical Physics.

Modest throughout his life, Einstein requested that his ashes be scattered in an unmarked spot. When the long-delayed volumes of his collected papers later began to appear, the *International Journal of Theoretical Physics* noted: "Einstein wished no monuments; this monument is the one he would have accepted . . . ." □

Thomas Hartwig Wolff
1954 – 2000

As *E&S* was going to press, Caltech lost two more faculty members. J. Harold Wayland (MS '35, PhD '37), professor of engineering science, emeritus, died on October 10 after a heart attack. And Bradford Sturtevant (MS '56, PhD '60), Liepmann Professor of Aeronautics, died October 20 of pancreatic cancer. Memorial services are pending; the dates have not yet been announced.

Thomas Hartwig Wolff, professor of mathematics, was killed in a car crash on the night of July 31 on SR 14 in Kern County, some 90 miles north of Pasadena. At a memorial service in Dabney Lounge on October 19, Steven Koonin (BS '72), provost and professor of theoretical physics, described him as "brilliant. Intense. Respected. The brilliance of his work has been well documented by people who understand it much better than I. The intensity is obvious to all who saw his famous random walks with a coffee cup somewhere to the southeast of Millikan Library. And the respect was shown by his colleagues, who nominated him to the Caltech faculty three times—I believe an Institute record." Wolff earned his AB in 1975 at Harvard and his PhD at Berkeley in 1979. After stints as an acting assistant professor at the University of Washington and a postdoc at the University of Chicago, he came to Caltech as an assistant professor in 1982. He was promoted to associate professor in 1985 and full professor in 1986, but left for NYU's Courant Institute of Mathematics. Caltech got him back from 1988 to 1992, when he joined the faculty at Berkeley, and recaptured him for good in 1995.

A Manhattan native, Wolff grew up steeped in math. His uncle, Clifford Gardner, had also been at the Courant Institute, and his mother Lucile was a technical editor for Volume 1 of the English translation of Courant and Hilbert's *Methods of Mathematical Physics*. The result was a sort of prodigy. In the words of Peter Jones, a collaborator since Wolff's postdoc days in Chicago, "It was like having Mozart around."

Wolff's specialty was analysis, in particular Fourier analysis. Fourier analysis is based on Jean-Baptiste Fourier's 1807 discovery that many differential equations could be solved by representing the unknown function as the sum (typically an infinite one) of simple periodic functions, including sine waves, called harmonics. The method is the key to understanding some of the most fundamental equations of classical physics—including Laplace wave, and diffusion equations—so an extensive body of work has grown up around it. In one dimension, the field is closely related to complex analysis, which is based on complex numbers (the square root-of-minus-one kind, that is, not the kind used by crooked bookkeepers) and provides a wealth of analytic tools that are not available in higher dimensions. Wolff started in one-dimensional Fourier analysis, where he demonstrated remarkable technical skills, but quickly moved to higher dimensions where he revealed a geometric intuition that allowed him to create tools that have no one-dimensional equivalent. In the words of Caltech Professor of Mathematics Nikolai Makarov, "He had a talent for explaining his constructions so you could actually visualize them, and what a beautiful world it was."

Wolff's virtuosity first became apparent while a grad student at Berkeley, where he bested the Corona Theorem. The Corona Theorem is a fundamental result about the existence of analytic functions of complex variables; it gets its name from a mathematical structure that pictorially (although not scientifically) resembles the sun's corona. The original proof, worked out in the 1960s by Lennart Carleson of Sweden, was quite long and very complicated but no alternative had been found. Wolff's version is very clear and only a few pages long.

Wolff didn't write up the

In a contemplative moment, Wolff takes a breather before tackling the east face of Mount Whitney with wife Carol Shubin and CSUN math professor John Dye in 1993.

proof, but he took it on the road and talked about it, which is more than Fermat ever did. UCLA's John Garnett recalled: "I first met Tom in 1978. I had gotten a letter from [Don] Sarason [his thesis advisor], saying he had this grad student who had gotten some good results and who was a little shy, but would like to visit. Tom came down to UCLA three times that year, and on his last visit he gave his new proof of the Corona Theorem. Paul Koosis and I were separately writing books on Hardy spaces at the time, and we each had to rewrite an entire chapter because of him. T. W. Gamelin then wrote a short journal article containing a further simplification, so we had the academic anomaly of three UCLA professors publishing independent accounts of a Berkeley student's work!"

It was typical of Wolff that he moved on without writing a Corona paper himself. "His approach was to pinpoint the most difficult problem and then quickly work a miracle," said Makarov, but lingering to exploit the advance didn't appeal to him.

Wolff "took on all the biggest, long-standing, open problems in analysis and made impressive results," said Makarov. He wrote about 50 papers—"not a world record, but enough for several mathematicians to have been recognized as leaders in the field." And he may just have been hitting his stride—"the last five years were the most productive in his career." For example, he wrote two papers on the Kakeya problem, which has to do with measuring the space occupied by sets of line segments that point in all directions. Wolff made the problem easier to handle by giving the segments a wee bit of thickness and bundling them into *n*-dimensional Koosh balls, if you will, which could then be combined in various ways to explore the space. While he didn't solve the problem, the tools he developed while working on it will inform all of mathematical physics. And that's really what it's all about—the problem itself is just a vehicle to spur one's ingenuity.

Wolff's works in progress won't be lost, said his wife Carol Shubin, herself a professor of mathematics at Cal State Northridge. She is sorting through his manuscripts and farming the most promising ones out to some half-dozen of his collaborators. Meanwhile, mathematicians around the world are building the edifices he sketched out in his papers.

Wolff "had a passion for whatever he wanted to do," Carleson recalled. "Nobody met Tom without feeling it." Jones agreed, "When you asked him where his ideas came from, it was like opening the door of a furnace and looking in." Not surprisingly, he worked by total immersion, making it a point to understand everything anyone had ever done on a topic, and how it all fit together—down to the minutest detail—before diving in. A period of intense concentration followed, during which he was so uncommunicative, said Jones, that even his colleagues couldn't tell what he was working on. "He was always seen with a cup of coffee and a cigarette, hunched over in his special body language," which said that "he was thinking at a million miles an hour, and mathematicians knew better than to disturb him." Eventually the breakthrough would come, and "pads and pads of scribbles would appear in his office, and you could creep in there and try to divine what he had done."

The passion proved stronger than the shyness, and Wolff metamorphosed into a teacher *par exellance.* Wilhelm Schlag (PhD '96), now at Princeton, said, "The most remarkable features of his teaching only became clear later, when I had to teach classes myself. His teaching was fresh and original—most of the proofs were his own, even if they were of well-known theorems. Of course, he was far too modest to mention this." Outside of class, "he was always available to offer his opinions and insights. He enjoyed talking mathematics with anyone, even if they didn't know much about the subject. He inspired with his enthusiasm for research and teaching."

Added Markus Keel, Caltech's Olga Taussky-John Todd Instructor in Mathematics, "Tom's unflinching honesty and bracing lack of self-consciousness set his classes far, far apart. Tom would speed into the room, looking for all the world like he'd just wrestled about 300 alley cats, half of whom were wielding squirt guns loaded with coffee. He'd distribute six or seven pages of immaculate notes which he had typed up, and apologize for a typo or two while handing them around. The lecture that would follow is impossible for me to describe in concrete terms—I really don't know how he did what he did, but it made me realize the courses I'd taken (and taught) up until then were, at their best, a lot like taxidermy: the stuffing of a slain, beautiful animal to make it look real. As in those little scenes you see in outdoor stores, a glass-eyed grizzly would stand menacingly on its rear legs with a salmon impaled on its claws. If the instructor was really good, it seemed as though the bear was looking at the student while simultaneously chomping into the fish. In Tom's hands, the grizzly would rumble into full life, drop the plastic fish some fool had pasted to its paws, and wreak havoc on the yuppie Patagonia displays in the menswear department... There was something both terrific and terrifying about Tom's course."

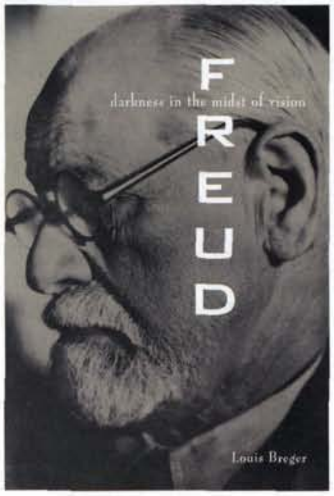
Wolff's drive to share and his intellectual honesty made him an ideal colleague as well, said Garnett. He was always generous with his advice, but when you told him your ideas on a problem, the problem remained yours. You could be sure he would not go home and try to solve the problem for himself.

Among Wolff's professional honors were the 1999 Bocher Prize, the 1985 Salem Prize, a Sloan Fellowship, invited named lecture series at the University of Chicago and Stanford, and invited addresses at what Makarov calls "the Olympics of mathematics," the International Conference of Mathematicians in 1986 in Berkeley and 1998 in Berlin.

On the personal side, Wolff was a skilled mountaineer who climbed many peaks in the eastern Sierra solo, or with Shubin and CSUN math professor John Dye. "Some of the best times we had were while climbing," she said. He was also an enthusiastic, if less skilled, cellist. Colin Carr, his brother-in-law, told about his mom going up to Berkeley to visit him at grad school. "As you know, Tom wasn't very concerned about the comforts of home, and his room was a horrible mess. There was a sleeping bag on the floor, and on the bed was his cello."

In addition to his wife, he is survived by sons James, 3, and Richard, 5; parents Frank and Lucile; and sisters Virginia and Caroline. A fund has been established for the boys' education; for more information contact Cherie Galvez in the math department office at (626) 395-3744 or cgalvez@its.caltech.edu. □

Books



Freud: Darkness in the Midst of Vision
by Louis Breger
John Wiley & Sons, Inc., 2000
472 pages

by Leslie Brothers, MD,
Associate Research Neurobiologist,
Department of Psychiatry,
UCLA School of Medicine

Sigmund Freud inspires mixed feelings, sometimes strong ones. Within recent memory such notions as the Oedipus complex, repression, and the tripartite model of the mind (id, ego, superego) have been embraced as hallowed truths—not only by psychologists, but also by social scientists, humanities scholars, and others. At the same time, however, psychoanalysis was and is ridiculed as pretentious mumbo-jumbo practiced by cultish headshrinkers. The coarser kinds of lampooning have been complemented by sober, rigorous debunking on the part of skeptical philosophers and sociologists. Citing flaws of logic and evidence, they have successfully demolished Freudian theory's claims to scientific status.

Debunked or not, Freudian ideas persist in everyday conversations about people and their motives. Common examples include the idea that it is healthy to "release"

The authoritarian style has been adopted by generations of psychoanalysts and by the major psychoanalytic organizations, to the serious detriment of both patients and would-be innovators—and therefore ultimately to the movement itself.

aggression (this derives from the so-called hydraulic model, according to which aggression and libido were powerful forces seeking expression), or the idea that people behave as they do because of their "conflicts." And Freud's influence continues to be felt in intellectual circles as well. For example, neuroscientists sometimes invoke his name in their accounts of brain and mind, suggesting he dimly glimpsed truths that can now be grounded in the brain's biology. Inside and outside academia, reverence and deep distrust compete.

Why do Freud's theories continue to exert such fascination? The key may be their source, the man himself, as he is revealed in a new book by Caltech professor of psychoanalytic studies, emeritus, Louis Breger entitled *Freud: Darkness in the Midst of Vision*. There Breger lays bare the relationships between Freud's deep personal difficulties, his theories, and the movement he founded. In contrast to previous biographies written by Freud's devotees, Breger's *Freud* is a penetrating, unsettling look at the most important determinant of Freud's thought—his character. This carefully researched portrait has drawn praise from Freud's granddaughter, Sophie Freud, for its compassion as well as its accuracy.

Breger portrays the young Freud as growing up amidst the insecurity of his easygoing father's chronic financial difficulties and his mother's numerous confinements in the family's cramped quarters. Turning in disappointment from his father's weakness, the young Sigmund developed a fascination for the heroic, identifying with such military figures as Hannibal, Alexander the Great, and Napoleon. He was able to realize his striving to be a conqueror, rather than the struggling offspring of an ineffectual father and preoccupied mother, through his intellectual gifts, which were recognized and encouraged. His mother, although she was too emotionally limited to be nurturing, idealized him, calling him her "golden Sigi." Like the exploits of the conquerors he so admired, the theories he developed in maturity were imperial in their reach.

Further, Freud rewrote his own life to make himself a hero, eliminating whenever possible episodes that revealed his vulnerability or inadequacy. Tragically, as Breger shows, a compelling need to be in the right rendered humility impossible when it was needed. For example, because Freud insisted on ignoring the actual, real-life predicament of his patient Dora, she ceased cooperating with the treatment: her rejection of him became the occasion for still another theory about her unconscious motives, rather than a call to reexamine his own behavior. This he was unable to do.

Breger also carefully documents Freud's complete intolerance for anything less than total adulation and compliance on the part of his students. Freud cast aside and viciously attacked the brilliant psychoanalysts Otto Rank and Sándor Ferenczi, among others, for daring to think independently. He was aided in his vengeful acts by an inner circle of loyalists including Karl Abraham and Ernest Jones, who remained in his good graces by submitting to his control. Breger methodically removes the mask Freud constructed, showing that ruthless domination characterized not only his professional relationships but also his home life, his relations with women, and his work with patients.

Freud attributed an Oedipal neurosis to himself, and made of it a universal. Breger's argument, that Freud's core issue was instead a lifelong effort to replace vulnerability and inadequacy with invincible grandeur, is persuasive. Breger also emphasizes some of the pernicious ramifications of Freud's self-deception. The authoritarian style has been adopted by generations of psychoanalysts and by the major psychoanalytic organizations, to the serious detriment of both patients and would-be innovators—and therefore ultimately to the movement itself.

Perhaps we instinctively resonate to the kernel of dangerous grandiosity in Freud's proposals, and are both attracted and disturbed by it. What emerges from this compelling biography is that if Freud is in some sense larger than life it is because he was driven to be. Breger's account should be read by everyone who has loved, hated, or merely been intrigued by Sigmund Freud. □

Baldeschwieler Gets National Medal of Science

John Baldeschwieler, Johnson Professor and Professor of Chemistry, Emeritus, is one of 12 recipients of this year's National Medal of Science. The medal is presented annually at the White House by the president to scientific leaders who have changed, or set new directions, in research and science policy.

Baldeschwieler was cited for his work on molecular assemblies for use in the delivery of pharmaceuticals, for his work on scientific instrumentation, and particularly for his development of ion cyclotron resonance spectroscopy, which identifies ionized molecules by their characteristic orbital frequencies in a strong magnetic field. He also pioneered the use of nuclear magnetic resonance spectroscopy, including double resonance spectroscopy, the nuclear Overhauser effect, and perturbed angular correlation spectroscopy in chemical systems. His recent work concentrates on the use of phospholipid vesicles in cancer diagnosis and therapy, the development of scanning tunneling and atomic force microscopy for the study of molecules on surfaces, and on the creation of new methods for producing combinatorial arrays of oligonucleotides.

John Baldeschwieler

Baldeschwieler joined the Caltech faculty in 1973, after several years at Harvard and Stanford. He was a member of the President's Science Advisory Committee from 1969 to 1972, serving as vice chairman from 1970 to 1972. He served as deputy director of the Office of Science and Technology from 1971 to 1973. A native of New Jersey, he earned his doctorate at Berkeley in 1959. He is a fellow of the National Academy of Sciences, the American Academy of Arts and Sciences, and the American Philosophical Society. □—*RT*

Honors & Awards

Frances Arnold, Dickinson Professor of Chemical Engineering and Biochemistry, has been selected by the American Institute of Chemical Engineers to receive its 2000 Professional Progress Award for Outstanding Progress in Chemical Engineering, sponsored by Air Products and Chemicals, Inc.

President David Baltimore will present the science-book award at the *Los Angeles Times* Book Festival, on April 27.

Assistant Professor of Planetary Astronomy Michael Brown has been selected to receive the Presidential Early Career Award for Scientists and Engineers, which is "the highest honor bestowed by the U.S. government on outstanding scientists and engineers beginning their independent careers."

Peter Dervan, Bren Professor of Chemistry, has been selected to receive the Tetrahedron Prize for his "creativity in developing a new field of bioorganic chemistry."

Michael Hoffmann, Irvine Professor of Environmental Science and executive officer for environmental engineering science, has been selected to receive the American Chemical Society Award for Creative Advances in Environmental Science and Technology, sponsored by Air Products and Chemicals, Inc.

Professor of Aeronautics and Applied Mechanics Wolfgang Knauss was presented the 2000 Lazan Award of the Society for Experimental Mechanics at the society's 2000 Spring Conference, last June. The award recognizes his "outstanding original technical contributions to experimental mechanics."

Associate Professor of Biology and Computation and Neural Systems Gilles Laurent has received a 2000 McKnight Investigator Award from the McKnight Endowment Fund for Neuroscience. The award "is given to stimulate research in neuroscience as it pertains to memory and, ultimately, to a clearer understanding of diseases affecting memory." Laurent will receive $50,000 per year for three years for his work on memory in olfactory network dynamics.

Professor of History James Lee has been named by the Social Science History Association a cowinner of the 2000 Allan Sharlin Memorial Award for his book *One Quarter of Humanity: Malthusian Mythology and Chinese Realities, 1700–2000*, coauthored with Assistant Professor of Sociology Wang Feng, of UC Irvine. "The book is recognized as breaking new ground in Chinese demographic history and will be a benchmark in the growing field of Asian demographic history."

Associate Professor of Mathematics Rahul Pandharipande has been chosen a 2000 Packard Fellow.

Alexander Varshavsky, Smits Professor of Cell Biology, has received the 2000 Albert Lasker Award in Basic Medical Research "for his groundbreaking work on the ubiquitin system that targets proteins for destruction." He shares the award with Avran Hershko and Aaron Ciechanover of the Technion—Israel Institute of Technology. The Lasker Awards are given each year by the Albert and Mary Lasker Foundation for basic and clinical medical research.

Mark Wise, McCone Professor of High Energy Physics, has been chosen to receive the American Physical Society's Sakurai Prize, in the field of theoretical particle physics.

Ahmed Zewail, Nobel laureate in chemistry and Pauling Professor of Chemical

Physics and professor of physics, was appointed to the Pontifical Academy of Sciences on November 13 at the Vatican, where he met Pope John Paul II and was presented with the academy's insignia. The academy's roots go back to 1603—the first exclusively scientific academy in the world—and it is a nonsectarian, multiracial body of 80 scientists "who have made outstanding contributions in their fields." The academy, which includes Caltech president David Baltimore (appointed in 1978), advises the Pope on scientific advances and their moral, ethical, and environmental implications. □

Professor Ahmed Zewail met Pope John Paul II in St. Peter's Basilica. The Pope spent more than two hours with the new academicians, speaking Italian in his formal address during the ceremony and later speaking English to Zewail one on one.

Ride, Lee Become Trustees, Rosen Elected Chair

Astronaut Sally Ride and Global Crossing cofounder David Lee (PhD '74) have been named Caltech trustees, and Ben Rosen (BS '54) was voted the new chair of the board. Gordon Moore (PhD '54) will continue as chair through December 31, 2000, and Rosen will continue to serve as vice chair through the end of the year.

Ride is the Hibben Professor of Physics at UC San Diego. Best known as the first American woman in space, Ride flew aboard the space shuttle *Challenger* in 1983 and was an astronaut on two additional shuttle crews. Her research interests center on the theory of nonlinear beam-wave interactions, primarily connected with free-electron lasers and related nonlinear systems. She also conducts research at the California Space Institute. She is a strong supporter of science and math education for young women, and has written three children's books about space. She has received numerous awards, including the Jefferson Award for Public Service and the National Spaceflight Medal. She holds a PhD in physics from Stanford.

Lee cofounded the transcontinental telecommunications firm Global Crossing in March 1997. Recently, he left Global Crossing, where he continues to serve on the board, to cofound and become managing general partner of Clarity Partners, a venture capital firm. Lee has established centers for Advanced Networking at Caltech and at the National Chiao Tung University in Taiwan. He serves on the board of overseers at the Keck School of Medicine at USC and also serves on the board of New Focus, Inc. Lee is a graduate of McGill University and holds a PhD in physics with a minor in economics from Caltech. He is also a certified public accountant.

Incoming chair Ben Rosen is chairman of the board of the Compaq Computer Corporation and has served as a Caltech trustee since 1986. □—*JP*

As part of the effort to assemble a National Millennium Time Capsule, the White House Millennium Council "asked former presidential and congressional medal winners as well as students from every state and territory of our country to tell us what they thought represented America at the end of the 20th Century or what their hopes are for the future." Among the respondents was Hans Liepmann, von Kármán Professor of Aeronautics, Emeritus, who won the National Medal of Science in 1986. Liepmann, who was born in Germany and emigrated to the U.S. in 1939 at von Kármán's invitation to join Caltech's Guggenheim Aeronautical Laboratory, and who became a naturalized citizen in 1945, had this to say: "I most certainly would like to preserve the qualities that struck me at the time as so different from the narrowness and pettiness of the Europe where I came from. The natural friendliness and openness combined with a natural pragmatic approach to life of the Americans I met on my long train ride to California made a deep and lasting impression on me. To codify these virtues in enforceable laws is unfortunately usually counterproductive and hence I hope for the survival of a sufficient number of role models to pass them on." He called the transistor's invention and the double helix's discovery the achievements of the century, and concluded: "For the future I hope for a stabilized or even reduced world population ... [our] only hope to preserve humanity with dignity and in permanent possession of a beautiful planet!"

Liepmann's letter will be on display at the National Archives in Washington, D.C., from December 1 until the presidential inauguration in January. □

Professor of Biology, Emeritus, Ray Owen has been selected as the Medawar Laureate for the year 2000 by the Transplantation Society. The prize, awarded annually since 1990, is named for Nobel Laureate Sir Peter Medawar, "the father of transplantation biology," and honors outstanding contributions to the field. Organ transplants are so routine today that, except in rare cases, they aren't in any way newsworthy, but it was Owen's discovery of the phenomenon of immune tolerance in the 1940s that made it clear that they were even possible. He transplanted hematopoietic stem cells—blood-cell precursors—between sets of twin cattle, and used genetic analyses and blood typing to show that there was no immune response to the foreign antigens belonging to the twin's cells. He then suggested that suppressing the immune system—with x-ray treatments, for example—would allow transplants to incompatible recipients, and in the 1950s he participated in the first experiments in human organ transplantation.

Meiron Named Czar of Bits and Bytes

In recognition of how deeply dependent we are on computer networks these days, it was announced—by e-mail, of course—that Daniel Meiron, professor of applied mathematics, has been appointed associate provost for information and information technology as of November 1. This half-time job puts him in charge of Caltech's Information Technology Services and the Computing Advisory Committee.

Said Vice President and Provost and Professor of Theoretical Physics Steve Koonin (BS '72) in the e-mail, "Dan brings to the task a deep knowledge of computing and computing technology, as well as experience as both executive officer for applied math and director of Caltech's ASCI effort," which he will use to look at how information flows through the campus and what technology is needed to manage it.

Among his specific duties will be overseeing our computing infrastructure, including the wired and (eventual) wireless campus network, e-mail delivery, computer security, software site licensing, and whatever the next generations of technology bring; helping to improve the quality, efficiency, and responsiveness of Caltech's electronic business systems; collaborating with Caltech's libraries to support access to their online resources and planning for the e-library of the future; and promoting the coordination and rationalization of Caltech's various electronic information resources. □

A Boone for SURF

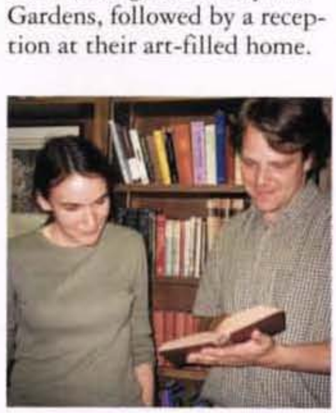
Every year, George and MaryLou Boone (top right) host SURF students on a tour of the Huntington Library and Gardens and a reception at their own San Marino home (above). Kathryn Todd (below right, with faculty mentor Kevin Gilmartin), one of the SURF students sponsored by the Boones, is using the Huntington's resources for her research on Jane Austen.

MaryLou and George Boone have been active supporters of the SURF (Summer Undergraduate Research Fellowships) program for several years; George Boone has served on the SURF Board of Directors since 1997.

The Boones, who are well known as art collectors and patrons, also support the Huntington Library, Art Collections, and Botanical Gardens, where MaryLou has been an Overseer since 1993. The latest evidence of their philanthropy is the recently opened MaryLou and George Boone Gallery there. Living in San Marino, they view both Caltech (they are also members of the Associates' President's Circle) and the Huntington as important institutions in the local community and have long been interested in fostering a closer relationship between the two.

This interest is reflected in their efforts to expose SURF students to the wealth of art and other related resources at the Huntington Library. The two Boone-sponsored SURF students this year are Kathryn Todd, a Caltech senior with a double-major in physics and literature, and Maria Brumm, a Caltech sophomore. Kathryn is working on a project entitled "Who Was Jane Austen?" with Associate Professor of Literature Kevin Gilmartin; and Maria is working with Associate Professor of History Alison Winter on a digital simulation of a 16th-century work on astronomy, to be part of the Huntington's current exhibition on art and astronomy (see page 9). Both students have made extensive use of the Huntington's outstanding archives in their research, and exemplify the collaboration that the Boones have encouraged between the two neighboring institutions.

In addition to providing generous annual support for the program, every year the Boones also invite all SURF students on a special tour of the Huntington Library and Gardens, followed by a reception at their art-filled home.



Founded 22 years ago, SURF, which enables students to conduct independent research, has become an integral part of the academic experience of most Caltech undergraduates. The SURF Board has set a goal of raising $10 million to increase the program's endowment, and the Boones' generous commitment through their estate plans goes a long way toward achieving this goal. When received, this gift will establish an endowment fund for SURF fellowships in the Boones' names.

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