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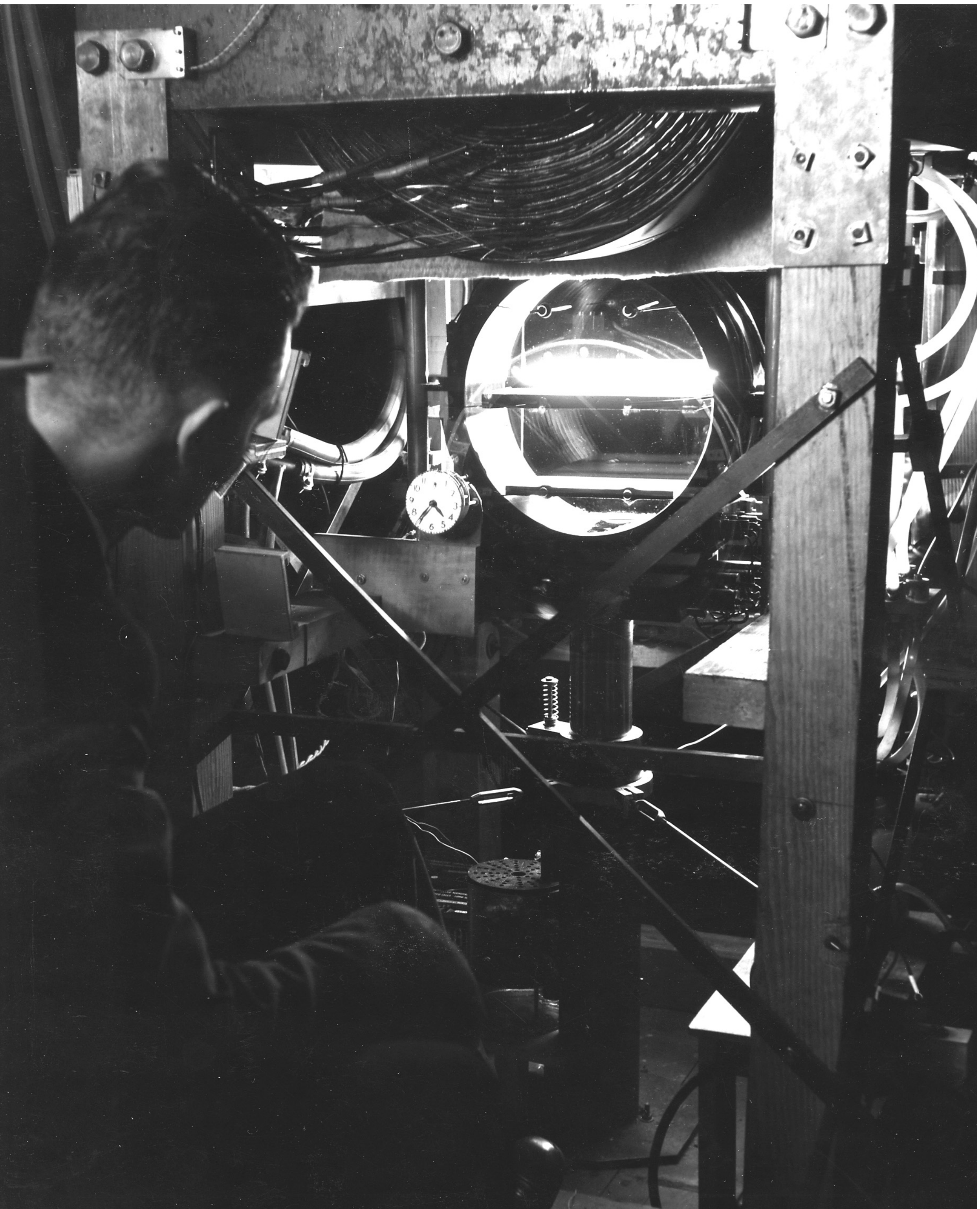

At the beginning of his long Caltech career, the late Bob Leighton studied cosmic rays with Nobel laureate Carl Anderson. Even then Leighton was constructing his own apparatus. He's shown in this 1949 photograph with the "falling cloud chamber," which he designed and built to take full advantage of the magnetic field. When the particles passed through, the round chamber remained enclosed in the magnet (top), and then dropped down into view in the fraction of a second before the tracks formed. Leighton's brilliance in building things later led to broadening the spectrum of astronomical observations. His journey from cosmic rays to millimeter-wave astronomy is described in an article beginning on page 18.

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On the cover: A male owl monkey carries his infant on his back. Owl monkey mothers nurse their infants but otherwise refuse to carry them around, a task the fathers assume shortly after the infants are born. In most primate species, including humans, the mother takes on the primary child-care role. The females of those species outlive the males, but the situation is reversed in owl monkeys: the males have a survival advantage. In a chapter from his new book, beginning on page 8, John Allman discusses why this might be so.

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MD/PhD, Caltech–USC

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

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

Now, That's What I Call Student Aid!

Rea and Lela Axline.

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

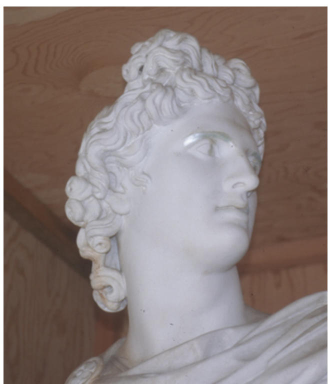
According to President David Baltimore, the gift could make Caltech the foremost institution in the world in terms of providing educational support for future scientists and technologists. "Providing sufficient graduate and undergraduate student aid to attract the very best students to Caltech is one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

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

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

Sympathy for Apollo

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



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

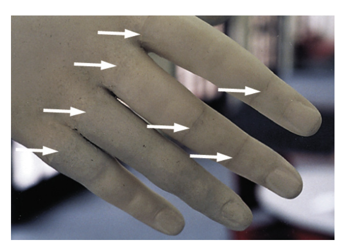
Caltech's Apollo Belvedere, recently reinstalled in glory in the lobby of the Braun Gym, has taken a long, strange trip over the last 25-plus years—from Throop Hall to Dabney Gardens to the steam tunnels to a warehouse. (See *Caltech News*, 1998, No. 3.) Like many travelers, he got pretty dirty; unlike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

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

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

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

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



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

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

We're Off to See the Comet

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

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

CBI Sees First Light

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

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

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

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

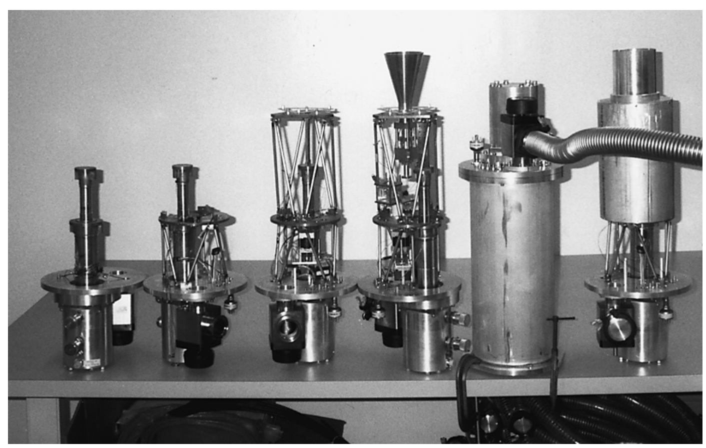
Current theories of how the universe formed posit that fluctuations of approximately this size and intensity should exist, but each theory makes different predictions about their specific size and exact nature. The past decade has seen an avalanche of papers on the subject, and, if the theorists are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

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

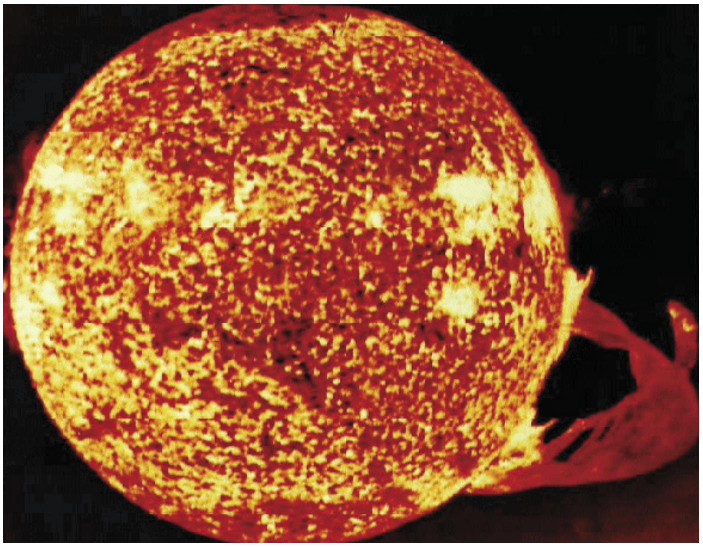
The CBI should be fully assembled and tested by April, at which point the receivers and other delicate gear will be removed and crated up, and the telescope mount will be bolted to a 40-foot "flat rack" (essentially a couple of girders) for the voyage to Chile, where it will be trucked to the 5000-meter-high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

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

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



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



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

Twisting the Night Away

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

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

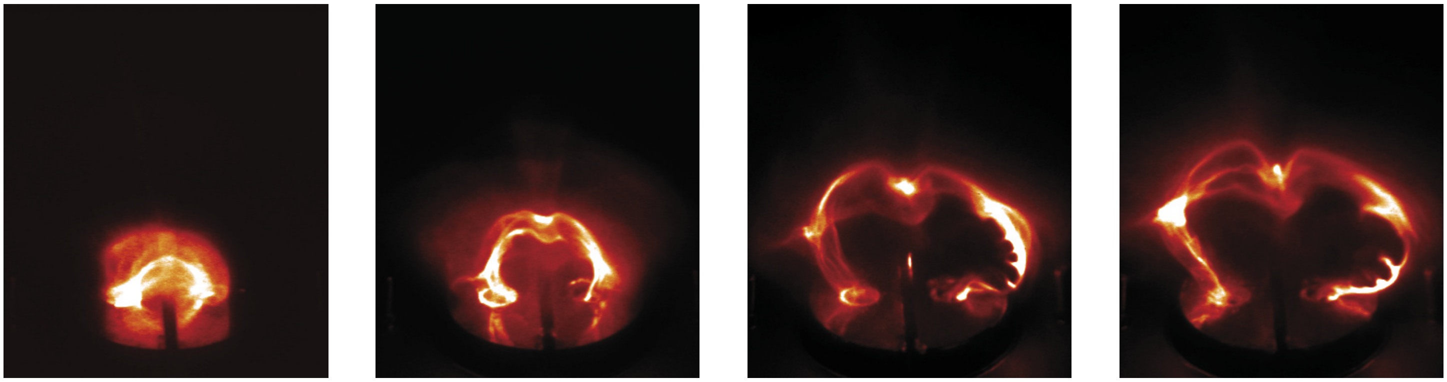
Paul Bellan, professor of applied physics, sees exploring the physics of solar prominences as a stepping stone toward the development of fusion reactors. Fusion, which powers the sun, is the forcible merging of two atomic nuclei, releasing enormous energy. Nuclei repel one another, so you have to slam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

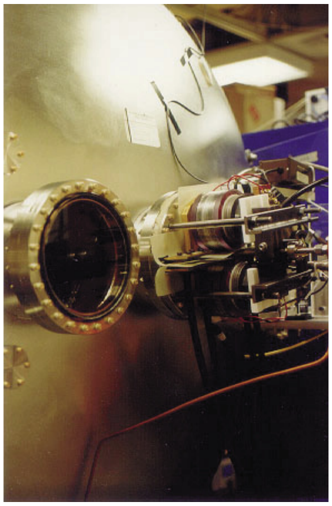
Unfortunately, reactors based on tokamaks would be large, complex, and expensive to build. Bellan thinks solar prominences are like spheromaks, which are magnetic "soap bubbles" that actually organize themselves into existence—set up the right conditions and, presto, they form from natural instabilities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

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

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

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



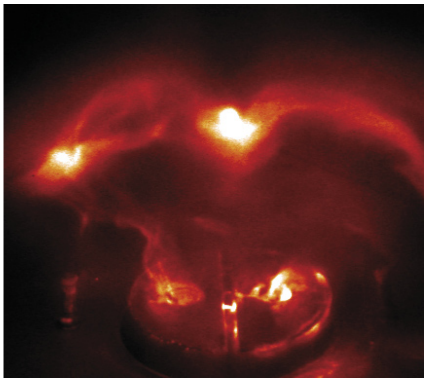


Above: The plasma gun is mounted on one end of the vacuum chamber, next to a viewport. The stubby cylinders are magnetic coils that generate a magnetic field of 3 kilogauss—typical of sunspots, with which active prominences are normally associated, and 10,000 times stronger than Earth's surface field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

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

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

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



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

Large-brained, slowly developing, dependent offspring require long-surviving parents to reach maturity. A measure of this parental dependency effect is the differential survival of caretakers versus noncaretakers.

An orangutan mother with her offspring. Except for mothers and their offspring, orangutans lead a solitary existence. The burden of taking care of the slowly maturing offspring falls entirely on the mother. Birute Galdikas found that the average interbirth interval for orangutan mothers is eight years.

Big Brains and Parenting

by John M. Allman

Having a larger brain is linked to enhanced survival. This being the case, why don't more animals have large brains? The answer to this puzzle is that the costs of growing and maintaining a big brain are very high both for the individual and for its parents. In a newborn human the brain absorbs nearly two thirds of all the metabolic energy used by the entire body. This enormous burden results from the very large relative size of the brain in human infants and from the additional energy required for dendritic growth, synapse formation, and myelination, which is far greater even than the considerable energy required to maintain the adult brain. Because the brain requires nearly two thirds of the infant's energy supply, this constraint probably sets an upper limit in the evolution of brain size because the muscles and the other vital organs, the heart, the liver, the kidneys, the stomach, and intestines, must use energy as well.

Nurturing a large-brained baby imposes enormous energy costs on the mother because of the burden of lactation, which is far more costly than gestation. In small mammals lactation can triple the mother's food requirements. The nutritional constituents of breast milk are probably optimized for brain growth in particular species. In a carefully controlled study of children tested at age eight, those who had been bottle-fed human milk as babies had an average IQ 10 points higher than did the children who had been fed formula.

The myelinating pathways in a 7-week-old human infant, from the work of Paul Flechsig. This is a horizontal section through the forebrain and cerebellum; myelin is stained blue. Note that the myelinated pathways are already well developed in the cerebellum and the central parts of the brain at this stage, but there is relatively little myelin in the white matter associated with the neocortex. However, there is a U-shaped pathway (arrow) of myelinating fibers leading from the lateral geniculate nucleus of the thalamus to the primary visual cortex. Bands of fibers also lead to the primary somatosensory and motor cortical areas. The fiber connections of the higher cortical areas myelinate much later in development.

Not only are the energetic costs high, but development is slow in big-brained babies. George Sacher proposed that the brain serves as a pacemaker for the growth of embryos. In primate species, relative brain mass scales with the time after birth required to reach maturity, implying that the development of larger brains requires more time.

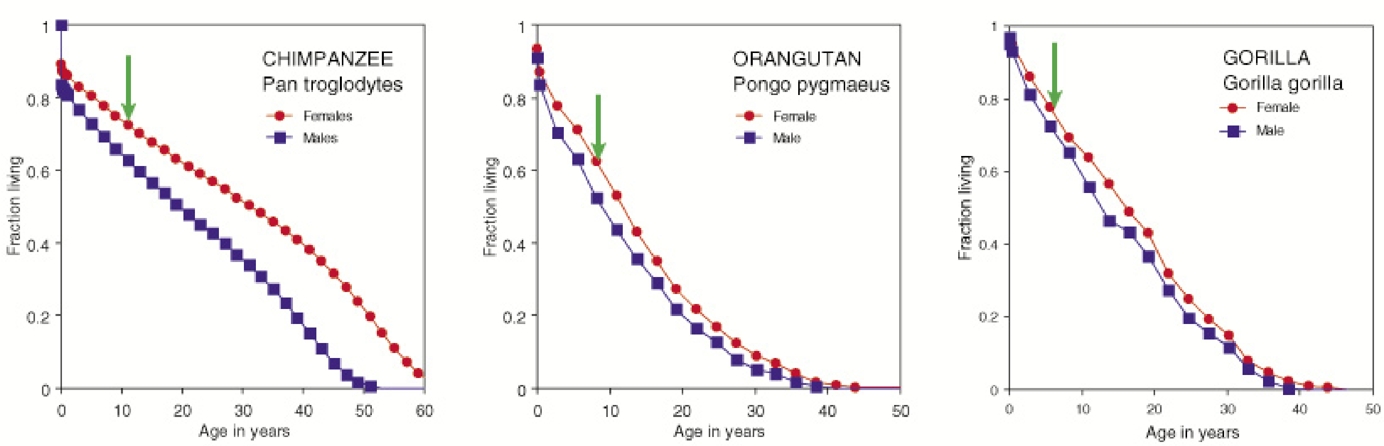
The additional time is needed for the postnatal growth of the brain, which in humans reaches its full adult size only by about the time of puberty. This postnatal growth includes the formation of myelin insulation around axons, which proceeds at different rates in different parts of the brain. Paul Flechsig showed that the axons of subcortical structures acquire their myelin insulation before the cortex, and within the cortex the primary sensory areas are myelinated long before the higher cortical areas in the temporal, parietal, and frontal lobes.

The rate of synapse formation also varies among cortical areas. Peter Huttenlocher found that synapto-genesis is much slower in the frontal cortex than in primary visual cortex. Time is also required for the formation of experience-dependent connections essential for adult functioning. For example, as discussed in Chapter 6, the capacity to judge the size and distance of objects develops very slowly and is still quite immature in eight-year-old children. The gradual refinement of this capacity probably depends on countless interactions between the child and his or her spatial environment, which in turn influences synaptic changes in the visual cortex that continue quite late in childhood. Because the brain is unique among the organs of the body in requiring a great deal of feedback from experience to develop to its full capacities, brain maturation may serve as a rate-limiting factor that governs the maturation of the entire body. As Steven Quartz and Terrence Sejnowski have suggested, the animal's experience in interacting with its environment directs the growth of dendrites and the formation of synaptic connections. They propose that learning is a process that occurs in successive stages, each building on the earlier ones. Larger brains require a longer time to develop because more stages are involved.

Thus the rearing of large-brained babies requires parental support for commensurately long periods. Moreover, large-brained offspring are mostly single births and the interbirth intervals are long, which probably reflect the large costs of rearing these offspring. The parents must live long enough past their sexual maturity to sustain the serial production and maintenance of a sufficient number of offspring to replace themselves while allowing for the early death or infertility of their children. Therefore, I hypothesized that in large-brained species that have single births, the sex that bears the greater burden in the nurturing of offspring will tend to survive longer. If the caretaking parent dies, the offspring will probably die as well, but if the noncaretaking parent dies, this event will have little impact on the offspring's chances of survival. The death of a noncaretaking parent might even enhance the survival of its offspring by removing a competitor for scarce food and resources. Thus genes enhancing the survival of the caretaking parent will be favored by natural selection, since they will be more likely to be transmitted to the next generation than genes that might enhance the survival of the noncaretaking parent. Male primates are incapable of gestating infants and lactating; but in several species, fathers carry their offspring for long periods, and the young may stay close to the father even after they move independently. According to the caretaking theory, females should live longer than males in the species where the mother does most or all of the care of offspring; there should be no difference in survival between the sexes in species in which both parents participate about equally in infant care, and in those few species where the father does a greater amount of care than the mother, males should live longer. Roshan Kumar, Aaron Rosin, Andrea Hasenstaub, and I tested this hypothesis by constructing mortality tables similar to those used by the life insurance industry for male and female anthropoids (monkeys, apes, and humans) and comparing these data with the sexual division of care for offspring.

The great apes are our closest relatives. Chimpanzees, orangutans, and gorillas nearly always give birth to a single offspring, and the interval between births ranges from four to eight years. Female chimpanzees, orangutans, and gorillas have a large survival advantage in data obtained from captive populations.

For example, in captivity the average female chimpanzee lives 42 percent longer than the average male. In the case of chimpanzees there also are data available from populations living in nature. In a 22-year study of a population of 228 chimpanzees living in the Mahale Mountains near

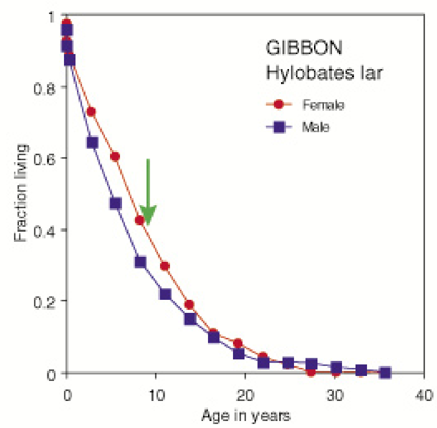


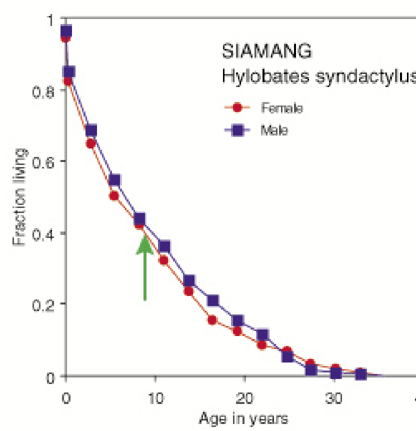
Differential survival between male and female apes. The chimpanzee data are from the work of Bennett Dyke and his colleagues; the orangutan and gorilla data were compiled from zoo records by Roshan Kumar, Aaron Rosin, Andrea Hasenstaub, and the author. (All the data in this chapter were published in the *Proceedings of the National Academy of Science*, Vol. 95, pages 6866-69, June 1998.) The arrow indicates the average age at which females give birth to their first offspring. The graphs show that at every age there are fewer surviving males than females.

A chimpanzee family studied by Jane Goodall at Gombe. The mother, Flo, was about 40 years old when this photograph was taken. Her infant, Flint, snuggles securely in her arms. Flo's adult daughter, Fifi, looks on, while the adolescent Figan grooms his mother. When Flo died a few years later, Flint, then 8 years old, died shortly thereafter, apparently unable to survive without her support. Maternal death is an important cause of death in young chimpanzees; maternal survival may even enhance the success of adult offspring. In her study at Gombe, Goodall noted that Flo's forceful personality contributed to the high status of her adult offspring. Male chimpanzees rarely care for their offspring. These factors would lead to natural selection favoring genes that would enhance female survival.

the shores of Lake Tanganyika, Toshisada Nishida and his colleagues found an equivalent number of male and female births but three times as many females as males in the adult population. This difference was not due to differential patterns of migration, and thus their observations indicate a strong female survival advantage for chimpanzees living in the wild. Chimpanzee mothers generally provide nearly all the care for their offspring, and females possess a very strong survival advantage. Although male care of infants is rare in chimpanzees, Pascal Gagneux and his colleagues have observed instances in which males have adopted orphaned infants and cared for them. Their observations indicate that the potential for male care is present in chimpanzees though rarely expressed. Orangutan mothers provide all the care for their offspring, which have very little contact with the solitary adult males. Gorilla mothers provide most of the care for their offspring, but the fathers protect and play with them. The female survival advantage in gorillas, while significant, is not so large as in chimpanzees or orangutans.

The lesser apes are our next closest relatives. Gibbons and siamangs live in pairs and have a single baby about once every three years. They maintain their pair bonds and defend their territories through spectacular vocalizations similar to the pair-bonding songs of birds. Gibbon mothers provide nearly all the care for their offspring, but David Chivers found that siamang males play a much larger parental role than do gibbon males. Siamang mothers carry their infants for the first year, but during the second year the male carries the growing infant. Siamang males are unique among apes in carrying their infants and in the closeness of their bonding with their offspring. Gibbon females have a survival advantage over males, but the situation is reversed in siamangs, where the males have a small advantage. Gibbon females on average live about 20 percent longer





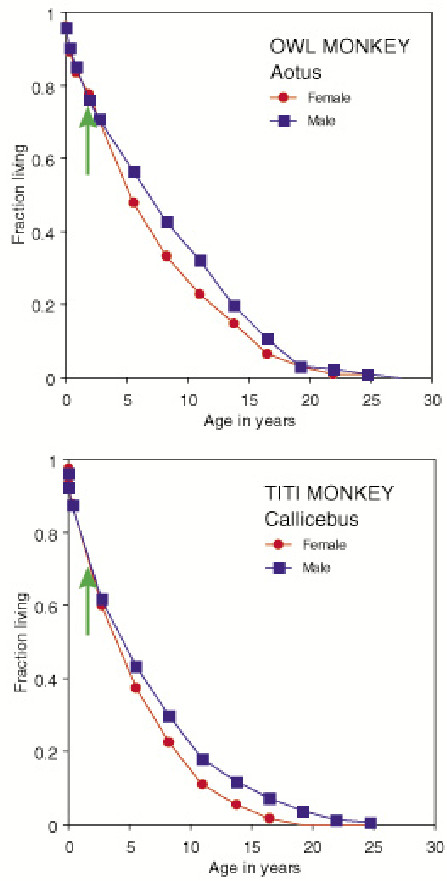
Differential survival patterns in gibbons and siamangs, closely related species living in the same habitat. Note that the female gibbons outlive males, but that male siamangs slightly outlive females. Siamang fathers are the only apes that carry their offspring on a regular basis. The data were compiled from zoo records by Roshan Kumar, Aaron Rosin, Andrea Hasenstaub, and the author.

than males, but siamang males live 9 percent *longer* than females. Siamang fathers are the only male apes that carry their infants and the only apes in which males outlive females.

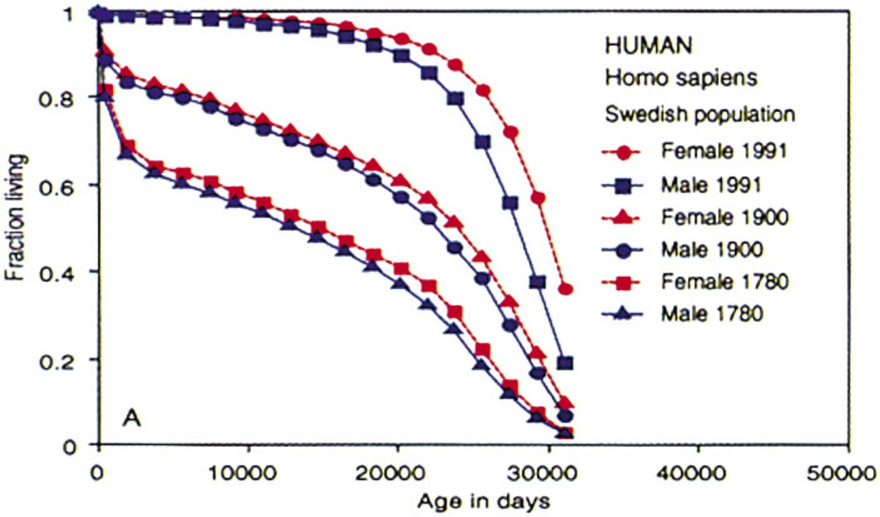
In Old World monkeys, females do most of the infant care, and several studies from natural populations show a female survival advantage. In New World monkeys, we found a significant survival advantage in captive spider monkeys, and John Robinson found a female survival advantage in the natural population of capuchin monkeys observed in Venezuela. In both spider and capuchin monkeys, mothers do virtually all the infant care. However the situation is dramatically reversed in two other New World primates, the owl monkeys and titi monkeys. These monkeys live in pairs like gibbons and siamangs, and also maintain their pair bonds and defend their territory through vocalizations. The fathers carry their infants from shortly after birth except for brief nursing periods on the mother and occasional rides on older siblings. I have observed in my colony of owl monkeys that if the father dies, the mother will not carry the infant, and thus the survival of the infant depends on the father. In both owl and titi monkeys, males and females die at the same rate until maturity, but after maturity the males have a survival advantage over females. Thus the timing of the male survival advantage corresponds to the period in their lives when they carry their offspring.

It is well known that women tend to live longer than men. It is often assumed that this is a modern phenomenon resulting from the greatly reduced risk of death in childbirth and other improvements in women's health practices. However, the female survival advantage is present in the oldest systematic records from a human population, which were collected in Sweden beginning in 1780, long before modern health practices were instituted. The female advantage is present at every age and for every Swedish census since 1780. In the Swedish population women live 5 to 8 percent longer than men. Similar female advantages were recorded in the earliest data from England and France in the 19th century and a female advantage has been present in most nations throughout the world in the 20th century. A female survival advantage has also been found for adults in the Aché, a well-studied hunter-gatherer population living in the forests of eastern Paraguay. These data strongly suggest that the survival advantage in human females has deep biological roots. However, it is smaller in relative terms than in gorillas, gibbons, orangutans, spider monkeys, and chimpanzees.

In most species there is a female advantage throughout life, but in all the anthropoids in which there are single births and the males carry their offspring, there is either no difference in survival between the sexes or there is a definite male survival advantage. These results run coun-



The adult male survival advantage in owl monkeys and titi monkeys, species in which the fathers carry their infants from shortly after their birth. The data were compiled from zoo records by Roshan Kumar, Aaron Rosin, Andrea Hasenstaub, and the author.



The human female survival advantage in the Swedish population in 1780, 1900, and 1991, plotted from data in the demographic study by Nathan Keyfitz and Wilhelm Fleiger and from the United Nations demographic database. (30,000 days is about 80 years.)

ter to the reasonable expectation that lugging a heavy squirming infant through the trees would increase the risk of falling or being eaten by predators. The magnitude of the difference in survival corresponds to the difference in the amount of care given to the offspring by each sex. Thus in the great apes where the mothers do virtually all the care, there is a large female advantage. Human males contribute significantly, but human females are the primary caregivers, and in humans there is a proportionally smaller, but still sizable, female advantage. In Goeldi's monkeys both sexes provide about the same amount of care and there is no difference in survival. In siamangs, both parents participate with the father taking over in the later stages of infant development, and siamang males have a small advantage. In owl monkeys and titi monkeys, males carry the babies most of the time from shortly after birth, and thus infant survival depends substantially on the male; in these monkeys there is a large male advantage.

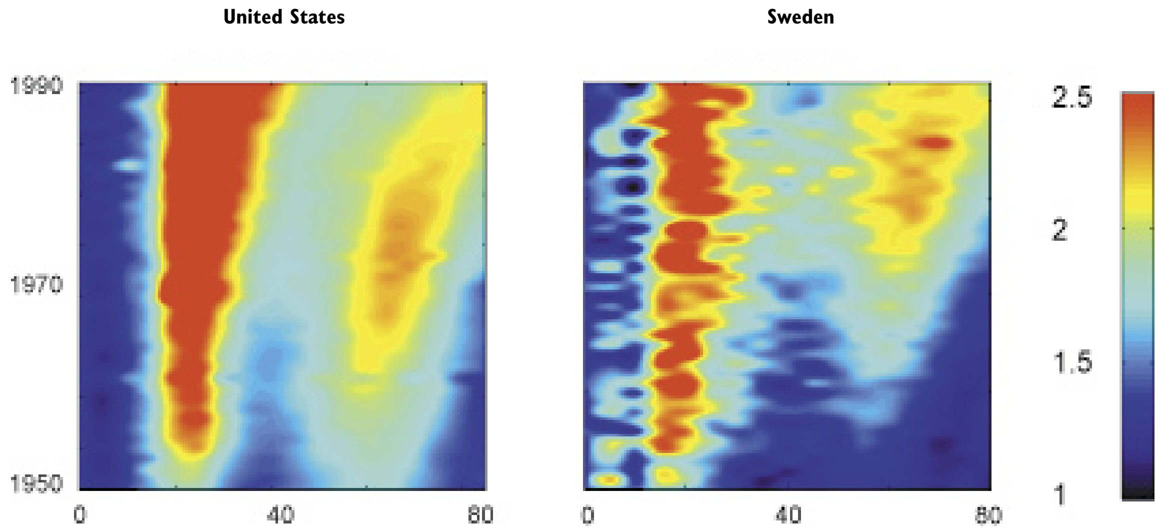
Similar data have come from a nonprimate, big-brained species. Killer whales have very large brains. Their calves are born singly with an interbirth interval of 5 years, and they remain in close association with the mother throughout their lives. Males appear to have little direct role in parenting. A long-term demographic study of a natural population of killer whales in Puget Sound found that female life expectancy is more than 20 years longer than in males. The average female lives about 75 percent longer than the average male.

The differential mortality between caretakers and noncaretakers may be in part because the former are risk-averse and the latter tend to be risk-seeking. Caretakers tend to avoid risk because they risk not only themselves but also their offspring. This may be a conscious decision or the result of genetically determined instincts that would be favored by natural selection because they would lead to more surviving offspring. A second major factor may be a differential vulnerability to the damaging effects of stress. Natural selection would also favor the evolution of genes in caretakers that protect them against the damage induced by stress. The ratio between the rates at which males and females die varies during the course of life. In humans, the female survival advantage begins shortly after conception and continues throughout life with the largest advantage, in terms of the size of the ratio between male and female age-specific death rates, occurring at around age 25. In many countries, including the United States, Japan, and Sweden, there is evidence for a second smaller peak in the male to female death ratios later in life. Although smaller, these two peaks were present in the Swedish population in 1780. They also are present at about the same stages in the life cycle in some nonhuman primates such as gorillas and gibbons. The peak in early adulthood corresponds approximately to the period of greatest responsibility for childcare in women. The second peak appears to be related to a higher risk of heart disease and

PRIMATE	FEMALE/MALE SURVIVAL RATIO	MALE CARE
chimpanzee	1.418	rare
spider monkey	1.272	rare
orangutan	1.203	none
gibbon	1.199	pair-living, but little direct role
gorilla	1.125	protects, plays with offspring
human (Sweden, 1780–1991)	1.052–1.082	supports economically, some care
Goeldi's monkey	0.974	both parents carry infant
siamang	0.915	carries infant in second year
owl monkey	0.869	carries infant from birth
titi monkey	0.828	carries infant from birth

increasing male survival

increasing male care



Excess male deaths as a function of age from 1950 to 1990 in the United States (left) and Sweden (right). Similar patterns are present in the data for Japan, Canada, and many other countries with well-developed health-care systems. The red pattern in the young-adult years indicates that more than twice as many men as women die at this stage of life. The pattern is smoother for the United States because of the much larger population size. The earlier Swedish data, going back to 1780, consistently show similar peaks in early and late adulthood, although the peaks are not as large as for modern data. This consistency suggests that biological factors are partially responsible. The second peak occurs after child rearing but reflects differential responses to stress earlier in life. The analysis was done by Andrea Hasenstaub and the author.

other afflictions in men. I believe that these two peaks represent two underlying mechanisms, one of which is mainly acting on the young and the other on the old. The first peak is largely due to differences between males and females in risk-taking behavior which results in higher rates resulting from accidents and violence in younger males. The second peak may result from increased male vulnerability to pathological conditions that develop without overt symptoms over a long period of time, such as high blood pressure and clogged arteries, which may be related to the cumulative effects of stress. By contrast, in owl monkeys and titi monkeys, the male survival advantage emerges shortly after maturity at the time when fathers begin to care for their offspring. This hypothesis would predict that their enhanced survival may be due to reduced risk-taking and vulnerability to stress.

In the contemporary United States population, women have lower risks than men of dying from the 13 most prevalent causes of death, indicating that the female survival advantage has an extremely broad base. A hormonal basis for this effect is evidenced by the observation by Francine Grodstein and her collaborators that post-menopausal women who currently receive estrogen replacement have a lower risk of death as compared to post-menopausal women who have never received supplemental estrogen. Estrogen enhances the actions of serotonin and thus may be responsible for reducing risk-taking behavior. Melanie Pecins-Thompson and her colleagues found in macaque monkeys that estrogen inhibits the expression of the gene that makes the transporter protein responsible for serotonin reuptake. Thus estrogen acts like drugs such as Prozac that inhibit the removal of serotonin at synapses and consequently increase the synaptic concentration of serotonin. Because of estrogen's effects on the serotonergic system it has been called nature's psychoprotectant.

Another possible basis for differential survival may be related to the stress hormones, the corticosteroids. The clearest evidence for this comes from a study by Robert Sapolsky who encountered and studied a group of vervets that had previously been subjected to chronic stress by overcrowded living conditions. Vervets are a type of monkey in which females do most of the care for offspring. Sapolsky found a substantial loss of neurons in a part of the cerebral cortex, the hippocampus, in males but not in females. The hippocampal neurons are richly supplied with receptors for the corticosteroid hormones, which are produced by the adrenal cortex to mobilize the body's defenses when subjected to stress. One role of the hippocampus is to regulate the pituitary's secretion of adrenocorticotropic hormone, which in turns signals the adrenal cortex to secrete the corticosteroid hormones into the bloodstream. The secretion of the corticosteroid hormones is the body's way of responding to severe, life-threatening emergencies, but the chronic secretion of these hormones can be very damaging. The hippocampal neurons are particularly vulnerable because they have many receptors for these hormones. Corticosteroids also suppress serotonin receptors in hippocampal neurons, which may diminish their stability and further increase their vulnerability. Because the serotonin reuptake mechanism is inhibited by estrogen, males may be more vulnerable than females in some species. The loss of the hippocampal neurons due to hyperexcitation means that the brakes on the secretion of the stress hormones are burned out, leading to escalating levels of damage and ultimately to death. Sapolsky's results indicate that male vervets are much more vulnerable to the destruction of the brain's system for regulating the stress response than are females. This may be the mechanism for male vulnerability in other species where females are the primary caregivers, and this theory predicts that the opposite would be true for those species where males are the primary caregivers.

What is the biological role for the higher level of risk-taking in males in some species? In *The Descent of Man* in a section entitled the "Law of Battle," Darwin linked male aggression to competition among males for females. This has led to the widely accepted idea that aggressive males become socially dominant and because of their dominance enjoy greater sexual access to females and therefore greater reproductive success. However, there is evidence to suggest that other factors may be involved in male risk-taking.

Let us begin by examining the first part of this relationship: does aggression lead to social dominance? In Chapter 2, I discussed the changes in social status in male vervet monkeys induced by experimentally manipulating serotonin levels. In this study, male status was invariably preceded by changes in affiliative behaviors with females in the social group such as grooming interactions. Increased affiliative behavior led to increased female support in dominance interactions with other males, which in turn led to rising status. Decreased affiliative behavior led to decreased female support, which in turn led to declining status. This investigation and many observational studies indicate that high status in primate groups is much more dependent on social skills and coalition building than on aggression.

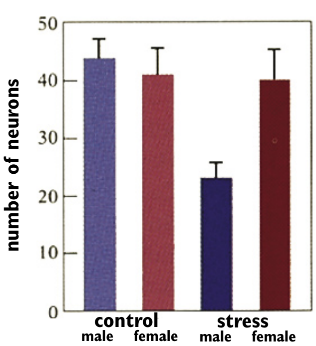
Now let us turn to the second part of the aggression-dominance-reproductive success theory: does the possession of high rank lead to reproductive success? Pascal Gagneux and his colleagues have conducted a long term study of the social structure of chimpanzees living in the Tai forest in the Ivory Coast. In order to measure male lineages, they extracted DNA from cells attached to hair samples for all the members of this group, and thus they were able to determine which chimpanzees had fathered which offspring. They found two surprising results. First, on the basis of the DNA patterns, they were able to rule out all the males in the group as possible fathers of half of the youngsters. Thus the females were covertly mating with males outside their social group; the status of those males within their own groups is unknown. Second, for the youngsters that were fathered by males within the social group, there was only a weak relationship between dominance and reproductive success. Brutus, the top ranking male for 10 years, and Macho, who was the alpha male for 1.5 years, sired no offspring during their periods of dominance, although each sired one after they declined in status. These results highlight the importance of actually determining male parentage through DNA studies, because it is only through such studies that male reproductive success can be determined, which is crucial for measuring the influences of different behaviors on the evolutionary process. Until there is a substantial body of genetically established data for a number of carefully observed primate species, the role of male dominance in reproductive success will remain undetermined. However, observations by Sapolsky in baboons does suggest that high male status does confer a different advantage. He found that the levels of cortisol, a corticosteroid hormone, are inversely related to social status. Therefore, high status males are less at risk to adverse consequences of this hormone. Important advantages of high status in males are reduced vulnerability to the deleterious effects of stress and better access to food resources.

There is strong evidence that high status does confer reproductive success in female chimpanzees, and it is clear that social competence plays an important role in determining the female dominance hierarchy. Goodall and her collaborators found that the offspring of high-status females are more likely to survive and that they mature at an earlier age. They also found evidence that the high-status females live longer than the low-status females. These effects may be the consequence of less stress and better access to food and other resources in the high-status females.

Social competence probably counts for more

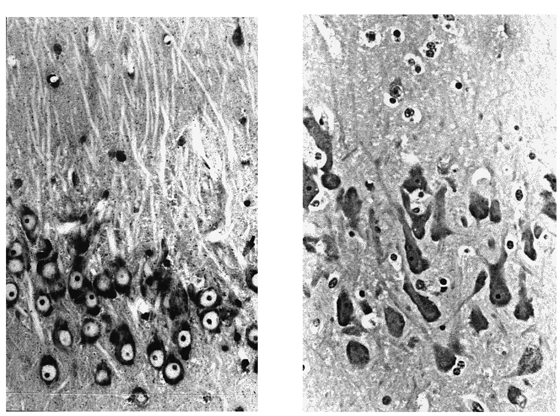
The graph below shows the number of neurons in samples of hippocampal area CA4 in unstressed male and female controls and in stressed males and females. Robert Sapolsky and his colleagues also found similar neuronal losses in the other CA fields of the hippocampus of stressed males. In these monkeys, the stress resulted when they were captured by the Kenyan government at the request of farmers and housed under crowded conditions.

The photomicrographs at right illustrate neuron loss in the hippocampus of stressed male monkeys. The left one is from the hippocampus of a control monkey; the right photomicrograph, from the same place in the hippocampus of a stressed male, shows a loss of neurons and dendritic atrophy in the remaining neurons.

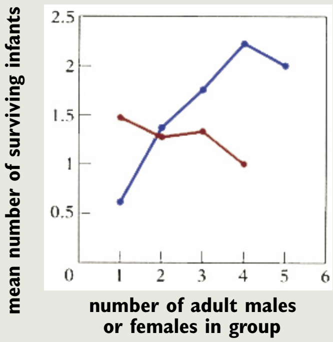


hippocampal area CA4

normal **stressed**



Cooperative Male Care in Marmosets and Tamarins



The graph shows that infant survival in tamarins increases as a function of the number of caretaking males in the extended family groups; having more females results in a slight reduction in the number of surviving infants. (Blue represents surviving infants based on the number of adult males; red is surviving infants based on the number of adult females.) This graph, from the work of Paul Garber, is based on observations of 47 extended tamarin families living in nature.

Marmosets and tamarins, which are small New World monkeys, have many more offspring than other monkeys and have an unusual solution to providing care for their infants. Unlike other monkeys which have single births, marmosets and tamarins usually give birth to twins or sometimes triplets. Shortly after birth, females become sexually receptive and can conceive again. Thus marmosets and tamarin females can produce up to six babies per year. These primates have developed a different way to nurture their multiple, slowly developing, large-brained infants. Marmosets and tamarins live in extended families in which everyone and especially the males participate in infant care. Marc Van Roosmalen has even observed a male assisting in the birth process by cutting the umbilical cords and eating the afterbirth. Paul Garber found that the presence of up to 4 males in the family enhances the survival of the infants.

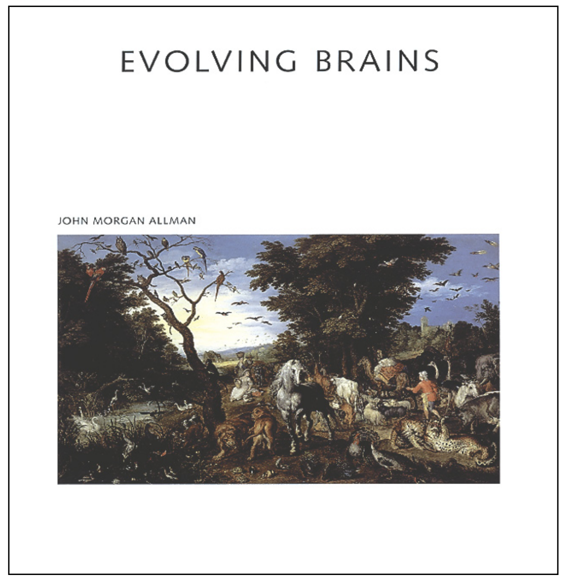
The males cooperate in caring for the infants in their group, and there is little aggression among males within the family. The males are very strongly attracted to the infants; they carry them whether or not they are actually their biological offspring, and they share food with them. I have even observed a male kidnapping the offspring of another family so as to carry it. Because of the cooperative care, offspring are less dependent on the survival of a particular caretaker. In our studies thus far we have found little difference in the survival of male and female marmosets and tamarins.

An extended marmoset family enjoys a quiet moment.

than aggression in achieving either high status or reproductive success in primates. Why then are the noncaretaking males aggressive and prone to risk-taking? Why would natural selection favor the evolution of behaviors that increase the risk of dying? I think the answer is that risk-takers constantly probe their world, seeking out new opportunities and detecting hazards in a constantly changing environment. Through their probing they generate new information that they communicate to close kin, thus enhancing their kin's survival and the propagation of their shared genes. Specific vocalizations for types of food and types of predators serve this communicative function. The risk-takers may also be crucial to colonizing new habitats during changing environmental conditions.

Both the evolution of large brains and the evolution of temperature homeostasis, as discussed in Chapter 5, required new developments in parenting behavior. Warm-blooded infants are dependent and cannot grow without parents to provide warmth and nutrition. Increasing brain size slows down postnatal development as measured by the ages at which different teeth erupt and by the age of sexual maturation. Large-brained, slowly developing, dependent offspring require long-surviving parents to reach maturity. A measure of this parental dependency effect is the differential survival of caretakers versus noncaretakers. In primates, the caretaker effect has a large influence on the patterns of survival with as much as a 42 percent female advantage when males have little role in nurturing offspring versus as much as a 20 percent male advantage when males carry offspring from soon after birth. The male caretaking effect is not as large because only females provide nutrition for their slowly developing offspring through lactation. The mechanisms responsible for the survival differences between caretakers and noncaretakers may ultimately be related to neurochemical differences that favor risk-aversive behavior in caretakers and risk-seeking behavior in noncaretakers, as well as greater vulnerability to the damaging effects of stress in noncaretakers. □

John Allman has been working with owl monkeys since his graduate student days spent mapping the owl monkey's visual cortex. Much of his work since then has concerned how the brain is organized and how it processes and interprets visual information. In 1990 he received the Golden Brain Award from the Minerva Foundation for this body of work. Although known as a neurobiologist, all of Allman's degrees are in anthropology: BA, University of Virginia, 1965; and MA (1968) and PhD (1970), University of Chicago. He has been a member of the Caltech faculty since 1974 and professor of biology since 1984; he was named the Hixon Professor of Psychobiology in 1989. In the book from which this chapter is excerpted, he combines his neurobiological research with a life-long interest in evolution—and in behavior. And the owl monkey, whose relatively simple neocortex made it a good neurophysiological model, turns out to have interesting parenting behavior as well, as the father and child pictured on the cover illustrate.



John Allman's Evolving Brains *(A Scientific American Library volume) is available in bookstores, or it can be ordered directly from the publisher, W. H. Freeman and Company.*

Imagine that piano keys stand for the electromagnetic spectrum. We have one octave if we confine ourselves to the visual. You can imagine how dull Mozart would be if he had to stay in one octave.

Other Octaves

Oral History — Robert B. Leighton

Bob Leighton spent more than half a century at Caltech before his death in 1997. His own story of his life was captured in a 1986–87 series of interviews by Heidi Aspaturian (now editor of Caltech News *and* On Campus*) for the Caltech Archives Oral History Project.*

Born in Detroit in 1919, Leighton came to Southern California as a young boy and later attended the John H. Francis Polytechnic High School in downtown Los Angeles, of which the late Caltech Nobel laureate Carl Anderson was also a graduate. He attended Los Angeles City College for two years, and when he transferred to Caltech as a junior in 1939, he realized that he "was 'home' intellectually." He never left, although he recounts in his oral history that after earning his PhD he was briefly tempted by a job at Rice University; he checked out a book on Texas from the public library (another profound influence on his education) and decided that it was too humid in Houston and that he would prefer to stay in Southern California.

If his geographical life was not varied, his scientific life decidedly was; he describes it in his oral history as having been "divided into a number of reincarnations." The first was as a theoretical physicist: he wrote his 1947 PhD thesis under Paul Epstein, professor of theoretical physics, on the vibration of atoms in a cubic crystal, a tough mathematical problem that Einstein and Bohr had attacked. Leighton ended up building a model of it in the machine shop. His paper was published in Reviews of Modern Physics*, but, he says, "What I learned from that experience was that I was not a theoretical physicist." (He also passed the shop course.)*

In his early years at Caltech, Leighton designed this cosmic ray detector to be flown on a balloon.

In his second incarnation, as an experimental physicist, he worked with Carl Anderson (with whom he had built rocket launchers for the Navy during the war) on cosmic rays, plotting the decay of muons and tracking what are now called strange particles (then they were called hooks and forks). When the competition of bigger and more powerful accelerators appeared to make the necessity of pulling the particles out of the atmosphere obsolete, Leighton found something else to excite his interest.

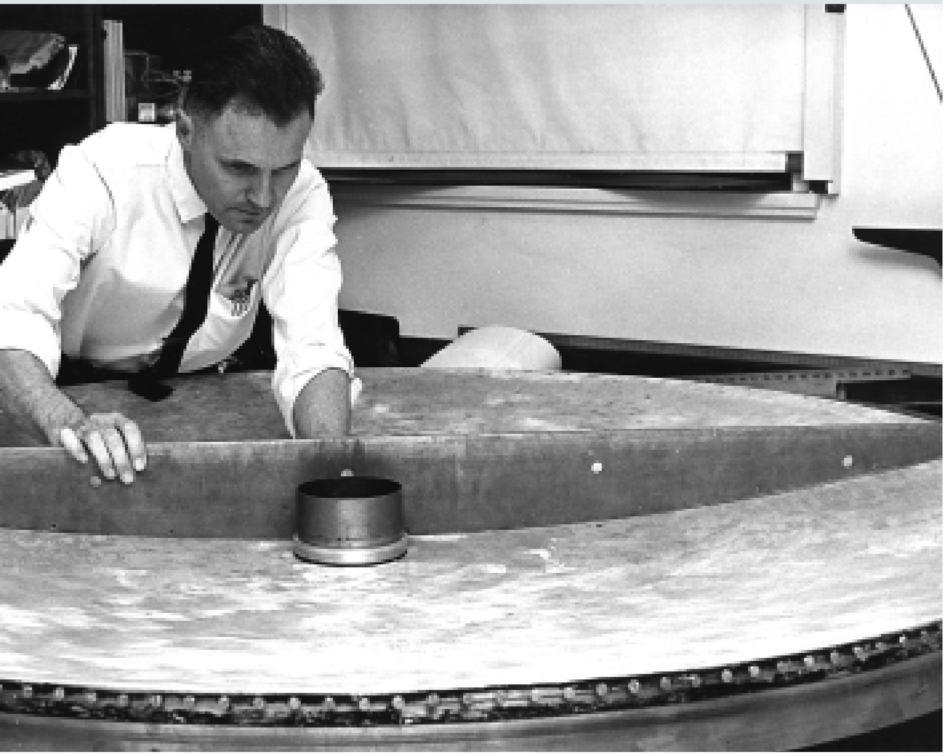
Although he doesn't say much about it in his oral history, Leighton was renowned as a teacher. He wrote an influential and best-selling textbook in 1959, Principles of Modern Physics*, and edited* The Feynman Lectures on Physics*, the famous three red books, into printed form. He was chairman of the Division of Physics, Mathematics and Astronomy from 1970 to 1975 and was named the Valentine Professor of Physics in 1984.*

Yet, it is as an astronomer and inventor of telescopes that Leighton is perhaps best known. He was "present at the creation" of all the major directions in astronomy that took off in the latter half of the 20th century—solar, infrared, and millimeter- and submillimeter-wave astronomy, not to mention the exploration of our own planetary system. So it is this segment of Leighton's Oral History, this final reincarnation, that we publish here.

Solar Astronomy

Heidi Aspaturian: I'd like to ask you about your research in solar astronomy, which seems to have started in the mid-'50s while you were still involved in the cosmic-ray research.

Robert Leighton: That's right. You'll remember that in connection with the cosmic-ray research, we had some apparatus on top of Mount Wilson. I had several friends from the war project who were astronomers working there—Horace Babcock, Olin Wilson, and others. Olin Wilson was in charge of the 60-inch telescope and knew I was interested in astronomy and photographing the sun and planets. Every once in a while, when he could find nobody who wanted to use the telescope, he would call me and say, "Why don't you



In the early '60s, Leighton sculpts the surface of the first infrared telescope, which is now in the Smithsonian Museum. At 62 inches, it was once the second largest telescope on Mount Wilson.

come use it, Bob?" So I'd say okay, even though it turned out that the times when nobody wanted the telescope were days like Thanksgiving or Christmas Eve.

I got interested at some point in the possibility of making a guider for the 60-inch that would hold the planetary images steady so you could take good pictures of the planets. These things often started as just bench-top, home-shop, or physics-shop activities, more or less as sidelines to research and teaching, but now and then something more interesting would show up. Anyway, very much on a shoestring basis, I built this guider. It automatically "shook" so as to keep an image of a planet centered, because it turned out that I needed to use long exposures, usually from a second to half a minute or so. I was taking time-lapse movies in order to see the rotation of Jupiter. Since Jupiter rotates so fast, in one evening you can virtually photograph an entire cycle. About 10 years later, this planetary work paid off with respect to the Mariner missions, because I was probably the world's expert on stabilizing images of planets. At the time, I didn't learn that much about the planets; I guess I was mainly interested in the technical aspects of getting good planetary images.

I did have in mind—if I got good pictures of Jupiter—to use them stereoscopically and see if it was possible to detect cloud layers on the planet. In view of later developments, it was not a very promising thing to do. But some of the things that showed up, say, on my images of Mars, were things that other pictures had not shown. That was also a challenge, since Mars can only get to be 20 arc seconds in size, even in the closest approaches. But with all the fantasies that people have had about Mars and the supposed nature of the surface—with canals and civilizations and things like that—and the seasonal wave of darkening, which was an accepted effect at the time—I was interested in these things.

I did feel a little uncomfortable about some of these things, particularly the planet guider, because planetary astronomy for practical purposes was an arcane art. Spectroscopists could do good things with the planets, but the people who just gazed at the planets and then wrote up what they saw or thought they saw were fairly widely disbelieved. And yet there was some substance to what they said, mainly regarding how big the polar cap was this year—you could make a measurement of that. Anyway, the fact that I was trying to get more accurate pictures of the planets was, in a way, a little tainted, I thought. But it was fun to do because I had the technical problem of how to hold the image steady, because that was the thing that you needed to make progress.

HA: Did any of your colleagues indicate to you obliquely that they thought you were wasting your time?

RL: Not at all. As a matter of fact, Bob Bacher, who was then the physics, mathematics and astronomy division chairman, met me in the hall one day and said, "Say, Leighton, I understand that you're using the Mount Wilson telescope to take pictures of Jupiter and other planets." I sort of shrank down in my collar a little bit and said, "Yes, that's right." He could have said, "Well, look, Leighton, you're supposed to be measuring the decay spectrum of so-and-so; why do I find you going up to Mount Wilson using the telescope?" Instead he said, "I want you to know I think that's a great idea. I think that a lot of people keep pursuing the same thing, and pretty soon it is no longer interesting. And others can't stay more than three weeks on the same path without diddling off somewhere else." I didn't know whether he was talking about me at that point or not. But he thought that originality and a little freedom of motion, of operation, was a great idea. And since he was the division chairman, I took that as a pat on the back. If he had said, "Well, look, you're in physics, and that's astronomy," I think I would never have kept on studying the sun. As it was, he said, "I think you refresh yourself by doing things like that. I like to hear about people extending themselves in an unfamiliar field." So I walked away a mile high.

It was great, because I like to have about four or five interesting problems to work on at any given time, on which I feel that I can make some progress, and yet not one of them so urgent that it has to be done at all costs at the expense of everything. I find it refreshing to be able to turn from one thing to something else and not have to feel that I'm giving up.

That work at Mount Wilson led eventually to my working on solar astronomy and also to my work on the Mariner missions in the 1960s. Let's take the solar astronomy first.

At that time, the 60-foot tower telescope at Mount Wilson was used only for a few minutes daily by an observer who was hired to take a daily picture of the total disk of the sun to show the sunspots, and to take a smaller image of the sun in H alpha and calcium K-line spectroheliograms.

About that same time, I had some contact with Fritz Zwicky. Fritz was hard to live with, a very interesting man. He was all hot on differential photography. He was taking pictures of galaxies in different-colored light, using the principle of cancellation. He would take a negative transparency of one of the pictures in one color and a positive transparency at the same scale and contrast as the other picture in another color, and then superimpose them. If they were the same picture, they would cancel out to a neutral gray. But if there was a preponderance of red light coming from certain things in the galaxy, and a preponderance of blue light coming from elsewhere, you'd get the blue and the red showing up as light and dark on the composite image. Fritz gave a seminar on this subject; it was a very contentious seminar as usual. If one of his talks didn't start out contentious, he'd make it that way by making bad remarks about all his competitors. "Well, I told those guys," was one of his favorite phrases.

During this particular talk, he showed a picture he had taken of a great big heap of tin cans that had been dumped in some remote canyon. Then he had thrown on one more can, and taken another picture within a few seconds—it looked to us the same as the first picture. But then he showed the cancellation picture, taking the negative of one and the positive of the other, carefully superimposed. The third picture was all gray except for the final tin can that he had thrown on the pile, and it really stood out. So his approach was a way to find out things—to bring out some essential thing that you may have a qualitative inkling about, but making it quantitative.

And the funny thing is, almost all the procedures that we used to do the job were absolutely available to George Ellery Hale perhaps 20 or 30 years earlier!

I was thinking at that time about whether I could study the magnetic field on the sun. It had been found, just a few years after the war, that during solar flares—eruptions on the sun—neutrons are emitted that come to Earth. Cosmic-ray particles are also emitted. This was evidence that some high-energy particles were being generated somehow—that nuclear reactions are going on in connection with the eruptions seen on spectroheliograms. It seemed to me that there might be an opportunity to study the relationship between the solar eruptions—that is, to look at what would make such an energetic eruption on the sun that it would emit mega-electron-volt-type particles. The answer evidently had to do with the decay of the magnetic fields embedded in rapidly changing sunspot groups. It was a naturally occurring accelerator; they called it a synchrotron or solartron. I thought it would be interesting to use the 60-foot Mount Wilson tower to study this. I was interested in the question of whether you could take enough high-resolution pictures of sunspot groups and their surroundings to be able to study the changes in the magnetic field pattern and the geometry of the sunspots during solar flares, using Zwicky's techniques of differential photography.

Up to that time the sun's magnetic field was studied with a magnetograph, which recorded the local magnetic fields along linear segments or "slices" going across the sun—a lattice of linear traverses. One could see fragments of weak fields here and there. But I wanted to get something with two-dimensional pictorial resolution so as to be able to study large areas in fine detail, rather than simply a series of slices across the image. I thought of doing this with the spectroheliograph—using a beam splitter to split out light of two different polarizations and treating that result à la Zwicky so as to bring out the Zeeman, and then looking at the light of a certain spectral line that happens to have a big Zeeman effect. That would, then, give an effect of looking at an image in one direction of polarization, and then an equivalent image taken at the same time but in the opposite polarization.

[*This cancellation approach, which Leighton worked on between 1957 and 1959, led to a "much better photographic resolution of the sun in terms of kilometers." The project "really took off," leading to Leighton's discovery of a five-minute oscillation in the solar atmosphere and of "supergranulation," caused by convection currents in cells of material on the sun's surface.*]

HA: What interested you, or what did you find more rewarding about this? The actual observations or the success of the instrumentation?

RL: Well, in this case, clearly the observations. But to know how to get the observations, that was just fantastic. I think that in almost any new experimental discovery there are phases. You don't just buy something off the shelf and say, "Let's run it," and then find something new that people hadn't seen before. You generally either buy something off the shelf and modify it so it can work 10 times better, or you gin up something yourself that you have the confidence will tell you something you might be interested in. We didn't

Perhaps I got off the bus too soon, perhaps very much too soon, from a certain point of view. But I wouldn't have had a lot of other experiences that I had, and I can't complain.

realize that we would find oscillations at all. We didn't know we would find the supergranulation. And the funny thing is, almost all the procedures that we used to do the job were absolutely available to George Ellery Hale perhaps 20 or 30 years earlier!

HA: Why do you suppose they had not been uncovered at that time?

RL: Interesting question. It just goes to show that the search for knowledge is consistently, almost automatically, undervalued. It's hard to get grants to do things. People will usually ask you, "What do you expect to find?" You can't tell them what you expect to find, because they automatically assume that if you have something to say about what you expect to find, it means that it's already known. On the other hand, if you say you don't know what you'll find, the assumption is that the project can't have much value because your imagination isn't good enough. So it's hard getting support.

[*Leighton's work led to Caltech's entry into the field of solar astronomy, the arrival in 1963 of Hal Zirin, now professor of astrophysics, emeritus, and the establishment of Big Bear Solar Observatory.*]

HA: Am I correct in thinking that once things had gotten beyond the stage of raw innovation, you wanted to go on to something else?

RL: Well, I wasn't afraid to. I don't like to be characterized as being a person who isn't interested in the things that his instruments will show, but only interested in the instruments themselves. But I'm afraid the fact of it is that I probably get my biggest kicks and make my best contributions on the instruments—up to a point. If I had really thought deeply about the solar things, I might have made some further significant contributions along the time-lapse lines. Perhaps I got off the bus too soon, perhaps very much too soon, from a certain point of view. But I wouldn't have had a lot of other experiences that I had, and I can't complain. But this was just the time when the linear arrays of photosensitive diodes were coming along. And the obvious thing to do was to get rid of the photographic plates up there and put a computer on the line and read out the spectral lines along the photodiodes right along the spectrograph slit. I was very late in getting into computers. As a matter of fact, George Simon, one of my graduate students, rubbed my nose in it so much that I just simply had to learn how to do FORTRAN. . . . And I've been hooked ever since. I still am not all that good at computer hardware, but that's just as well; otherwise I think I'd spend all my time doing that.

Infrared Astronomy

RL: I think it was in 1961 or '62 that Gerry Neugebauer [*now the Millikan Professor of Physics*] and I got interested in building an infrared telescope.

HA: Was Neugebauer a student here at that time?

RL: Gerry started his doctoral work with Carl Anderson, and then I think he moved over to the synchrotron to do a thesis. I knew him, but at that time not very well. Then, after he got his PhD, he went to JPL for his army service. We in the physics department were fishing to get him back down on campus. Anyway, right along in that period, he and I started to talk about making an infrared telescope. And when he came down as an assistant professor, we got serious about it. . . .

It boiled down to how we could make an instrument that would be sufficiently sensitive to be interesting and sufficiently precise to be able to locate objects in the sky—and how to make the whole thing sufficiently rapid in measuring the source to be able to cover the entire sky visible from here. Practically right away we started to think in terms of short-focus, large-diameter, optical mirrors as the way to do it. We looked very carefully at some searchlight mirrors, and they were fine for searchlights, but they were lousy for us: we could see the distortion with the naked eye. There were also a couple of groups that had been making spin-case epoxy parabolic reflectors. Gerard Kuiper's group in Arizona had made one or two pretty good spin-case mirrors, which were stated to resolve to five arc seconds or so. Kuiper had literally gold-plated the reflecting surfaces. But he didn't go much further than that.

You may be interested in some experiments I did—I didn't know I was experimenting, I was just having fun—when I was about seven or eight years old. I noticed in my mother's mop bucket, that when it was filled with clean water and had some sand grains or partially buoyant fragments of leaves, and you stirred the bucket to make the water swirl rapidly but smoothly, there's an odd thing—the sand or the leaves go round and round at the bottom of the bucket and finally get deposited as a pile of matter at the center of the bucket's bottom when the swirling dies out. It's a very striking effect. Considering that I went on into physics, I passed up an opportunity at some point in my life to explain what was then a big mystery. I believe it's called Eckmann pumping.

We built the reflecting dish along the same principles. You have a vessel with fluid in it and rotate it very smoothly in an equilibrium condition. This is where the vessel as well as the liquid is rotating so it doesn't slow down, but gradually builds up to a certain constant speed. Pretty soon the liquid is going at the same rotational speed as the vessel it's in. If the speed is just right, the upper surface of the liquid will then have precisely the shape of a parabola. But it sets, so pretty soon you can stop the vessel rotating and aluminize it (we didn't gold-plate ours), and you have a reflector. We made it in my office when we were in

Infrared astronomy was growing by leaps and bounds all through this period.
We just happened to be there first.

Bridge Lab, in a space partitioned off in the back of the office. That was the best place to work because it was on the ground floor, not upstairs where the building would vibrate. And it was in a place where nobody would tramp around or have heavy loads.

I think it's fair to say that a good fraction of the surface of that reflector was good to a few arc seconds. I was also working up drawings of a mounting for this thing. I had the mounting built in the central shop and assembled the whole thing in the cosmic-ray lab. In a matter of a few months we had a device with a photoelectric, infrared-sensitive cell at the focus. Just outside, between the Bridge library and the cosmic-ray lab, was about a 10- to 15-foot-wide space. We pulled the telescope base on a dolly out of the lab and lined it up as best we could. I'd made gear drives and other such things for it. It was kind of a nice telescope, as a matter of fact.

HA: Was your interest in this mainly the new technology? How much did it actually have to do with observations in the infrared?

RL: We were inventing the instrument in a form suitable to make a sky survey. We had automated the gear drives and the declination drives. Whether we did that before looking at something in the sky, I'm not quite sure. But by the time we took it to Mount Wilson, it had been an operable instrument down here on the campus, where we wheeled it out at night to test it and brought it back in during the day.

HA: What were you looking at?

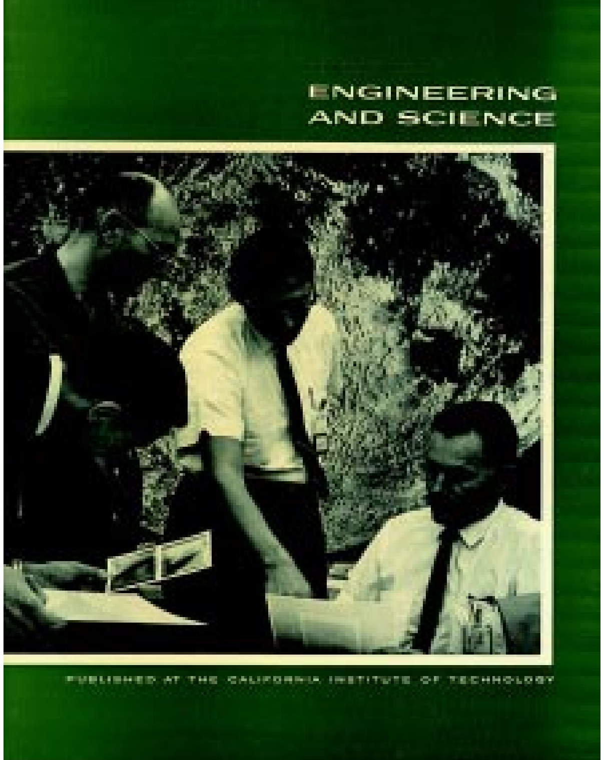
RL: Beta Pegasi was the first infrared, very bright red, cool star that we found. The fact that we had found one meant that the survey was worthwhile, because we could only improve from that point. . . .

I can tell you about one of our most interesting discoveries. As Neugebauer and I were both watching the moving chart paper on which an electronic signal was being recorded, we both noticed a very strong infrared signal that had no visual counterpart. Now, you can appreciate that if you go back and forth and back and forth, you get pretty tired of seeing these signals coming along. When you're doing a lot of other things, like reading the right ascension when the signal changes over and writing it on the chart record, you don't pay too much attention to watching the signal. Nevertheless, we both most have been more or less watching the chart as a huge triple "bump" came through one of the infrared channels. We didn't remark about it at the time, but it was pretty big. We did both notice that the red signal data coming through on an adjacent channel and delayed a few seconds in time was not very big; in fact, we didn't even notice it! So we both sensed that something was missing. Either we hadn't seen a big "bump" before the infrared one came, or, as I believe, we were going in the direction where the red signal would come after the infrared signal.

HA: So you had something that indicated high infrared intensity but very little visible intensity.

RL: Oh, yes! We knew that was a prize source. We were at that time trying to find some of these objects on the Schmidt survey—up in Cygnus somewhere. We noticed another one. And that one became known as NML Cygnus—Neugebauer, Martz, and Leighton Cygnus. And it gave rise to the term "dark brown" stars. They were so cool that they were not even red; they were brown. Altogether we found some tens of thousands of sources. This was a lot more sources than anybody thought we would ever come across, and several of these were of the type I have just described.

Infrared astronomy was growing by leaps and bounds all through this period. We just happened to be there first. There were other surveys. I think what wasn't appreciated at the time was how many sources there were in the sky that were intrinsically quite bright, but were embedded in nebulosity, possibly of their own making, which made them not part of what the astronomers were originally calling a star. It was a star under special conditions, you might say. They weren't expecting to find so many of these.



Above: Picture number 11, snapped by Mariner IV from a distance of 7,800 above Mars, was definitive evidence of craters on the planet.
Top: Leighton (lower right corner), principal investigator for the Mariner IV television experiment, studies the first pictures from Mars with other Mariner scientists. (The heavily cratered body in the background is the moon, not Mars.)

HA: Who else, in addition to Neugebauer and you, was involved in this project?

RL: Neugebauer ran the group. He's the type of person who always has students around him. I'm not good at things like that; the students have to sort of come to me. On many of the things that I've done, I hated to take up the valuable time of a graduate student doing the engineering that needed to be done to get whatever finished I was trying to finish, like redesigning the spectroheliograph or something like that.

HA: So did you end up doing it yourself?

RL: I wound up doing the design and a lot of the actual construction work myself, because, again, money's always tight, and I knew what I wanted, and I could do it much faster than any shop person could. This was not true on the infrared telescope; that was built over in the central shop. . . .

Mariner Missions to Mars

HA: You also worked with Neugebauer on the first Mariner project, in 1964. Did that initially start as a result of your collaboration on the infrared sky survey?

RL: Partly, yes. Because of my work at Mount Wilson, which I discussed earlier, I was known at Caltech, and maybe in certain circles around the country, as something of an expert in planetary photography. I can't say I had put years into it the way some people had, but I got some pretty good results with what I had done. Now, in the early '60s or late '50s, while Gerry was up at JPL, he was put in charge of, or was assigned to help with, evaluating proposals for possible scientific payloads for some of the Mariner shots. One of these was Mariner IV, which was slated to go to Mars. Among the various proposals, there was notably missing any proposal just to take photographs of the planet. There had been studies done on what possible approaches could be used to take pictures. These were farmed out to various possible participants. . . .

Neugebauer and Bruce Murray, who was fresh on the staff [*later to become director of JPL, and who is now professor of planetary science and geology*], brought me into it. Bruce was interested in planets as physical objects; he's a real planetary scientist. And Gerry was interested in the infrared. He and Bruce arranged very quickly to write and get accepted a proposal for planetary photography—the Mars imaging experiment. I became a principal investigator on that experiment. I went to a lot of engineering meetings. JPL did all the hands-on craftsmanship.

HA: That must have been a change for you.

RL: That's right. I didn't get near a bench. I guess the only important comments are that I, and perhaps Bruce (Bruce was familiar with this), intervened in the matter of deciding how the pictures of Mars were to be encoded in pixels. It was not necessarily a problem of how many pixels there were, but of how many bits of information would there be per pixel, in order to have a wide-enough range to distinguish the shades of gray that there are on the relatively blank Martian surface. JPL was going to use about three bits, but we absolutely insisted on there being, I think it was, eight bits. The photograph-TV part of the mission would have been a real failure if they'd only used the eight shades of gray that are possible with three bits.

HA: Here you were participating in what must have been the first effort to get pictures of another world in the solar system. What struck you and your colleagues at the time as more important—the actual instrumentation planning or the implications of what it was you were doing?

RL: Well, it was to find something out about Mars, the surface of Mars, in sufficient detail that we could get to another, higher level of understanding. But you have to appreciate that it was done with 20 pictures. That was it.

HA: Why only 20 pictures?

RL: Tape recorder storage capacity. Things had to be taken in a rapid mode as you went by the planet and stored on a tape recorder on a TV; and then it had to be played back at a few bits per second, picture by picture. I guess I was actually on the TV when the pictures were coming back; it was real time when they were broadcasting some of the things that were being found out. I figured out that one picture's worth of bits was like pearls strung some miles apart on a string from Earth to Mars: the length of time it took to transmit one picture from Mars to Earth was about the time it took light to get to Earth from Mars. So there was your picture, all strung out and coming in. And I thought that was kind of a nice way to look at that.

The thing that Mariner IV discovered on Mars was what a lot of people had for years expected and talked about, and that's craters. Now, it wasn't clear that Mars should have craters; it wasn't clear that it shouldn't. So the decisive result was important, because then it stops a certain body of science that was pushing no craters. So now the arguments go on a different plane.

There were two more Mariners [*VI and VII*] that I was closely associated with. Then I had sort of a peripheral role on the Viking Lander and the photos that were taken. I got a lot of data; I got to see the pictures. But I was too busy being division chairman then to actually enjoy myself.

[*Besides craters, Mariner IV discovered that the density of the Martian atmosphere is only about 10 percent of what Earth-based observations had suggested. The swaths of Mars photographed by the three spacecraft Leighton was involved in all revealed astonishingly varied terrains.*]

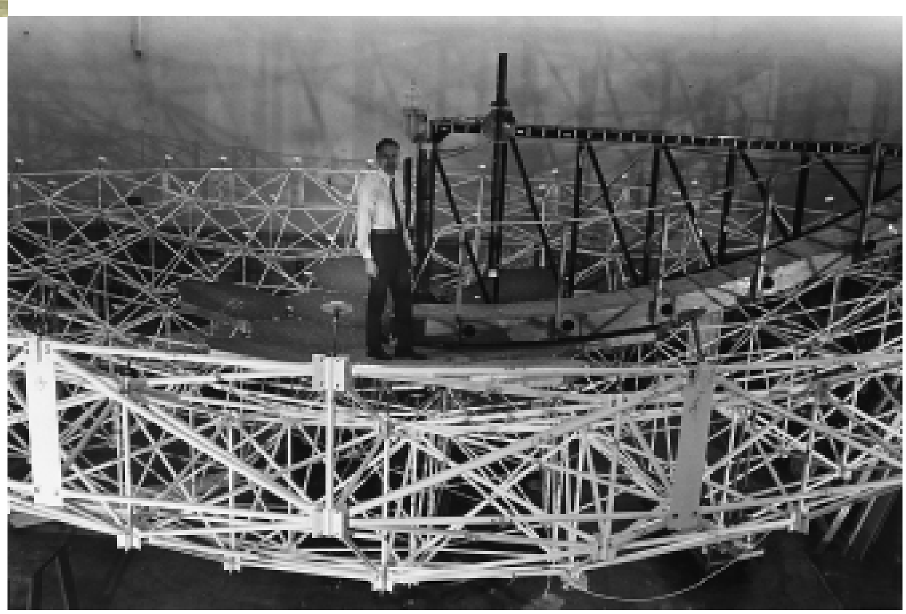
Unfortunately, I fell down on the job with those three experiments. I didn't have the wit to realize that if you could send three spacecraft past Mars in an essentially random manner, being certain only not to look at the same main area twice, and come back with something new each time, that must mean that the chance of seeing something new again was very great. It should have been a tip-off that there were many more things on Mars that would turn out to be examples of something that was being seen for the first time. And indeed that proved to be the case. Eventually, many more distinctive things, like the big volcanoes and the big, deep gullies, in which evidently fluid has flowed, were found. So that was a bit of an oversight on my part. Anyway, those were great times.

Millimeter and Submillimeter Astronomy

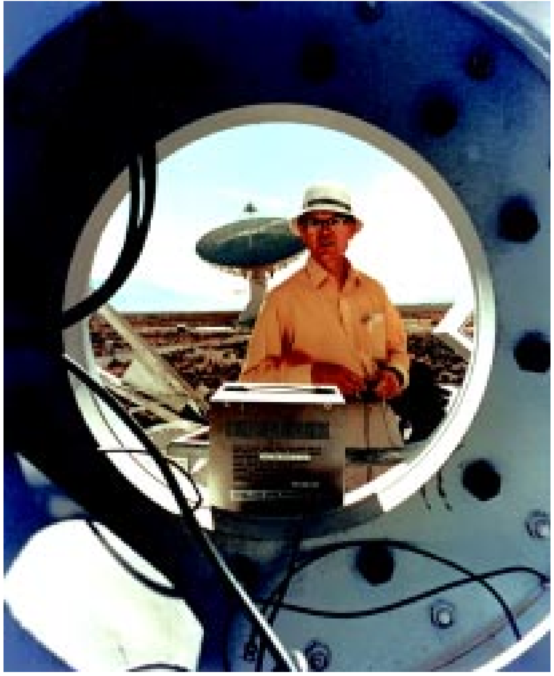
HA: After your work on Mariner, you went on to still another project—instrumentation for millimeter and submillimeter astronomy. How did that come about?

RL: You have to remember that I participated in the infrared sky survey, but for one reason or another, maybe being involved with Mariner, I didn't participate in established observing programs, where you take some nights at the telescope and go and measure this or that star. That didn't interest me. I did make a machine to look for polarized stars or nebulae, but, it turned out, after a week or two in the shop, I figured out that my way wasn't the way to do it. Then I saw a very nice device at Mauna Kea—the University of Hawaii telescope there—which showed me how it should be done. But by that time—about 1965—I was no longer interested in it. I did become interested, though, in building a new dish for infrared observations that would be twice the size of the original. It was basically a question of how much epoxy had to be mixed up in a short time, and how uniformly it had to be mixed. It's a little bit like pulling taffy, so at those dimensions it just fell down. It was a moderately useful thing, but in the meantime, we decided that was not what we wanted to do. For one thing, Neugebauer and his group had access to the 200-inch, which was so much bigger and better that it sort of took the pressure off making our own device.

However, in the process of thinking about this two-times-larger dish, we found the way to make a proper support structure—the tubular or other kinds of members on the back surface of the dish that



Bottom: Leighton constructs the first 10-meter dish on campus in the early 70s. In 1998 there are six of these millimeter-wave telescopes linked together as an interferometer at Owens Valley Radio Observatory.



With OVRO's huge 40-meter telescope looming over his shoulder, Leighton looks through the elevation bearing of the first Leighton telescope during its construction in 1978.

hold the surface in the proper shape. We figured out a way to build posts and struts very easily in the shop, so that the process of putting the support structure together really became one of assembling pieces. It was a procedure of reducing the whole construction of the support structure to what you could call a one-dimensional problem: make struts and posts to a precisely set, precisely defined dimension, and you're on your way.

It turned out that while I was sitting at my desk in the division chairman's office, I had a little terminal hooked into the PDP-10 over in the computing center. And I was able to use that to design the basic structure for a bigger dish. We decided to see how big a dish we could think of making—not actually doing it, but devising the ways to do it and estimating how accurately we might do things. Once we had come up with a way of making the struts to the right length, taking into account as far as possible the stresses and deformations they would be subjected to, Jim

You get a new idea, and you can't stand it until you've exploited the idea. Either it works and you love it and you do things with it, or else it doesn't work and you improve it, or forget you ever had it.

Westphal, who's famous over in planetary science, said, "What you really need is a laser interferometer to measure the length of these things." And indeed, that's the secret beyond a certain point. If you want to go smaller than three thousandths of an inch, you just about have to have something that goes down to the wavelength of light. So we bought a laser interferometer and used it in the shop to build the struts to the right lengths, which were calculated by a very simple computer program. The idea was that if you had a whole lot of struts coming together at the bottom of, say, a post, these struts had to be lined up in such a way that, if they were projected into the axis of the post, they would all meet at the same point. If you got right on line, the thing would have the stiffness of the original strut itself. In this way we had come up with a support structure that was very easy to build.

Now, we had set 10 meters as the right size for the dish, but we still had not solved the problem about how to make the surface. The surface was a factor of three bigger than the double-sized prototype we had made out of epoxy and thrown out. We made some experiments in the shop and found that making the surface out of aluminum honeycomb was clearly the way to do it. By then we had enough NASA money to build a prototype without having to convince the NSF that they should fund it. The 10-meter dish wouldn't exist today if we'd had to go to new sources of funds.

HA: What was the rationale for going into submillimeter and millimeter? Just to look in a different wavelength?

RL: Yes. Imagine that piano keys stand for the electromagnetic spectrum. We have one octave if we confine ourselves to the visual. You can imagine how dull Mozart would be if he had to stay in one octave. And there's something new in everything, you know.

So in the late '60s, in discussions with the radio astronomers, particularly with Al Moffet, we talked about making several dishes and making a radio interferometer for high-frequency, short radio waves. We were thinking in terms of one to five millimeters, and then the submillimeter came along as an idea. We thought that it might be worthwhile to go to a mountaintop with one of those telescopes, where you could get thin enough atmosphere to have a submillimeter window. However, we also thought the next time we make a dish, we'll improve it somehow. And so the dishes did improve somewhat as time went on. We learned more about them. They were certainly better built, if not more accurate. So we then pushed very hard on the Mauna Kea Observatory, and now we have the Caltech Submillimeter Observatory there.

It was like typical research: you get a new idea, and you can't stand it until you've exploited the idea. Either it works and you love it and you do things with it, or else it doesn't work and you improve it, or forget you ever had it. Once you start on a thing like that, you don't know how long it's going to take before you're finished. If you did, you'd never start in the first place, in some cases. However, it was very straightforward to do the millimeter and submillimeter stuff.

HA: So basically, this was initiated as an effort to find out new things about interstellar chemistry.

RL: That's right. And of course, the people who

Bottom: Leighton climbs up the struts of the Caltech Submillimeter Observatory (CSO) when it was first erected on the Caltech athletic field in 1983–84. It was disassembled and moved to the 13,300-foot level on Mauna Kea, where it was dedicated in 1986 (below).

build the detectors and the radiation receivers always are pushing their frequency range or whatever to new limits. Or else they run into the atmospheric wall that prevents them from doing that.

We began working on a prototype for the millimeter dishes now at Owens Valley Radio Observatory in about 1974 or '75. I was making sketches of possible things to do in about 1971, but we didn't actually start building things until about 1975.

HA: And then did that become sort of your chief research project for the next several years?

RL: Yes, for a while. I was division chairman at the same time. . . .

HA: Was there anything you found rewarding about being division chairman?

RL: Not that would make it an intrinsically desirable thing to do. The most significant thing I did as division chairman was to use the computer behind my desk to calculate the properties of our 10-meter dishes. . . .

HA: You have spent your entire academic and research life at Caltech, from undergraduate to professor emeritus.

RL: That's the way it worked out. I've had research that had some interest to people elsewhere, but I like to combine different things. I did a lot of that. As it is, I don't know how significant the things are. Perhaps it's like a lot of bric-a-brac in a ceramic shop—a lot of pretty pieces but only one of a kind. I think the right word is eclectic—seeing opportunities and salvaging the best of them. But I had the freedom to do it without being looked down upon as that funny guy who looked at planets, or something.

HA: Do you think this would have been possible at another institution, what you did here?

RL: I have no way to tell. I do think that "publish or perish" was more of an imperative elsewhere than it was here. Now I think we've become more like the others, unfortunately. I think that to be a young experimentalist just coming on line, you might say, at Caltech or any good institution, is a terribly difficult position to be in. As a result of all my other interests, I've become lazy. I haven't published very much, except now and then a textbook.

HA: Did you do a lot of publishing when you were younger? Or once you got out of the whole cosmic-ray area, did you kind of taper off simply because you had the opportunity to do all this other stuff?

RL: I've been on a lot of papers with the infrared and the millimeter and submillimeter projects. I've latched on to a couple of things and pursued them, sort of sideways, extracting them from the pile of results that were coming in. And I think my work on the behavior of volatiles on Mars and the atmosphere—this business of the low atmospheric pressure and the fact that most of the atmosphere was lying on the ground in the wintertime—was a totally new idea. This came out of the Mariner experiments. To be there, able to see that and do it, and then to have a guy like Bruce Murray around, who'd done volatiles on the moon—we just naturally gravitated together and did a joint paper. There were only two authors on that. I like that much better than finding my name on a paper where I don't even really basically remember what the objective was.

HA: Do you have any sense of what you consider the most important or significant thing you did here?

RL: Well, almost everything could have been done by somebody else. As a matter of fact, one of the nicest and one of the worst things about the solar results is that there was no technique, other than possibly the optical coating of surfaces to eliminate reflections (which was needed to show the magnetic fields and discover the solar oscillations) that went beyond the intrinsic capabilities of what had already been built at Mount Wilson by 1908.

Originally, Mount Wilson was ahead of the world in solar astronomy. But the whole field gravitated to counting sunspots and keeping track of how they disperse and things like that. And the Greenwich Observatory, not to mention the Mount Wilson Observatory, essentially got stuck at that level, of studying sunspots. Ike Bowen, when he was the head of the Mount Wilson and Palomar Observatories, said that the one thing that he saw which was just like day and night with respect to astronomers versus physicists, was that physicists used apparatus and did real experiments—in the sense of designing an experiment, taking data, and so forth—whereas astronomers wanted to know what spectroscopes were available, already built by somebody, that they could use to study the spectrum of such-and-such kind of binary stars. Not that those types aren't also needed, but they're just different.

HA: Looking back, do you have anything you want to say regarding your past 40 years at Caltech?

RL: It can't be literally true, but I have the distinct feeling that when I first came to Caltech as a junior, I didn't change after that. I still have the feeling I'm the same person I was when I came here in 1939—in the sense of what I'm interested in, what I really find exciting in terms of subject matter, what I read. I do try to read *Science* and *Reviews of Modern Physics*, not that I can keep up with it, really. The things that are going on in elementary particle physics are things that I really wish I'd done more of, except that the circumstances were such that I just didn't want to lead that kind of life, having to travel for a week or two at a time to some remote place, and then having to do double teaching when I got back. It was just too much of an upset of an orderly life.

HA: Was there a point when you realized you basically were happy to just stay here, that this was your preferred environment?

RL: In the abstract, I guess I realized that it was not necessarily so that I would always be here. And as a matter of fact, I got some job offers from what became aerospace industries. But when it actually came down to leaving, well, I was perfectly happy to do what seemed to be the next thing to do here. . . .

HA: Is there anything you're working on now?

RL: Well, there's one more dish in the works that we haven't yet got the full funding for, but it goes with the struts that are in the lab.

HA: If OVRO gets the funding for the other three dishes, are you going to build them? [*There are now six Leighton dishes at Owens Valley.*]

RL: There is a proposal for that. However, so far unproposed but prepared for, is to make a replacement dish for Mauna Kea. I know that if we were to make another dish like the one we have now on Mauna Kea, but with three support points for each of the 84 hexagonal panels, we would improve the surface precision by a factor of two, maybe three. Even a factor of two would make surface accuracy to five microns; and that might permit much more meaningful measurements in the 30-micron window of the submillimeter range. So there's another window that would open up for ground-based observing. As a matter of fact, I wanted to build that dish. I've got ideas that go beyond what we're doing now in the submillimeter.

In this connection, I remember a story about my father. Although he and my mother were separated when I was growing up, and he was in the East most of those years, every now and then he would show up unexpectedly and spend part of the day with us. He would spend his time telling me how accurate his die-work was, and how he'd made this four-inch-in-diameter surface smooth to three ten-thousands of an inch. And then he'd raise an eyebrow as if I was supposed to say, "Oh boy, that's great!" I didn't know what he was talking about. But the funny thing is that his son has perfected a system for making a radio-dish surface, not a mere four inches or so in diameter only, where you have control of everything, but on this big, strange four-*hundred*-inch-diameter structure, which floats delicately on a thousandth of an inch air film, and which flops around a little bit. That surface is good to maybe one or two *ten-thousands* of an inch! So it's rather interesting. Without any instruction from him, I must have had it in my genes. He, no doubt, endowed me with the right DNA to have the interest. It's all part of a pattern. I've always been enamored of mechanical things like that. □

I think the right word is eclectic—seeing opportunities and salvaging the best of them. But I had the freedom to do it without being looked down upon as that funny guy who looked at planets, or something.

PICTURE CREDITS:
23 – JPL; 24 – Jane Dietrich; 25 – Peter Bostrøm; 26 – Florence Photography

A booklet, “Women at Oxford,” caught my eye. Of 100 women from around the world, the only American mentioned is Muriel Beadle, along with her book, *These Ruins Are Inhabited*.... Oxford still remembers the brouhaha Muriel’s book caused.

As Oxford’s Eastman Professor, Harry automatically became a Fellow of Balliol College and lived in the Eastman House.

In the spring of 1997, my husband, Harry, Caltech’s Beckman Professor of Chemistry, was named Oxford University’s Eastman Professor by the Rhodes Scholarship Trust. Eastman Professorships run for one year and can be selected from any field. At Columbia in the ’60s, we had been friends with two Eastman Professors, Lionel Trilling and Garrett Mattingly (both, alas, now dead). Trilling, who lived in the apartment next to us, was already New York’s leading literary critic. He often entertained a young, barefoot student named Allen Ginsberg. Mattingly, who was writing the definitive history of the Spanish Armada, lived upstairs. Only four chemists had ever previously been named Eastman Professors—Harold Urey, Melvin Calvin, Clyde Hutchison, and our own Linus Pauling. Moreover, George Eastman, the founder of Eastman Kodak and the donor of the Eastman Professorship, was a chemist! We were most flattered to be invited. Besides Pauling, only two other Caltech faculty had been so honored—George Beadle and James Bonner, both biologists.

Since the Middle Ages, Oxford’s colleges and their Fellows, i.e., the faculty, have offered the finest education in the English-speaking world. As innocent students, future kings, queens, heads of state, and distinguished scholars have all taken an oath in Latin to swear to scholarship, honesty, integrity, and persistence in attaining worthy academic values. The colleges began as rooming houses, says one authority, “with a master in charge to see that the young scholars behaved themselves and got enough to eat. From those halls they went out to lectures given under the auspices of the university. If a boy had a bit of trouble with his Latin, nothing could have been more natural than to ask help from the house master; and so a teaching function was added to the colleges. They are still the basic social and instructional units at Oxford.... Given close fellowship with brilliant minds in an elegant

THESE RUINS ARE *STILL* INHABITED
Caltech at Oxford, 40 Years On

by Shirley I. B. Gray

The ceremonial installation of a proctor includes a procession from the Sheldonian Theatre (the building in the top picture), down the Turl (one of the principal streets of Oxford), and off to who knows where—the faculty club, one supposes.

and civilized setting, it is not surprising that the Oxonian's loyalty and affection go first to

the company of people with whom he has lived. (That's all 'collegium' means, anyway—a company of like-minded people.) The American university graduate identifies himself as a Yale man, but the graduate of Oxford is likely to tell you that he was at Balliol."

Caltech's undergraduate houses are based on the Oxonian model, so we were not entirely unfamiliar with the system. As Eastman Professor, Harry was automatically a Fellow of Balliol College.

Oxford has a Disneyland quality, replete with costumes, pageantry, and a background of splendid, but authentic, architecture. Robes are worn to all official university functions, from tutorials to faculty meetings. (Imagine Caltech professors wearing academic dress to a Watson lecture or to a dinner at the Athenaeum!) Harry and I found we were wearing academic dress at least once a week—but, being forewarned, we had fortunately brought the proper attire with us. The mere installation of a new proctor, the lowest rung on the academic ladder, is sufficient cause for a procession through the streets by faculty in full academic regalia, led by three officials carrying enormous silver maces. Bobbies and barricades cordon off the side streets while mounted policemen and motorcycle cops clear the way.

Most of these parades begin or end at the legendary Sheldonian Theatre, designed by Sir Christopher Wren. The Sheldonian is an academic assembly hall for investitures, faculty meetings, and the like. But it's also a real theater, at which concerts are presented. It has become a major tourist attraction, complete with the inevitable gift shop in the foyer, where a booklet, "Women at Oxford," caught my eye. Of 100 women from around the world, the only American mentioned is Muriel Beadle, along with her book, *These Ruins Are Inhabited*.

Right: The wide selection of game available in Oxford's Covered Market is quite a novelty to an American accustomed to shrink-wrapped steaks on styrofoam trays.

Above: Redmond and Muriel aboard the Cunard Line's *R.M.S. Britannic* in September, 1958. With no VCRs, video games, or personal stereos, there was plenty of time to read the ship's daily paper, the *Ocean Times*, from cover to cover.

(The passage two paragraphs above was excerpted from *These Ruins*, which is also for sale in the gift shop.) Muriel's husband, George, a Caltech geneticist and soon-to-be Nobel laureate, was the Eastman Professor for the 1958-59 academic year. She and their teenage son Redmond spent the year at Oxford with him, and Muriel, a professional journalist, wrote the book upon their return home.

Oxford still remembers the brouhaha Muriel's book caused. Some readers took her gentle teasing as criticism and failed to smile. Others found her outsider's insights to be accurate. The townsfolk, in general, were a bit offended. Oxford's founding, 40 years ago, of the highly successful newcomer's welcoming group is a direct result of Muriel's comments in *These Ruins*, and Cambridge has since followed suit. I had read *These Ruins* when we first moved to Caltech. I reread the book twice before departing for Oxford.

The Beadles had sailed from New York to Southampton with enough winter and summer clothing to last the year. No returning home for Christmas on frequent-flier miles for them! Since it no longer takes eight days by steamship and eight hours by airplane to travel from Oxford to the West Coast, Harry and I returned to Pasadena three times. We used e-mail on a daily basis, and we called the U.S. with impunity. (Placing a transatlantic telephone call in the Beadles' day was a major affair, and, of course, e-mail did not exist.) Clearly, travel to Europe has changed, and life in Oxford has changed as well. I thought that I owed it to the tradition of Caltech women visiting Oxford to offer an update on Muriel's observations.

Food. In defiance of stereotype, British food is frequently wonderful. This was not always the case in Muriel's day:

> I quit worrying about [Redmond] altogether the day he said, "Birkett and I tried lunch at the Muni"—the Municipal Restaurant, a cafeteria not far from the school—"and it wasn't bad. Only a shilling, too."
>
> "Only a shilling. *Fourteen cents?* At that price, what on earth did they give you?"
>
> "The daily special. I don't know what was in it."
>
> "A meat dish?"
>
> "I guess so. With potatoes and bread and Jell-O."
>
> "Well, what did the meat look like? What shape was it?"
>
> "Lumps."
>
> "What color was it?"
>
> "Sort of gray."
>
> "What texture?"
>
> "Soft."
>
> "Good grief, Red!"
>
> "But it was nice and hot, Mom."

The British have always been worldly, and setting a good table is now a matter of honor. The BBC televises cooking competitions, and food is earnestly discussed as a conversational topic. And yes, British cuisine even includes spicy foods nowadays—what with the population influx from the subcontinent, Indian food competes with pizza and spaghetti as daily fare. (These latter, being fast and easy, appear to have become the most common food on Earth. We have eaten them from New Zealand to Israel.) In fact, I would say the average Englishwoman knows her curries better than the average Angelena knows her dim sum. And the British sandwich has evolved from yesteryear's simple tomato on bread with butter to encompass ciabatta (which resembles French bread) stuffed with curried chicken, Thai salad, or hummus.

TESCO, a major supermarket outside of Oxford, has 23 checkout lanes and is larger than any store in Pasadena. Variety exists in the three states of matter: frozen, fresh, and "heat and eat." With the global market, anything in season anywhere is for sale. In Oxford, the gentry favor the Covered Market—a farmer's market where, one fall weekend, I found fresh grouse, pheasant, deer (both red- and white-tailed), duck, hare, and rabbit all displayed in one shop. I went home to fetch my camera. At the university, dinner in hall—and not even special dinners!—has included plaice and lobster. Here I was one up on Muriel, as women weren't allowed to dine in hall during term in her day. But she heard all about those meals from George, so we know that "an elegant English dinner menu, such as the colleges serve, has a Victorian flavor: soup course, fish course, joint of beef or lamb and three vegetables, a pudding or pastry of some sort (never cake or ice cream), fresh fruit, and cheese with crackers.… Coffee—strong and bitter-black—is served demitasse. In order to kill the taste it's customary to pour in sugar and hot milk. Liqueurs or port may follow. (Also, some hours later, a need for bicarbonate of soda.)" Harry declines the snuff horn that is passed with the port. Cigars after dinner are still common.

The British breakfast, however, is in a state of decline. One finds the traditional full breakfast, with its kippers, black pudding, and broiled tomatoes only in tourist hotels or being eaten at 10:30 a.m. by pensioners in the lunchroom at Littlewoods, a department-store chain.

The midday meal is still serious. An Oxford chemistry wife decided to entertain newcomers from Japan by preparing a "typical British lunch" in her home. She served orange and carrot soup, lamb with apricots, vegetables *en casserole*, rhubarb crumble, banana mallow with raspberries, and a choice of Stilton, blue Shropshire, or cheddar cheese. I was ashamed that earlier I had served a sandwich to a fellow math professor after *her* lecture. (Yes, Oxford now has female faculty, and they dine with the men.)

At the university, dinner in hall—and not even special dinners!—has included plaice and lobster. Here I was one up on Muriel, as women weren't allowed to dine in hall during term in her day.

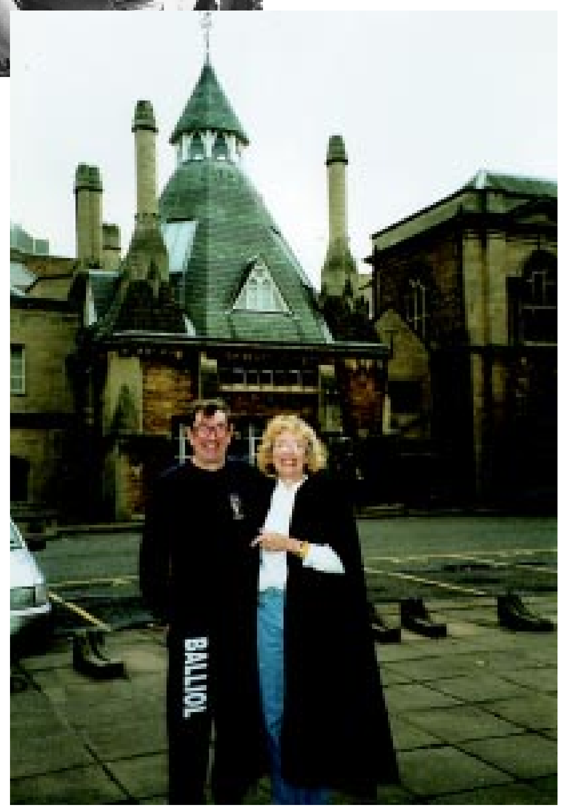
The Role of Women at Oxford. Muriel, as a Caltech faculty wife, was accustomed to being included at collegiate functions, and was shocked and infuriated to find the Oxford faculty and all its doings to be an exclusively male preserve. Faculty wives were expected to stay home, or entertain themselves by attending bird-watching lectures at the public library or joining women's clubs. In one respect, however, Muriel's Oxford was light-years ahead of Caltech. Oxford had been admitting women as undergraduates for 40 years; Caltech's first female frosh wouldn't arrive until 1970.

Nowadays, most Oxford colleges have at least one female tutor in every department. This is partly in response to the changing demographics of academia in general, and partly precautionary. As Muriel explains Oxford's instructional practices, "Whereas the American student 'majors' in a subject, the Oxford undergraduate 'reads' it. Literally. His work is directed from his college by one or two tutors who are experts in his chosen field. For three or four years, in weekly private session, he presents an essay based on his reading, hears his mentor discuss and criticize it, may be forced to defend it, is finally sent on his way with a new reading assignment and a new essay topic. That's all there is to the academic side of an Oxford education: Mark Hopkins on one end of a log and a student on the other. It's the best possible method of teaching, and also the most expensive. The cost can be justified only if teacher and pupil are of top intellectual caliber." But if the teacher and pupil are of opposite sexes, and instruction takes place behind closed doors in the tutor's rooms, as is traditionally the case, the potential for scandal and lawsuit in this day and age is enormous.

Hats. Muriel wrote, "English academic society puts on full dress much more often than its American equivalent. If a dinner invitation does not specify 'informal,' guests assume that black ties will be worn. Young ladies then wear short formals, and old ladies wear floor-length dinner dresses. If the invitation specifies 'orders and decorations,' men climb into white-tie-and-tails, young ladies shift to ball gowns, and old ladies add white kid gloves and tiaras to their floor-length dinner dresses." A black-tie dinner still occurs at least every week or two in most colleges, but it is the hat that truly distinguishes the British from Americans. From the porter's bowler to the cricketer's cap, from the hunter's helmet to the fisherman's sou'wester, it is the pleasure of wearing a hat that makes one truly British. Queen Elizabeth is in complete harmony with her public by always wearing a hat. It is simply something one does. An invitation to a garden party at Oxford often includes the request from the host, "He hopes that some Ladies will wear Hats."

News, Pop Culture, and Mail. In Muriel's day, many expatriate Americans read every single word, including the classifieds, of the *International Herald Tribune*. The *Herald Trib* is still a good paper, but its news now is global, and more likely to cover a financial crisis in Asia than an art-show opening on the Continent. Television is now the main source of information. At lunch in college, the conversation often deplores the unhealthy alliance between Prime Minister Tony Blair and media mogul Rupert Murdoch, or bemoans Murdoch's "making a killing" with Sky TV, his version of CNN.

The late-night shortwave BBC newscasts of Muriel's day have been supplemented (but, fortunately, not entirely supplanted) by talk-radio shows that capitalize on the time change between Britain and the United States. BBC researchers track down funny stories in the States, and set up interviews with the parties involved. So while it's the middle of the night in Europe, wide-awake



Left: The Beadles at home in their Oxford living room. Below: The Grays in front of the Abbot's Kitchen, an Oxford laboratory where seminars in inorganic chemistry are held. Harry gave several there.

callers in the U.S. chat with British hosts. The American accent attracts attention, and the BBC has a knack for the oddball. One example I recall is the owner of a newspaper in a small Virginia town (population some 1,500) being sued by *The Times* of London for the use of the same name. On a more somber note, the BBC also talks to American callers about American tragedies, such as the schoolyard shootings in Oregon and Texas. There's a definite tabloid mentality to these segments—the more horrific the story, the better. But in every case, from the silly to the serious, the Americans were articulate and well-spoken. I was very proud of them.

American pop culture is highly influential—much more so than in Muriel's day. But unlike in the U.S., there's no free TV. The BBC collects a "license fee" of 100 pounds sterling (minimum!) per year per television set. Satellite TV is even pricier, but is as ubiquitous as cable TV is here. The 49ers vs. Dallas, the Super Bowl, and the Breeders Cup were on live television. The World Series was on radio. Boathouse audio systems spill Aerosmith, Van Halen, and other hard rockers across the Thames on Bumps Week—a series of intercollegiate boat races held every spring. The sound is not unlike the opening of a Chicago Bulls game.

As in Muriel's day, timely mail delivery is still taken seriously. Junk mail and superfluous catalogs do not burden the postman.

Majors, Fees, and the Oxford Degree. Students at Oxford read a single subject, which they declare upon matriculation. Of some 3,000 freshmen, as many as 200 (about 7 percent) may be reading chemistry and 150 (5 percent) the classics. In contrast, the class of 1998 at Harvard—the only proper university in the United States, as far as Oxford is concerned—numbered 1,654, of whom 38 (2 percent) were chemists and nine (0.5 percent) were classicists. Oxford clearly has a far greater percentage of chemists and classicists. Why is this?

Chemistry at Oxford offers a four-year BSc degree, with the final year devoted to a research project. An Oxford education remains largely free to British citizens, although just this year the university began charging a nominal annual tuition on the order of $1,600. (Contrast that with the $30,000 or so, including room and board, that a year at Caltech costs!) With tuition

Cindy Quezada, a grad student of Harry's who came with us for the year, once attended a masquerade ball in this room. Strobe lights flashed above the dancers, animating the paintings. She told me later that she felt as if she was being haunted by the Ghosts of Success.

Above: Cindy and Harry in the doorway of the Hall at Balliol College.
Below: Lewis Carroll, aka Charles Lutwidge Dodgson, mathematician and creator of *Alice in Wonderland*.

and fees unimportant, many students prefer the four-year degree to the three-year baccalaureate typical of the humanities. One also hears that the best job offers from London—those in government and finance—are going to degrees that emphasize applied math and computer skills as well as writing skills. And chemists *do* learn to write—Oxford tutors proofread lab reports and grade them for grammar and style as well as content. Thus one studies chemistry not so much for chemistry's sake as for the peripheral skills. In Muriel's day, students took a lab science for the subject matter—one was learning a trade, as it were. Margaret Thatcher is an example of a chemistry student whose career went awry.

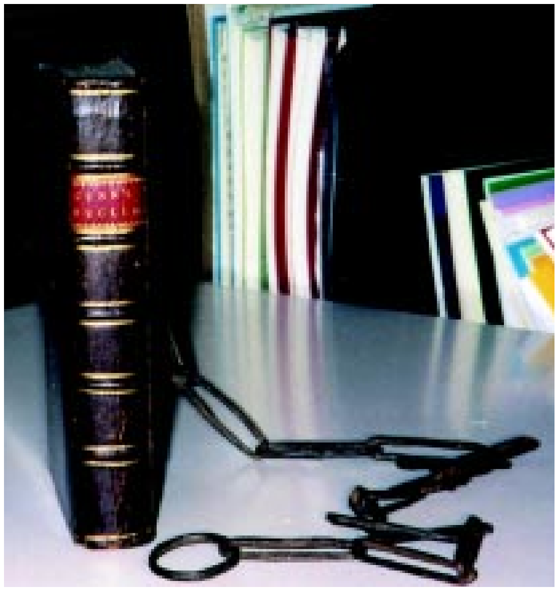
On the other hand, the classics have always been the means to acquire the trivium—writing, logical, and rhetorical skills. Oxford has traditionally prepared the ruling class for government service, and knowing antiquity and its literature was not nearly so important as learning to communicate with one's future colleagues and constituents.

In Muriel's day, admission to Oxford was largely limited to applicants from the Commonwealth. Nowadays, however, Oxford truly wants to become an international university, and is trying very hard to recruit foreigners. The effort is paying off, and an Oxford degree has become quite popular abroad. One now meets many German, Italian, Greek, Spanish, Portuguese, Mexican, and South American students, even though these students pay tuitions comparable to American rates.

Muriel quoted George Bernard Shaw as saying, "'If Oxford is not highbrow, what on Earth *is* Oxford?' An undergraduate may be the son of a Birmingham collier and his speech may still be faintly tinged with Black Country dialect, but the college porter will address him as 'Mr.' He and his fellows are always referred to as 'gentlemen.' And his tutor will offer him a choice of sherries as gravely as if he were a connoisseur. Thus he begins to become one. There isn't much doubt that life as lived in the Oxford colleges stretches the mind, sharpens the wit, and refines the taste."

An Oxford degree will continue to be a golden key for the foreseeable future. When one dines for three years in halls decorated with the portraits of prime ministers and presidents, why not dream big? I sought out the portrait of Lewis Carroll for my mathematics students. He hangs in hall at Christ Church with William Penn, Robert Boyle, John Locke, Elizabeth I, Henry VIII, Cardinal Wolsey, and 13 prime ministers. Cindy Quezada, a grad student of Harry's who came with us for the year, once attended a masquerade ball in this room. Strobe lights flashed above the dancers, animating the paintings. She told me later that she felt as if she was being haunted by the Ghosts of Success.

(Cindy also attended the Royal Ascot horse race in June. When the Queen is in attendance, getting in is slightly more complicated than just buying a ticket at the front gate. One has to be invited, which, in this case, meant that Harry had to write her a letter of introduction to the American embassy, attesting to her good character. She also had to buy a hat for the occasion.)



When they put a book "on reserve" at Oxford, they really mean it. Some books still retain the medieval chains that once secured them to the shelves.

Libraries. Oxford has the oldest and largest libraries in the English-speaking world. The Bodleian Library, founded in 1602, is the university's main library. It is also a copyright repository—the British equivalent of the Library of Congress—and, as such, holds copies of every book that's been printed in the United Kingdom since 1610. (A friend of Muriel's gleefully reported finding *The Life and Times of Mickey Mouse* there.) For 400 years, "Readers" (patrons with research privileges) at the Bodleian, with hand held high, have made a declaration not "to bring into the Library or kindle therein any fire or flame," nor to "mark, deface, or injure in any way, any volume, document, or object belonging to it."

In an American university library, the photocopier and the computer are vital equipment. They're also essential at Oxford, but in far different proportions. The Bodleian's books don't circulate. Readers don't even have access to the stacks—you fill out an order slip, and a member of the staff fetches your book and brings it to your seat. The staff also does all the photocopying. If the book was published before 1800, the page is photographed instead, so as not to injure the binding. This, of course, is much more expensive and takes longer—especially as the attendant first checks to see if there's a negative already on file. The negative-storage area takes up the entire attic floor of the library, and is a seemingly endless warren of corridors piled high with dusty boxes. If you just want to take notes, you may do so in pencil. Pens are strictly forbidden, for fear of marring some priceless volume. Thus the laptop computer has become the optimum way to take knowledge home. The Duke Humphrey Collection in particular, some of whose books still retain their medieval chains, attracts "laptop Readers."

Muriel noted that it was sometimes more efficient for George to have journals airmailed to him from Pasadena than to try to find them in the Oxford libraries:

> There are over fifty libraries at Oxford, some maintained by the university, some by the colleges, some by departments. Cataloging systems vary from library to library, and sometimes even within them. There is no central catalogue that lists what's supposed to be in all, and such lists as are available are often out of date. In trying to run down one periodical, listed at two department libraries, George had found that one of the two had stopped subscribing to the magazine in question in 1933, and the other had sold its back copies during a period of economic pinch. He still talks about the fact that to locate all reference material pertinent to a survey of evolution required visits to seventeen libraries.
>
> This sort of thing doesn't bother a lot of people at Oxford. Some have more fun sampling their way through the Bodleian than women at what the English call a jumble sale.

Well, this sort of thing has apparently begun to bother people since then. The university *still* doesn't have a comprehensive central catalog, but many colleges are beginning to set up on-line catalogs of their own holdings. Balliol College, where we were, is well on its way.

College vs. College; Oxford vs. Cambridge. Since medieval times, says Muriel, nobody has "remembered the university with special affection. It was only cold lecture halls and colder-eyed examiners. Therefore, the rents from a bit of property or some fine silver plate passed from a fond graduate to Merton or Exeter or Queens, or to whatever college was his ancient English equivalent of good old Kappa Sig. Hence, over the years, the colleges grew wealthy, developed into wholly autonomous institutions, became more important and more powerful than the university. Although they have now been forced to yield ground to the university for the maintenance of the modern science labs that no individual college can afford, they are still far more than the administrative subdivisions that the word 'college' connotes to Americans when it occurs within the context of university organization here." The colleges still go their own way, financially, and conversations at the faculty dinner table often focus on which colleges seem to have the funds to provide a good life for their members.

George collected anecdotes illustrating college rivalries, and how jealously each one guarded its prerogatives: "I don't see how this can be true, even at Oxford, but here's how I heard it. The Botanical Garden—you know, the buildings and grounds along the Cherwell just below Magdalen Bridge—is owned by Magdalen College, and they lease it to the university. Somewhere in the deed or lease there's a provision forbidding vehicles to drive on the property. And for a solid week during

Unlike Pasadena, Oxford has four distinct seasons. Left: In spring, the Caltech orange of California poppies brightens the front garden of the vice chancellor's house. Right: Redmond's grandmother, who paid the Beadles a Christmas visit, thaws the birdbath in their backyard.

one cold winter, while the supply of coal to heat the greenhouses dwindled away to nothing, Magdalen refused to let the university deliver coal—because it had to come by truck!"

At the level of Oxford vs. Cambridge there is tremendous respect and seemingly little rivalry. Muriel says, "The fundamental similarity of the two great British universities… is recognized by the English in common reference to them as one entity called 'Oxbridge.' They have equal prestige, and jointly are the mecca for the best young brains in the commonwealth." (Unlike in the U.S., where a prospective student with a high tolerance for paperwork could conceivably apply to every school in the Ivy League, in Britain one can apply to either Oxford or Cambridge, but not both. This is a concession to the faculty, as all successful applicants to both universities are interviewed by three faculty members.) The term "Oxbridge" notwithstanding, there are major differences between the two universities. For example, at Oxford, faculty must retire at age 65 and move out of their college. At Cambridge, faculty never have to retire, nor vacate their college-owned offices and flats. In an era of increased longevity, Cambridge's administration is becoming concerned about this policy. Oxford is standing by the very expensive tutorial system, while Cambridge is moving toward lectures and sections taught by graduate students.

In both universities, a faculty member's time is split between his responsibilities at his college and his research career, which is housed at a separate institute. Most feel pressure to do double duty, although sooner or later, one is forced to choose where to spend one's time.

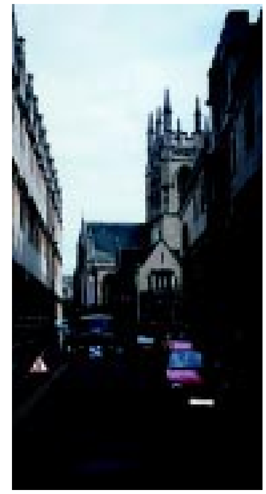
During our stay, a popular tutor received a permanent post, i.e., tenure, though other candidates had far better research and publication records. He had chosen the college instead of the institute, and put in huge amounts of time serving on every committee imaginable, from gardening to admissions to wine. So, unlike research universities in the U.S., where advancement is based on publications and scholarship, in the U.K. it is possible to advance by being a good teacher and a good member of one's college.

On the other hand, a fellow we know who became head of his laboratory had to leave his college, to his great regret—it was like being booted out of his fraternity. There is lots of camaraderie and little competition among a college's faculty—for example, Balliol has only a few chemists, so there isn't much jockeying for lab space or students. And you aren't competing with the math or philosophy professors at all, so it's very easy for them to be supportive of you. But the institutes are very focused, so you may be vying with, say, eight other inorganic chemists.

Living. While the winter's rains are irritating, nothing is more wonderful than a spring day in the northern latitudes. If the early light does not awaken you, a symphony of birds will. The smog-free skies are a reminder that Pasadena does have some faults. The most depressing aspect of life in Oxford is its traffic. The city is scaled to walking and bicycles, and public transportation is highly developed, but Oxford is moving to the family automobile. A parking space is highly prized. If any one thing threatens downtown Oxford it is the demands put upon the city by the automobile, coupled with the university's need to find the space to expand, especially for new science buildings, while remaining a place where one walks and interacts with friends and colleagues.

Muriel thought that the traffic was bad in 1958, what with the surge in car ownership as Britain's economy finally recovered from World War II. She describes their first drive into Oxford:

> The street, wide up to this point, suddenly narrowed; and as suddenly filled. Cars and busses seemed to spew into it from a series of side streets, and we inched along until a bend brought us face to face with



Left: Traffic in England wasn't always horrific. Here George gets his bearings while touring the Cotswolds, some 20 miles from Oxford.
Right: The only thing worse than a narrow two-lane road is a narrow two-lane road under construction. There's a reason why bicycles remain popular!

> a roundabout (a traffic circle; the British prefer them to intersections controlled by traffic lights [which is still true today!—ed.]). It resembled a runaway carousel, and I caught my breath. But George, thanks to his drive from London the previous day, was a veteran, and he tackled the maelstrom ahead of us with cheer and confidence.
>
> "There's no right of way at these," he explained, his head swiveling and his foot ready on the gas pedal. "The trick is to cut in front of the first driver who hesitates. A good time to catch 'em is when they're shifting gears… So!" He shot into the stream like a salmon in springtime.… [W]e had made the mistake of tackling the town during the morning rush hour, and vehicles were approaching… in a spirit of no quarter given, none expected. The street was raucous with the roar of motors, and a bluish haze born of exhaust smoke eddied about the patient queues of people at the bus stops. No sleepy university town, this; it was like traveling on a cross-town street in Manhattan at high noon.

That and a drive through the Oxford countryside the next day scared her—a battle-hardened veteran of rush hour on the L.A. freeways!—so badly that she refused to drive for the duration of their stay. (Fortunately for their touring plans, George had nerves of steel.) But she hadn't seen anything, compared to what it's like now.

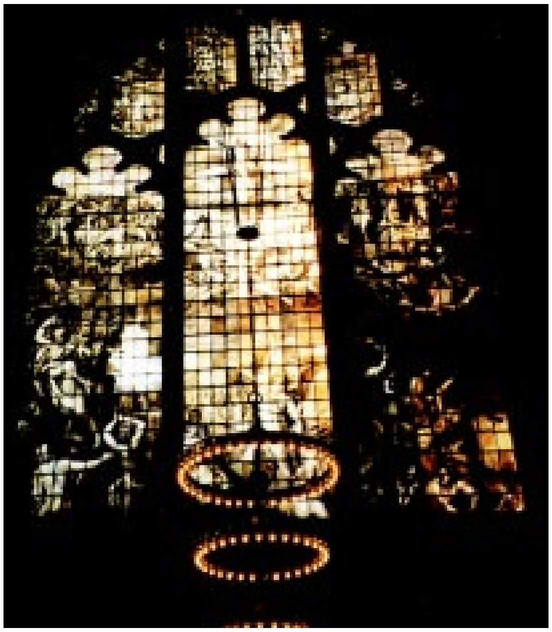
Precollegiate Education. Muriel, with a son in a British grammar school, became keenly interested in educational issues. Her first parent-teacher meeting, however, disabused her of the notion that the British educational system wanted her input, or that teachers were held accountable to parents. Teachers were revered and left pretty much alone—as professionals, they were expected to know best how to do their job. "[Parents] believed that it is as bad form to express opinions on the content and methods of education as to tell a physician how to prescribe for a patient." The American system of having the community, through the vehicle of the school board, dictate to the faculty was unheard-of. Nowadays, being scrutinized is accepted as part of the system. Schools are rated by the government, and the ratings appear in the newspapers. At university, individual departments are rated, and even declared redundant if not performing at a reasonable level of expectation. Faculty have found themselves in the awkward position of having tenure in a department that has ceased to exist.

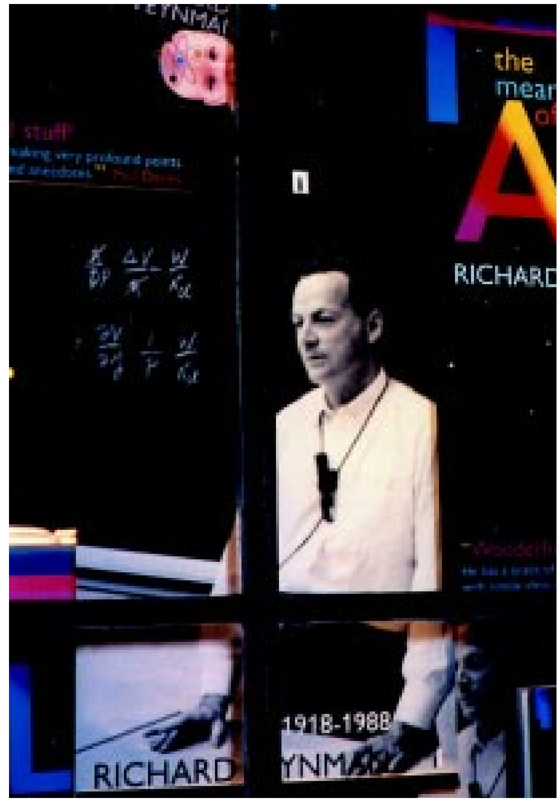
But although British parents are more vocal now, they still show far more respect for teachers than we do. It is considered the family's responsibility to civilize its children—you don't just dump them into the school system and expect the teachers to raise them for you. Consequently, British teachers spend far more time teaching and far less time baby-sitting than ours do.

While concerned American parents have rammed every educational fad of the last 50 years down our schools' throats, British teachers stuck to the three Rs. Muriel noted that, "It is characteristic of the English, who never discard anything that still works, to have supplemented existing facilities rather than to have created entire new systems, as the Americans would have done…. They like cautious experiment, rather than radical change, and if this predilection sometimes muddles them up, costs them money, and slows them down, at least it spares them the disillusionment that can follow the collapse of some grandiose but untried scheme."

On the positive side, we give far more second chances than the Brits do. Their system of three national, standardized exams taken at ages 11+, 16, and 17 or 18 is very unforgiving of slow starters or children with other disadvantages.

Tourism. Tourists have found Oxford, an undiscovered treasure in Muriel's day. The daily





Caltech is remembered in Oxford's windows. The magnificent sepia window at right is in the chapel at Magdalen College, and was restored as a gift from Caltech Professor of Organic Chemistry John Richards and his wife, Minnie. The photograph of Caltech Nobelist Richard Feynman at far right is part of a window display at Blackwell's, a famous Oxford bookstore.

scene at the Sheldonian reminds one of the crowds at the Duomo in Florence. The tourists include world leaders—King Hussein of Jordan and Empress Michiko of Japan headed the list last spring. Empress Michiko's son was at Merton and her daughter-in-law was at Holywell Manor, a 200-year-old dorm for graduate students. Cindy Quezada hosted a Tokyo TV-news crew on its tour of the colleges while the empress was having lunch in the Master's Lodgings at Balliol. It is a setting worthy of royalty, as every college has, over the centuries, accumulated a priceless trove of antiques for the private use of its faculty. The Master's dining-room table and chairs are original mahogany Chippendale, a gift of Jane Austen's uncle, himself a Master of Balliol. This is not atypical—the furniture, art, china, and silver are commensurate with the architecture.

In Parting. Caltech has left its mark on Oxford. We found a brass plaque near a large sepia window in the Chapel at Magdalen that reads:

THE WEST WINDOW
was originally installed in the 1630s
and restored in 1996
in gratitude for a marriage
on Midsummer's Day 1975

John Hall Richards	Minnie McMillan
California and Magdalen	Somerville

Jack took his BSc degree at Oxford, and has been a chemistry professor at Caltech since 1957. In addition to Jack and Minnie, the porters, college heads, and Fellows remember John Bercaw, Chris Brennen, Marshall Cohen, Peter Fay, Roy Gould, Bob Grubbs, Morgan Kousser, Aron Kuppermann, Rudy Marcus, and, of course, George and Muriel. People also remember that Rhodes Scholars Norman Davidson and Nelson Leonard were returned to the United States in 1940 because of the "Gathering Storm."

For our parting gifts to our English friends, we followed in the path of the Beadles, who were very keen gardeners. The year we were there, the Chelsea Flower Show featured a pale pink trailing fuschia named "Harry Gray." We left Harry Gray in gardens all over the city. □

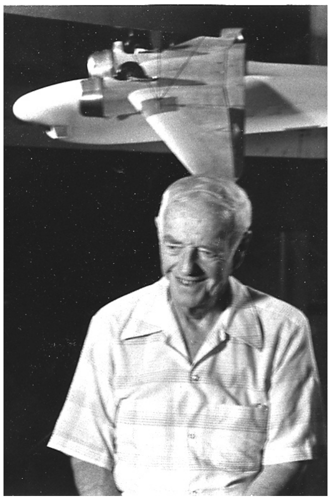
Shirley Gray is a professor of mathematics at Cal State L.A. Harry Gray, the Beckman Professor of Chemistry and director of the Beckman Institute, has been a Caltech fixture since 1966. An article on his work on solar photochemistry can be found in E&S, Volume LX, Number 3, 1997.

George Beadle was chairman of Caltech's Division of Biology in 1958, and won the Nobel Prize two days after he arrived at Oxford. He subsequently became a Caltech trustee, and president of the University of Chicago. In addition to being a professional journalist and writer, Muriel served the Caltech community in many ways, such as being president of the Women's Club.

And the Beadles' story continues—Nobel Laureate Paul Berg and Maxine Singer are frequent campus visitors, interviewing close friends of the Beadles and combing the archives in preparation for writing a scientific biography that will, we daresay, once again put Caltech in Blackwell's window.

PICTURE CREDITS:
28, 30, 32–35, 37 – Shirley Gray; 29, 33, 36 – Doug Smith; 30 – George Beadle; 32 – Eugene Kammerman; 35, 36 – Muriel Beadle

The Passing of a Man and His Era



William Bailey Oswald and the original DC-3 test model, shown here in Caltech's 10-foot wind tunnel, both starred in the PBS *Nova* show commemorating the plane's 50th anniversary in 1985.

William Bailey Oswald, PhD '32, who died on July 30, 1998, at the age of 92, was one of the outstanding figures of American aviation in the "heroic era" of its development, the roughly 30-year span during which commercial aviation reached maturity. He earned one of the very first PhDs in aeronautics awarded by the California Institute of Technology and was an outstanding representative of the type of modern aeronautical engineering that was the hope and aim of the new school of aeronautics led by Theodore von Kármán.

The year 1926 is remarkable in the history of aviation in the United States because in this year the Daniel Guggenheim Fund for the Promotion of Aeronautics was established with the aim of stimulating advanced training and research in the field. Robert A. Millikan recognized the importance of aviation for the U.S., in particular for California, and was able to obtain a grant of $300,000 to establish the Guggenheim Aeronautical Laboratory at Caltech (GALCIT). With surprising insight he chose von Kámán to lead the new school. Of the first three graduate students who completed their PhD degrees in the new school, one was destined to become a major player in the rapid expansion of aviation: William Bailey Oswald, known to practically everybody in or around aviation as "Ozzie."

A 10-foot wind tunnel, one of the most advanced facilities of its time, was designed and constructed as the major research facility of the new school. The GALCIT wind tunnel started operating in 1928 and, under the guidance of Clark B. Millikan, rapidly became a most important link between academia and industry. Practically every airplane designed in this country during the following quarter century was tested in this facility. Ozzie was one of the first who used the tunnel in cooperation with the Douglas Company. By a strange quirk of fate, Ozzie's first appearance at Caltech coincided with the birth of the tunnel; his last visit to the campus was occasioned by its decommissioning in 1997.

Ozzie came to Caltech in 1928 with a degree in physics from UCLA and was awarded his aeronautics PhD degree four years later with a surprisingly theoretical thesis: "The transverse force distribution on elliptical and nearly elliptical bodies moving in an arbitrary potential flow." The study was aimed at the motion of airships but consisted essentially of a rather complicated application of three dimensional potential theory. Ozzie's fame, however, originated with an NACA (National Advisory Committee for Aeronautics) report published in the same year: "General formula and charts for the calculation of airplane performance." For many years this report was the bible of aeronautical engineers faced with performance predictions. A. E. Raymond, chief engineer and later vice president of the Douglas Company, who at the time taught aircraft design at Caltech, had suggested the subject to Ozzie and in addition had hired him for the summer to work at the Douglas Company. It didn't take much longer before Ozzie was chief aerodynamicist at Douglas Santa Monica, and the summer extended to his full professional life.

The combination of a highly theoretical work, his thesis, and a very practical and down-to-earth report, NACA Rep. 408, completed in the same year, demonstrates the new trend in aeronautics of the time: in the design of a flying machine one cannot compensate for ignorance with safety factors. Even a safety factor of two

The first DC-3 (a DST—Douglas Sleeper Transport) appears about to run over a Northrop Gamma pursuit plane at Mines Field (now LAX) in 1936. The American Airlines flagship crashed at Chicago's Midway Airport in 1942.

will keep any design from getting off the ground. The designer has to be able to predict forces as well as the structural response very accurately indeed, and this requires a deep understanding of the physics, supplemented by a keen awareness of the limitation of theory and the corresponding need for empirical corrections. Even the advent of the modern computer has not much altered these requirements. When, some years later, the speed of aircraft started to approach or surpass the speed of sound, the need for a grounding in the basic physics and mathematics became even more obvious.

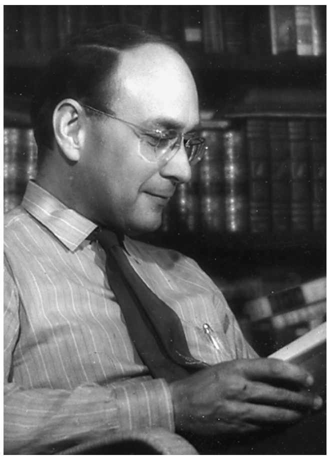
Ozzie's professional life spans the time in which commercial aviation developed from an adventure to routine and the speed range of aircraft progressed from low subsonic to transonic and supersonic speed. Probably the most spectacular success of the early Douglas team, in which Ozzie became a prominent member, was the legendary DC-3, an airplane that put commercial flying on the map and, as a byproduct, demonstrated the importance of a solid grounding in the basic science of aeronautics, competent wind-tunnel and flight testing, and the interaction between industry—Douglas—and academia—GALCIT. This cooperation, which involved not only aerodynamics but the structural dynamics of thin shells as well, is a classic example of the mutual beneficial interaction between an upcoming industrial corporation full of plans for new products and an academic research and educational team full of enthusiasm and new ideas. Of course, the number of design engineers at Douglas and the number of faculty members at GALCIT were at the time of the same order. The increase in speed, size, and sophistication of aircraft led obviously to an ever-increasing divergence in the number of professionals within the industry and academia. Similarly the necessary test facilities became too large and expensive to incorporate within academia. The rather short-lived Co-op wind tunnel owned by five cooperating aircraft industries and operated by Caltech required for its operation up to 30,000 kilowatts, some 40 times more than the GALCIT 10-foot tunnel. The interplay between academia and industry is certainly as important as ever, but necessarily and regrettably has to take a different shape than the easy intimacy in Ozzie's era.

Today transatlantic flights in aircraft with two engines has become routine, but the DC-1, prototype for the DC-3, had to demonstrate a flight, including take off and landing, with only one engine before the airlines accepted the configuration (three engines were usual). Once the two-engine plane was accepted, it completely dominated commercial flying until the end of WWII. During the war the DC-3 became the C-47, the flying jeep, and during the early Cold War made the Berlin Airlift possible. In many parts of the world the DC-3 still serves today, and short-hop airlines even in this country occasionally employ reconditioned DC-3s. No other commercial plane has approached this success.

With Ozzie as chief of aerodynamics, the Douglas commercial series went on through the propeller-driven DC-4 and DC-6 to the jet-propelled DC-8. Each one adopted an essentially new design feature: the DC-4, the nose wheel; the DC-6, pressurization; and the DC-8, turbo-jet propulsion. Ozzie's hopes and expectations for an American supersonic, commercial plane unfortunately did not materialize during his time.

Ozzie is survived by his wife, Lucia, and any account of Ozzie's life would be incomplete without a few words about her. Indeed Lucia, known to all Douglas team members as the genial hostess for their famous yearly party, already appears in the early days of the DC-3: as part of the Douglas team, Ozzie participated in a sales trip to TWA in Kansas City. He apparently directed and delayed the return car trip to California by insisting that every day he had to be in a preprogrammed city where a letter from his fiancée was waiting for him in General Delivery. Sixty-three years later Lucia brought Ozzie in a wheel chair to GALCIT for his last visit.

Hans W. Liepmann
Theodore von Kármán Professor of Aeronautics, Emeritus
Director, GALCIT, 1972–85



John Scott Campbell 1912–1999

John Scott Campbell, who was an instructor in engineering design at Caltech from 1947 to 1954, died in Pasadena on January 7, 1999, at the age of 86. Although Caltech was only one square in his checkered professional career, he was an extremely popular teacher, several of whose devoted former students called or wrote in to note his death. He taught drafting on the top floor of Throop Hall, under the eaves, remembers Howell Tyson Jr., '50. Campbell assisted Tyson's father, who was professor of mechanical engineering, in courses on descriptive geometry and kinematics, and edited the senior Tyson's textbook for publication after the professor's death in 1966. During the war Campbell had also worked on Caltech's Eaton Canyon rocket project, where he developed instrumentation for pressure and thrust at the static-firing bay for the Sidewinder, Tiny Tim, and Bazooka rockets.

Campbell also wrote the music and lyrics for an opera called *Spooks in the Basement*, which, as well as his "Double Double Concerto" for two base viols and orchestra, was performed in Caltech's late Culbertson Hall. This was recalled by Walter Chamberlin, who had been a student of Campbell's at Pasadena Junior College (now Pasadena City College), where Campbell had written a play for the engineering club that climaxed in a sword fight with slide rules. He also wrote science fiction for *Amazing Stories* magazine.

His sense of adventure kept pulling him away from his Hill Avenue home, across from the Athenaeum. In the 1940s, according to an obituary Chamberlin wrote for the *Pasadena Star-News*, Campbell bought a bus and ran tours of Southern and Central California. In the '50s, he founded the Pacific Institute of Technology, which failed to attract the necessary funding, and in the '60s he conceived the idea of a floating college to offer "A Semester at Sea." He tried to buy a French ocean liner but had to settle for the 570-ton *Aquillo.*

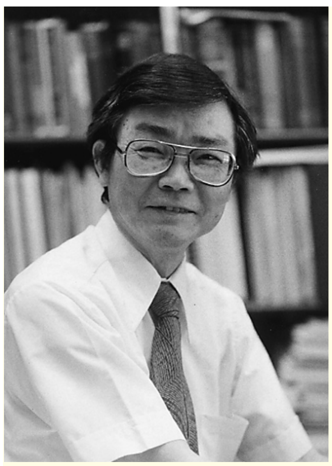
"John well knew the physics principles," wrote Chamberlin, "but lacked hands-on maritime experience. Therefore, there were at least three significant accidents. First, he miscalculated the stopping time of 570 tons and, on returning to the harbor, smashed a pier. . . . Second, he managed to get the *Aquillo*

Albert W. Atwood Jr., BS '32, MS '33, died September 2, 1998, in Pasadena. Atwood was the first editor of the *Caltech Alumni Review*, predecessor of *Engineering & Science* (R. A. Millikan rechristened it in 1943). In June 1937, when the first issue was published (on an Alumni Association grant of $150), Atwood was back on campus as the resident engineer for the Metropolitan Water District at Caltech's Pump Lab. Atwood said in a 1987 interview that he was able to manage his job and the magazine at the same time because the Pump Lab shared motors with the 10-foot wind tunnel and could perform tests only when the wind tunnel wasn't running. This was usually at night, leaving him the daylight hours for his journalistic activities. Atwood had never intended to be a journalist, but, since his father was a well-known writer for the *Saturday Evening Post* and *National Geographic*, he seemed to inherit a reputation. It was "the bane of my life all through school," Atwood said in 1987. "English teachers would expect me to be a writer too, and I wasn't." In September 1938 Atwood turned over the editorship of the *Caltech Alumni Review* to Ted Combs, BS '27, and went on to a long and distinguished career as an electrical engineer with Southern California Edison.

tightly wedged under a bridge. That tied up traffic for hours. . . .” The final mishap occurred during a run from Seattle to Long Beach, when the *Aquillo* encountered a storm that sent various unsecured items, including a piano and a propane tank, banging loose around the ship. The propane tank set the engine room on fire, and when the Coast Guard responded to save the *Aquillo* for the third time, “they kept right on pouring water until at last, to their great relief and John’s disappointment, they sank both the fire and *Aquillo*. That put a real damper on the hoped-for semester at sea in 1963.”

Despite the collapse of his entrepreneurial educational efforts, Campbell continued to teach engineering design at Art Center College of Design in Pasadena until a few months before his death. And, undefeated, he persevered at his extracurricular activities as well.

“John was also an inventor,” wrote Chamberlin. “In about 1925 he was awarded a patent for the inverse feedback circuit, a vital part of all modern electronic systems. Unfortunately, that patent expired long before it was recognized by industry. Also, about that time he invented the metal detector. Neither of these inventions gained him anything.” More recently, he invented a mechanism that could create a force without a reaction, which he thought would make fixed-wing aircraft and helicopters obsolete. The final crucial test failed last summer, according to Chamberlin. “As you can imagine, John’s heart was broken. That failure, along with a serious heart condition, sent his health in a downward spin and hastened his demise.”



Toshi Kubota, professor emeritus of aeronautics, died February 1, 1999, at the age of 72.

A native of Westmorland, California, Kubota received his bachelor of engineering degree in 1947 from the University of Tokyo. Returning home from Japan for graduate studies at Caltech, he earned his MS in 1952 and his PhD in 1957. Kubota remained at Caltech as a research fellow for two years before becoming an assistant professor in 1959. He was named associate professor in 1963 and full professor in 1971.

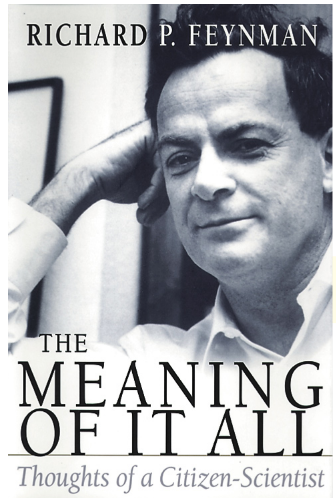
When he retired in 1990, he was honored with the establishment of the Toshi Kubota SURF Aeronautics Fellowship to “perpetuate the spirit and tradition of outstanding teaching, mentoring, and interest in undergraduate students demonstrated by Toshi.” The SURF (Summer Undergraduate Research Fellowship) fund “will ensure that Toshi’s legacy of commitment to the education . . . of young people continues.”

During his 43 years at Caltech, Kubota did much research in the field of fluid mechanics, focusing on topics such as hypersonic wake flows, supersonic turbulent shear flows, and supersonic boundary layer separation. He also served as a consultant to several engineering companies ranging from TRW to Lockheed.

In addition, Kubota held positions in the Society of Sigma Xi, the Physical Society of Japan, the American Physical Society, and the American Institute of Aeronautics and Astronautics.

He is survived by his wife, Yoshiko Phebe Nihira, and his three children, Misa Sophia, Miya Eliza, and Yuri Susan.
—DT

Letters



Feynman’s Meaning

“Look at the ideas themselves and judge them directly. . .” (p. 61). Do not accept them on the basis of authority. Question, question, question, especially, your own ideas. Look at problems from all angles. Try to determine what is wrong with your solution (before someone else does).

If there was one admonition Richard Feynman tried to convey to everyone, this was it. Regrettably, until *The Meaning of It All* came along, this message was imparted only indirectly, as in Feynman’s contribution to the *Challenger* investigation.

At long last this material is available to those who did not have the memorable opportunity to witness the occasional, impromptu gatherings where R. P. would expand on these, and somewhat more technical matters, at some length and in considerable detail. These were not “off-the-cuff” meanderings, but carefully thought-through analyses, delivered straight and seasoned with his special touch of humor. Despite the intervening years, Feynman’s voice rings in every word of the text, and his playful, adventuresome spirit of discovery is unmistakable.

While it is Chapter III, “This Unscientific Age,” in which Feynman goes to considerable lengths to advise us on how to judge the validity of an idea, it is in Chapter I, “The Uncertainty of Science,” and Chapter II, “The Uncertainty of Values,” where he

Karvel Thornber heard Feynman speak on innumerable occasions during his undergraduate and graduate years at Caltech and worked closely with him in 1965–66 solving a problem suggested by Carver Mead. He says that "in May 1966, Feynman stated that he enjoyed the problem because for so long we had had no idea how (or even if) it would eventually turn out. Many of the questions raised in The Meaning of It All *were still on his mind during this period.*

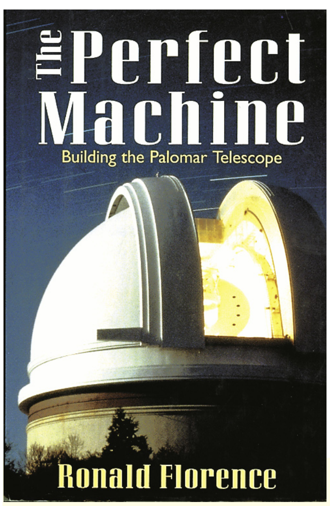
lays the foundations of his philosophy. He does this most adroitly by first motivating the nature, especially the excitement, of science, in layman's terms, and based on this as preparation, directly focusing on the meaning of life. He then briefly calls attention to the most intriguing problem of self-reference, "this thing [man] that looks at itself and wonders why it wonders," followed by an objective outline of the complementary roles of religion and science. Regarding the pursuit of science, Feynman writes, "The imagination of nature is far, far greater than the imagination of man" (p.10), and, "If you look closely enough at anything, you will see that there is nothing more exciting than the truth, the pay dirt of the scientist, discovered by his painstaking efforts."

Having transmitted the excitement of the adventure of science to the reader, along with the caveat that "all scientific knowledge is uncertain" (p. 26), he applies his experience with doubt and uncertainty to the question of the meaning of it all. And, in a manner so characteristic of the novelty of his insight, concludes "that we do not know. But I think that in admitting this we have probably found the open channel" (p. 33). By keeping our options open, he feels we will find what we want even if we do not know what that may be. "It is in the admission of ignorance and the admission of uncertainty that there is hope for the continuous motion of human beings in some direction that does not get confined, permanently blocked, as it has so many times before in various periods in the history of man" (p. 34). The second lecture concludes with his case for complete intellectual freedom.

I have carefully read this book and found it to be quite authentic. In sharp contrast to the concluding paragraphs of David Goodstein's review (*American Scientist* 86 (4), pp. 374–7, July–August, 1998, and *Engineering & Science* 61 (2), pp. 38–40, 1998), I feel it is an important addition to Feynman's writings. Readily accessible to a broad audience, it provides a rare insight into his assessment of a variety of issues of interest during the '50s and early '60s, his important post-QED but pre–Nobel Prize period. By all means buy a copy of this book before it goes out of print.

Finally, although I very much admire Goodstein for his raising of the issues, I do not agree that this book honors neither Feynman's wishes nor his memory. Were Feynman alive, this book would, of course, be regarded as a publication summarizing his philosophy regarding the issues he raises, and he would be held duly responsible for any apparent lack of scholarship. But clearly this is not the case. First, Feynman himself provides the disclaimer (p. 61). Second, and more to the point, this book is a historical document (pp. vii, ix). It expresses how one very introspective and imaginative person thought in 1963 on issues still largely unresolved 35 years later. It is to his credit that he attempted to grasp problems beyond our reach. All of us leave behind unfinished works; often these concern problems we believe to be important. Alive, they are our responsibility; after our life, they become everyone's responsibility.

Karvel Thornber, BS '63, MS '64, PhD '66



The previous issue of *Engineering & Science* (1998, No. 3) carried a brief story commemorating the 50th anniversary of the dedication of the Hale 200-inch telescope on Palomar Mountain. Anyone desiring to learn the whole story of the Hale Telescope from its conception should read Ronald Florence's book *The Perfect Machine* (HarperCollins, 1994), which provided background material for the article.

Lab Notes

Prof. Kevles (*E&S*, No. 3, 1998) would attribute the prominence and longevity of the "Baltimore case" to congressional thirst for publicity coupled with media ignorance, arising within a climate of suspicion and fear of biological science. This climate in turn presumably originated with the debut of genetic engineering, the recombinant DNA debate, the prospect of cloning, et al. Concurrent issues of corruption and fraud elsewhere in public life also tainted the general atmosphere.

Likely all true. But the Baltimore case had another singular component that confused and prolonged the issue. This controversy centered around a novel and quite surprising scientific result, which was certain to draw careful scrutiny of the evidence presented. And as the issue proceeded, it developed that that evidence relied upon records maintained in such a slovenly fashion that it was not necessarily unreasonable to question their validity.

The principals were—in my view, appropriately—ultimately exonerated of fraud. But—also in my view—the longevity and intensity of conflict in this case derived in no small part from the revelation of the disorderly and seemingly capricious handling of the underlying research records.

Robert L. Sinsheimer
Professor Emeritus
Department of Molecular, Cellular and Developmental Biology, University of California, Santa Barbara

Dan Kevles replies:

Yes, Imanishi-Kari was something of a sloppy record keeper, but her habits in this regard had nothing to do with prolonging the case for the (unconscionably) long period of a decade. What had everything to do with it was the search for evidence of fraud by a congressional subcommittee and an investigative agency of government that began in 1989 and that through the next six years denied Imanishi-Kari elementary rights of due process, including the right to see the evidence against her and to confront and cross-examine the witnesses against her.

John Brady

Ken Farley

Honors and Awards

Associate Professor of Political Science R. Michael Alvarez and Associate Professor of History William Deverell have been selected to receive 1999 Haynes Foundation Faculty Fellowships.

Harry Atwater, associate professor of applied physics, has been elected by the Materials Research Society to serve on its executive committee and council for three years—one year each as vice president (1999), president (2000), and past president (2001). His term commenced on January 1.

Professor of Chemistry Jesse Beauchamp (BS '64) has been selected as the 1999 recipient of the American Chemical Society's Peter Debye Award in Physical Chemistry, which is sponsored by DuPont.

John Bercaw, Centennial Professor of Chemistry, will be the recipient of the American Chemical Society's 1999 George A. Olah Award in Hydrocarbon or Petroleum Chemistry.

Seymour Benzer, Boswell Professor of Neuroscience, Emeritus, and Crafoord laureate, has been named a 1998 Ellison Medical Foundation Senior Scholar as part of the Ellison Medical Foundation Senior Scholars in Aging Program. Benzer's current research centers around the "Methuselah" gene, which, when mutated in fruit flies, increases the fly's life span by one-third. It is not yet known whether humans carry an analogous gene.

John Brady, Chevron Professor of Chemical Engineering and executive officer for chemical engineering, has received the Professional Progress Award for Outstanding Progress in Chemical Engineering from the American Institute of Chemical Engineers. Given to a person under the age of 45 who has made a significant contribution to the science of chemical engineering, the award is sponsored by Air Products and Chemicals, Inc.

Peter Dervan, Bren Professor of Chemistry and chair of the Division of Chemistry and Chemical Engineering, will receive the American Chemical Society's 1999 Alfred Bader Award in Bioinorganic or Bioorganic Chemistry.

Associate Professor of Geochemistry Kenneth Farley has been selected to receive the James B. Macelwane Medal of the American Geophysical Union, "which is awarded for significant contributions to the geophysical sciences by a young scientist of outstanding ability."

Petr Horava, Sherman Fairchild Senior Research Fellow in Physics, has been awarded a Junior Prize of the Learned Society of the Czech Republic for outstanding research in theoretical physics.

Hans Hornung, Johnson Professor of Aeronautics and director of the Graduate Aeronautical Laboraories, will be awarded the 1999 Ludwig-Prandtl ring at the annual congress of the DGLR (the Geman Society for Aeronautics and Astronautics) in Berlin in September. The award is given to one person per year in academia or industry for his or her contributions to aeronautics and astronautics. Previous Caltech recipients include Theodore von Kármán, who got the first one in 1957, and Hans Liepmann.

Norman Horowitz (PhD '39), professor of biology, emeritus, has received the 1998 Thomas Hunt Morgan Medal, which "recognizes a lifetime contribution to genetics," from the Genetics Society of America, which cited not only his impact on genetics and evolutionary biology, but his contribution to the scientific education of the public. As a grad student, he assisted in experiments performed by Thomas Hunt Morgan, the medal's namesake and the first chairman of Caltech's Division of Biology, who won the Nobel Prize in 1933 for his work in genetics.

Matthew Jackson, professor of economics, has been elected a Fellow of the Econometric Society.

H. Jeff Kimble, Valentine Professor and professor of physics, has received the 1998 International Award on Quantum Communications from the Fourth International Conference on Quantum Communication, Measurement, and Computing "for his outstanding experimental advances in the areas of quantum measurements, cavity QCD, and quantum logic."

Nobel Laureate Rudy Marcus, Noyes Professor of Chemistry, was honored at the American Chemical Society's 216th National Meeting as one of the "Top 75 Distinguished Contributors to the Chemical Enterprise" by *Chemical & Engineering News*.

Gerry Neugebauer (PhD '60), Millikan Professor of Physics, Emeritus, has been awarded the 1998 Herschel Medal by the Council of the Royal Astronomical Society "for his inspiring leadership within the astronomical community."

Anatol Roshko (MS '47, PhD '52), von Kármán Professor of Aeronautics, Emeritus, has been selected to receive the University of Alberta's Distinguished Alumni Award for "his outstanding career and important contributions in the fields of gas dynamics, fluid mechanics, and aerospace engineering." He received his BSc from Alberta in 1945.

Anneila Sargent (MS '67, PhD '77), professor of astronomy and director of the Owens Valley Radio Observatory, has been presented with the NASA Public Service Medal, "in recognition of [her] leadership, dedication, and commitment to NASA as a member of the NASA Advisory Council and as Chair of the Space Science Advisory Committee."

Wallace Sargent, Bowen Professor of Astronomy and director of the Palomar Observatory, has been elected an associate of the Council of the Royal Astronomical Society in recognition of "his inspiring leadership within the astronomical community and outstanding work in observational astrophysics."

Thomas Wolff, professor of mathematics, has been selected as a corecipient of the 1999 Bocher Prize, which honors research in the mathematical field of analysis, "for his contributions to the theory of harmonic analysis."

Professor of Physics Nai-Chang Yeh has been selected by the Overseas Chinese Physics Association as the winner of the 1998 Outstanding Young Researcher Award "for her outstanding achievements in physics."

Ahmed Zewail, Pauling Professor of Chemical Physics and professor of physics, has received two medals from the American Chemical Society for his work in femtochemistry. The 1998 William H. Nichols Medal was awarded by the New York Section and the Nichols Medal Jury, while the 1997 Linus Pauling Medal was awarded by the Oregon, Portland, and Puget Sound Sections.

Three Caltech faculty members have been elected to the National Academy of Engineering: Chevron Professor of Chemical Engineering John Brady, Professor of Applied Mechanics Wilfred Iwan (BS '57, MS '58, PhD '61), and William Johnson (PhD '75), Mettler Profesor of Engineering and Applied Science.

Beckman Wins Public Welfare Medal

The National Academy of Sciences (NAS) has selected Arnold O. Beckman (PhD '28), life trustee and chair emeritus of the board of trustees, to receive the Academy's most prestigious award, the Public Welfare Medal. Beckman was chosen for his leadership in developing analytical instrumentation and for his deep and abiding concern for the vitality of the nation's scientific enterprise. Established in 1914, the Public Welfare Medal is presented annually to honor extraordinary use of science for the public good. Previous recipients include Vannevar Bush, C. Everett Koop, and Carl Sagan. The NAS Public Welfare Medal, consisting of a bronze medal and an illuminated scroll, will be presented to Beckman during the NAS annual meeting in April 1999. The National Academy of Sciences is a private, nonprofit institution that provides science advice under a congressional charter.

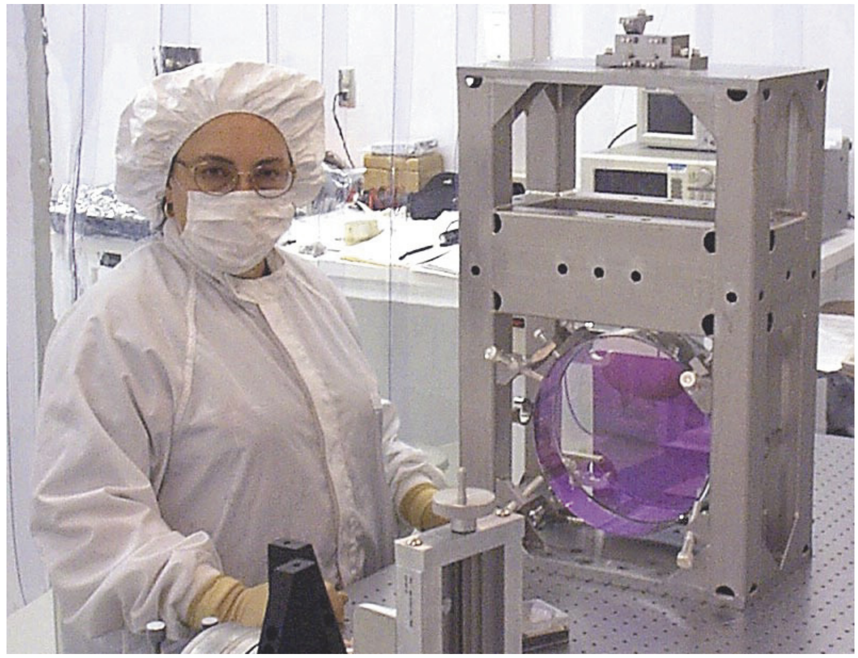
Anderson Wins National Medal of Science

Don L. Anderson (MS '58, PhD '62), McMillan Professor of Geophysics and a Crafoord laureate, has been named a 1998 recipient of the National Medal of Science—one of nine Americans to be awarded the country's highest scientific honor. The announcement was made on December 8, 1998 at the White House by President Clinton, who cited the nine for "their lifetime of passion, perseverance, and persistence to bring about new knowledge that extends the limits of their fields and drives our nation forward into a new century." Anderson was cited for his contributions in understanding the processes of Earth and Earth-like planets, as well as his promotion of the earth sciences.

The National Medal of Science was established by Congress in 1959 to be bestowed annually by the President of the United States. The first Medal of Science was awarded by John F. Kennedy in 1962 to Caltech's Theodore von Kármán, a pioneer of aerospace engineering. To date, 362 American scientists have been awarded the Medal of Science. Of these, 44 have been Caltech professors and alumni.

LIGO Honored

LIGO (Laser Interferometer Gravitational-Wave Observatory; see *E&S,* No. 2, 1998) won the Distinguished Engineering and Science Project Achievement of the Year Award for 1999, from the Engineering Council (a group of large engineering organizations). LIGO was nominated by the Parsons Infrastructure & Technology Group Inc., which acted as architect/engineer on the project. The award was presented to LIGO Deputy Director Gary Sanders in a ceremony on February 27. Meanwhile, work on LIGO continues toward its turn-on date in 2001.



At the Hanford, Washington, site (the women behind the mask is Helena Armandula) one of the exquisitely sensitive fused-silica mirrors was recently hung in its mounting. Waiting to pick up a gravity-wave signal, laser beams will bounce back and forth between mirrors such as this one, hung kilometers apart. The purple surface on the mirror is a multilayer stack of alternating dielectric materials that is highly reflective to the laser's infrared light.

And (right) at the LIGO site in Livingston Parish, Louisiana, Allen Sibley works on the vacuum equipment, housed at the meeting point of LIGO's two four-kilometer-long beam tubes, through which the laser beam passes.

Engineering & Science

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