California Institute of Technology

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Volume LXVI, Number 4, 2003

The Mudeo returned to Caltech after a six-year absence. Organized by Jeff Cox, a senior in mechanical engineering, it happened on January 19. Mudeos are traditionally held at construction sites, in this case the future home of a 700-space underground parking structure going in beneath the athletic field north of the gymnasiums. The decades-old tradition is designed to maximize the muck per square inch of skin, with events including a tug o' war, wheelbarrow races, a "tire spree," keep-away, and wrasslin' matches. What does one wear to a Mudeo? "Whatever you don't mind throwing away," says Cox.

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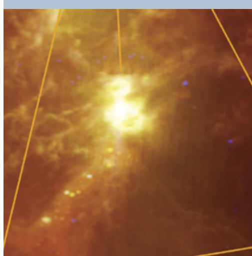

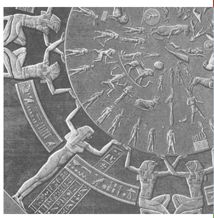

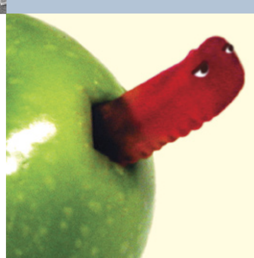

On the cover: Like the five blind men's descriptions of the elephant, how the cosmos appears depends on who's looking. The Elephant's Trunk Nebula, which lies in IC 1396, 2,450 light-years off in the constellation Cepheus, is an ebony blotch to our eyes (inset). But to the Spitzer Space Telescope's infrared vision, it becomes a luminous womb. One of the two bright young stars in the central void was seen only dimly before, indicating it may still be surrounded by its placental planet-forming disk. For more on the Spitzer, see page 8.

Cover image credits: Spitzer image—NASA/JPL-Caltech/W. Reach (SSC/Caltech); inset image—Canada-France-Hawaii Telescope/J.-C. Cuillandre/Coelum, and the Digitized Sky Survey

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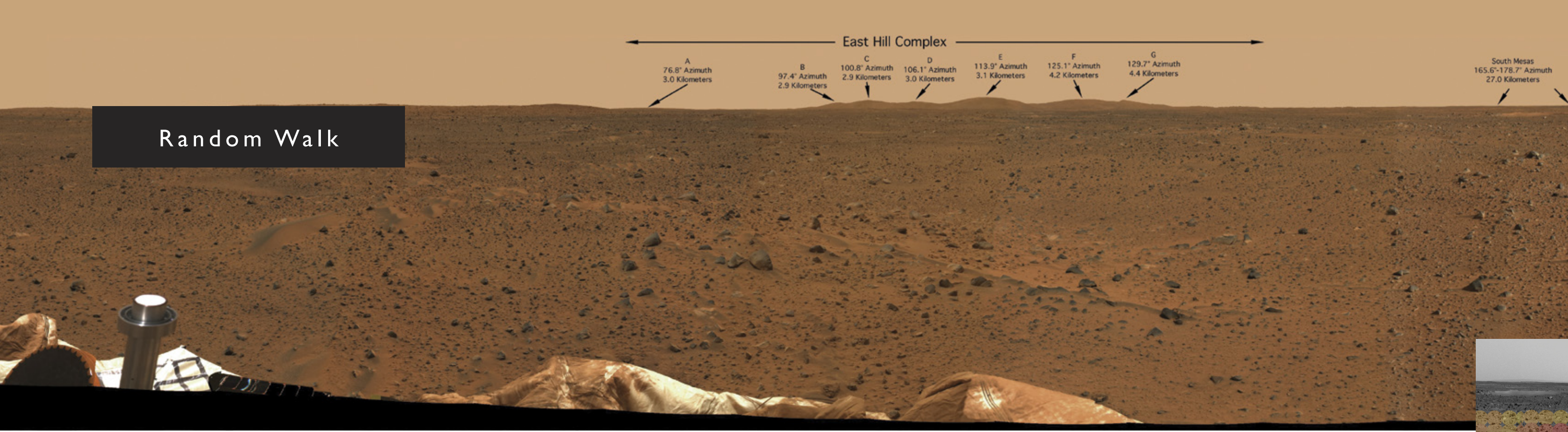
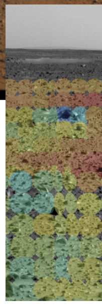




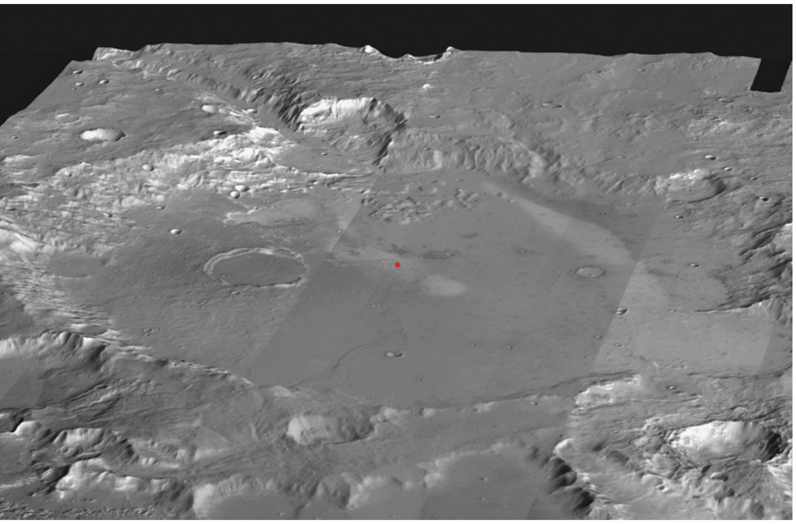
Above: This 360-degree panorama was taken before Spirit turned 115° clockwise to roll off the northwest ramp. The camera mast is also a periscope for the mini Thermal Emission Spectrometer (mini-TES), which sees infrared light; that is to say, heat. Warm, red regions like the shallow depression in the distance tend to be dusty, and perhaps treacherous. The infrared spectral data also help the geologists decide which rocks are worth visiting. In the inset, mini-TES data are superimposed on a corresponding panoramic camera image.

We're Baaack. . .

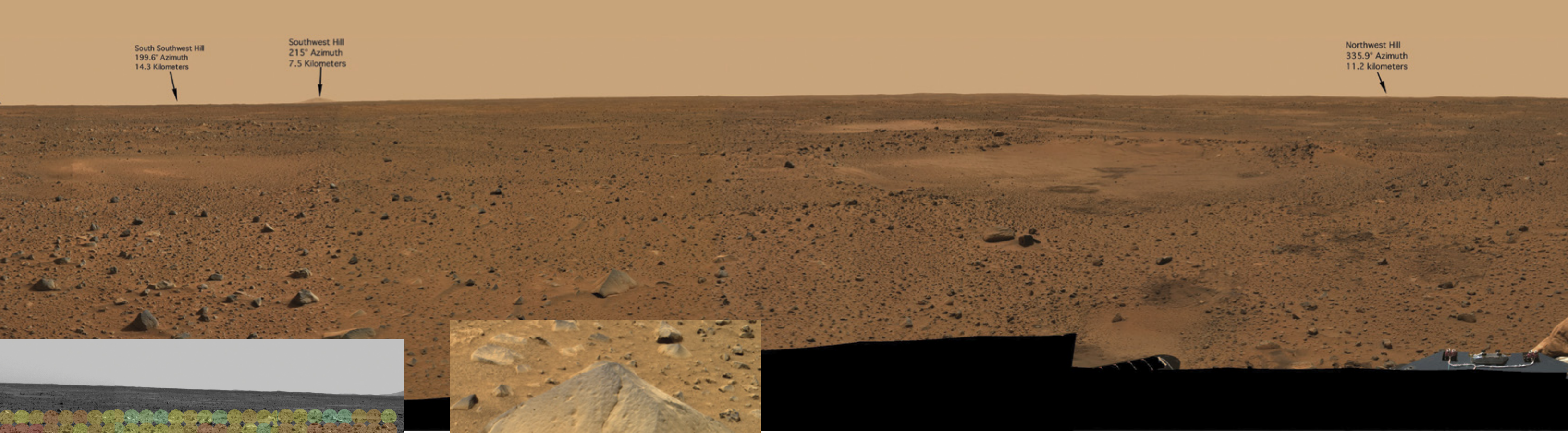
Above: NASA Administrator Sean O'Keefe pours champagne for, from left, Mars Exploration Rover Project Manager Pete Theisinger (BS '67), Deputy Project Manager Richard Cook, and Rover Entry, Descent, and Landing (EDL) Development Manager Rob Manning (BS '82) at the post-landing press conference on January 3.

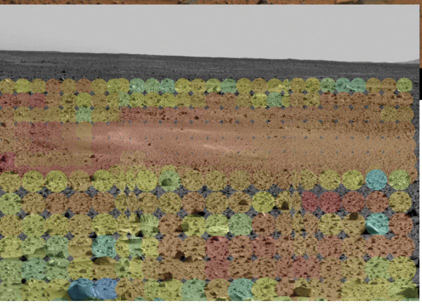
Unless you've been living under a rock yourself, you know that a JPL Mars rover named Spirit has rolled off its lander and is preparing to sample rocks. (Spirit's twin, Opportunity, was still en route as *E&S* went to press.) These robot geologists are the next best thing to being there. Each stands about five feet tall, so its panoramic camera gives us a human's-eye view of the landscape; its Swiss-Army-knife tool arm is about as long as a human's; and the arm's microscopic imager is the strength of a geologist's loupe, discriminating things as small as a grain of salt—all in hopes of positively identifying rocks that on Earth only form in the presence of water. It can turn in its own length, clear basketball-sized rocks, and traverse a 45° slope without tipping over. And it has to think for itself—since it takes about 10 minutes for a radio signal to reach Mars, you can't drive it with a joystick. You just give it marching orders.

This amazing machine is only beginning to get to work, but here's the story so far. ☐—*DS*

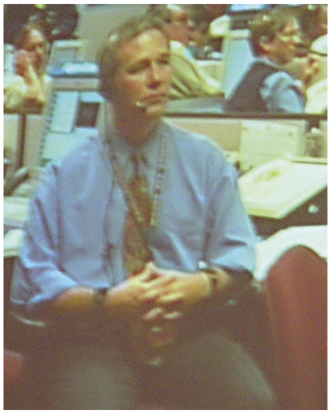


Left: Spirit (red dot) landed in Gusev Crater, which may once have held a lake slightly smaller than New Jersey. Ma'adim Vallis enters Gusev from the south (at top in this image) after running some 900 kilometers—about the distance from Baton Rouge to St. Louis—and appears to have been carved by flowing water about two billion years ago. (This Mars Odyssey daytime infrared image was draped over Mars Global Surveyor [MGS] topography.) Right: Spirit's planned itinerary includes a jaunt of some 250 meters to a 192-meter-diameter crater dubbed Sleepy Hollow by the jet-lagged mission team. With luck, clambering down into the crater's interior will give access to older subsurface rocks that may reveal a sedimentary history. Then we'll head for the (East) hills, two to three kilometers away. The long arrow points to Hill B—the black blob at the top (south) of this image, which is a composite of MGS photos and images from the lander's descent camera. The dark streaks are dust-devil trails.



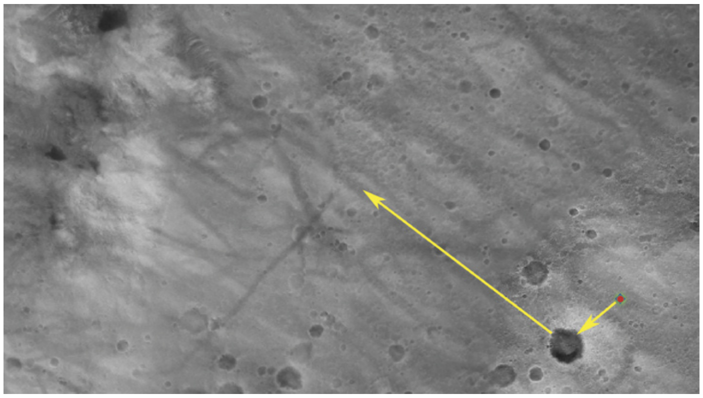


Left: Spirit's first target is Adirondack, a football-sized rock chosen for its flat, dust-free surface. (Adirondack can be seen in the panorama directly above the inset.) After exposing the rock's interior with an abrasion tool and determining its composition by both Mössbauer and alpha-particle X-ray spectrometry, Spirit will make its way by easy stages to Sleepy Hollow, the crater in the middle distance directly above. The patches of disturbed soil on Sleepy Hollow's floor may be bounce marks.



Left: Those patches may resolve a mystery—the top layer of soil scraped up by one deflating airbag crumpled up and peeled away almost as though it was wet sand overlaying dry, which it clearly is not. Spirit can't examine this area, called the Magic Carpet, for fear of getting fouled in the airbag, so perhaps the same soil-peeling process will be found to be at work where the airbags bounced.

Above, left: Spirit Mission Chief Mark Adler (PhD '90) practices patience as Mission Control waits to hear if Spirit survived its landing. The rover should have bounced to a stop in five minutes or so, but there was no signal for nearly 10. Right: That's more like it! Adler and EDL Chief Engineer Wayne Lee celebrate as the first pictures begin to come down. Below, right: The rovers are solar powered, so team members must live and work on Mars time. Garo Anserlian, of Executive Jewelers in nearby Montrose, has modified several batches of 21-jewel timepieces by inserting precisely calibrated lead weights into their works to slow them to match the Martian day, which is about 39 minutes longer than an Earth day.

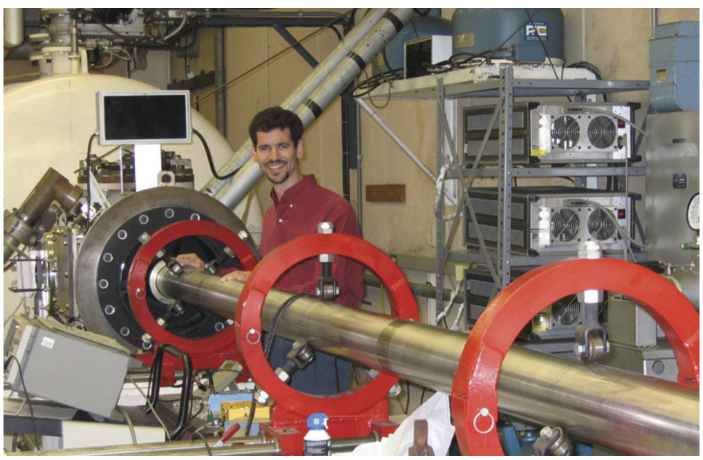


Right: It's a bird! It's a plane! It's grad student Sean Humbert taking wing from a medieval siege engine known as a trebuchet (that's French for "Really Big Catapult") into the bracing waters of San Francisco Bay.

Between a Rock and a Hot Place

Earth's core-mantle boundary is a place none of us will ever go, but Caltech researchers using a special high-velocity cannon have shown that there may be molten rock there, at a depth of about 1,800 miles. Further, it may have rested peacefully at the interface between the rocky mantle and the metallic core for eons.

At the fall meeting of the American Geophysical Union, Professor of Geophysics Thomas Ahrens (MS '58) reported new measurements of the density and temperature of magnesium silicate—the stuff found in Earth's interior—when it is subjected to the conditions that exist at the planet's core-mantle boundary. The team did their work in Caltech's shock-wave laboratory, where an 80-foot light-gas gun is specially prepared to fire one-ounce tantalum-faced plastic bullets at mineral samples at speeds up to 220,000 feet per second—about a hundred times faster than a bullet fired from a conventional rifle. The resulting impact replicates the 1.35 million atmospheres of pressure and the 8,500 degrees Fahrenheit that exist at the core-mantle boundary.



Paul Asimow operating the supergun.

The bullets were fired at natural semiprecious gem crystals of Sri Lankan enstatite—a form of magnesium silicate—as well as synthetic glass of the same composition. Upon compression, these materials transform to the 30-percent-denser structure called perovskite that dominates Earth's lower mantle at depths from 415 miles to the core-mantle boundary.

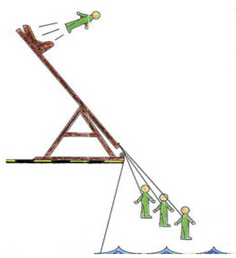
Ahrens and Assistant Professor of Geology and Geochemistry Paul Asimow (MS '93, PhD '97), along with grad students Joseph Akins (MS '99, PhD '03) and Shengnian Luo (MS '01, PhD '03) demonstrated that the perovskite form of magnesium silicate melts at the pressure of the core-mantle boundary to produce a liquid whose density is greater than or equal to the mineral itself. This is highly unusual—most solids are denser than their melted form. Water is an exception, which is why lakes under the ice in Antarctica don't freeze all the way down to the bottom. Similarly, this implies that a layer of partially molten mantle would be gravitationally stable at the core-mantle boundary over geologic timescales.

The work was motivated by the discovery of ultralow-seismic-velocity zones at the base of Earth's mantle by Donald Helmberger, the Smits Family Professor of Geophysics and Planetary Science, and Edward Garnero (PhD '94), now a professor at Arizona State University. Most prominent beneath the mid-Pacific region, these zones appear to be 1-to-30-mile-thick layers of rock at the base of the mantle that behave like molten material. Many researchers assumed that this partially molten zone might represent atypical mantle compositions, such as a concentration of iron-bearing silicates or oxides with a lower melting point than ordinary mantle—about 7,200°F at this pressure. The new results, however, indicate that no special composition is required. □—*RT*

Not First Class, But Plenty of Leg Room

At the 2003 Red Bull Flügtag San Francisco, held in October, the kilt-clad team El Toro Guapo (“the handsome bull”) took first prize by adapting a trebuchet to lob a human into the bay rather than a rock over a castle wall. Sean Humbert (MS ’99), grad student in mechanical engineering, volunteered to be flung from the “Medieval Missile”—or perhaps he was the only one crazy enough to do it—and was launched into the air when Brent Hedgpeth, Brent Holloway, Ted Scheel, and Dave Campbell, harnessed to the other end of the throwing arm, jumped off the 30-foot-high pier. (A Flügtag is a tongue-in-cheek human-powered flight competition.)

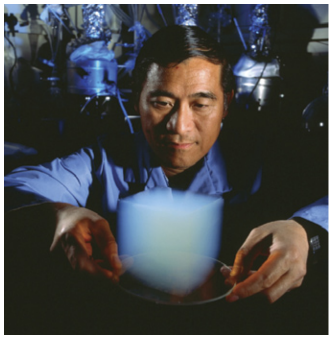
“The only preparation or training we were able to do was with a one-fifth scale model, from which we launched several weighted Barbie dolls to verify my computer simulation,” said Humbert. He was catapulted out of the specially designed wooden chair at a velocity of about 30 miles per hour, not knowing if what had worked for an overweight Barbie would also work for him. “The initial acceleration whipped my neck forward quite a bit,” he recalls, “but within a fraction of a second I was tossed out 50 feet above the water. Time seemed to stop and I couldn’t hear any sounds as I glided to a feet-first landing 61 feet from the end of the pier.” This is the second year in a row that El Toro Guapo has won the Frisco Flügtag, and Humbert is already working with aeronautics grad student James Faddy on the entry for 2004. And in case you were wondering what was under those kilts: their modesty was preserved by scarlet Speedos. □—*BE*

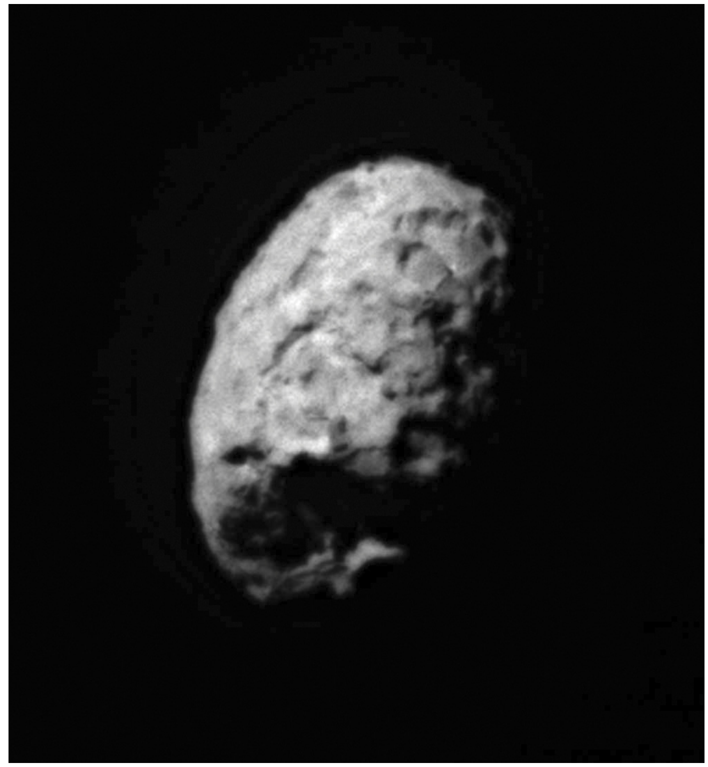


Caltech Wins Olympic Gold—in Physics

Three incoming freshmen were medalists at the 34th International Physics Olympiad, held in Taipei, Taiwan in August. The annual event is the world’s major physics competition for secondary-school pupils, and students from 54 countries participated. Axline scholar Pavel Batrachenko, who is originally from Moscow, had the highest overall score, 42.30 points, and won a gold medal; Axline and Lingle Scholar Emily Russell, from Yorktown Heights, New York, and Yernur Rysmagambetov, originally from Kazakhstan, each took silver. Russell was also named Best Female Participant. Russell and Batrachenko are majoring in physics, and Rysmagambetov is majoring in computer science. □

Right: In October, William and Delores Bing played for the Los Angeles Master Chorale’s first concert in its stunning new home, the Frank Gehry–designed Walt Disney Concert Hall. William Bing is director of bands at Caltech and a lecturer in concert band and jazz band, and Delores directs the chamber music program.





Far right: An image of comet Wild 2 (pronounced Vilt-2, with a Swiss accent) taken by JPL's Stardust spacecraft on January 2 shows the pockmarked, roughly spherical nucleus, with one hemisphere in sunlight, the other in shadow, similar to a view of the quarter-moon from Earth. The craft got to within 240 kilometers of the comet, protected from the sandblasting stream of cometary particles by laminated shields of five sheets of carbon filament and ceramic cloths. Stardust captured some of the particles in aerogel, the silicon-based porous material developed at JPL that's so light, it's almost not there (shown above with Peter Tsou, Stardust's deputy principal investigator), and will drop them off in Utah on January 15, 2006—the first comet samples in the history of space exploration, and the first time any material has been deliberately brought back from deep space. Tom Duxbury, Stardust's project manager, remarked that it couldn't have gone better in a fairy tale. And co-investigator Ray Newburn (BS '54, MS '55) added, "These images are better than we had hoped for in our wildest dreams. They will help us better understand the mechanisms that drive conditions on comets."

Spring Watson Lectures Set

John Schwarz, the Harold Brown Professor of Theoretical Physics, kicks off the spring Watson lecture series on February 11 with a talk titled "String Theory: Past, Present, and Future," followed on March 3 by Professor of History Robert Rosenstone with "Inventing Historical Truth on the Silver Screen." On March 31, Richard Murray (BS '85), professor of mechanical engineering and chair of the Division of Engineering and Applied Science, will present "Team Caltech: Racing to Win the DARPA Grand Challenge," and Charles Elachi (MS '69, PhD '71), director of the Jet Propulsion Laboratory and professor of electrical engineering and planetary science, will share with us the "Challenges and Excitement of Space Exploration" on April 28. All Watson lectures are at 8:00 p.m. in Beckman Auditorium; no tickets or reservations are required. The lectures also become available online at Caltech's Streaming Theater, http://today.caltech.edu/theater/, about a week after the event.

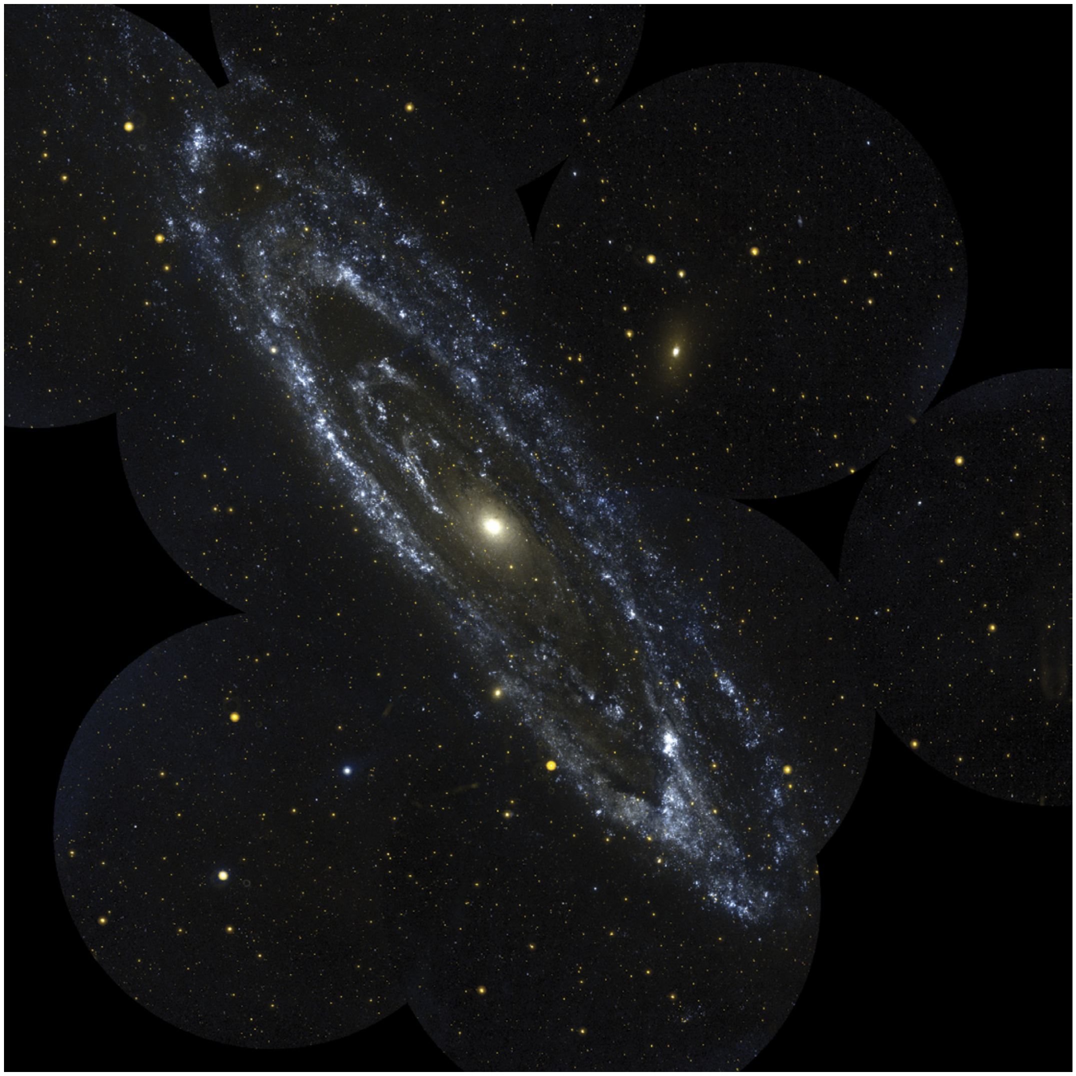
The Stems of Brain Cancer?

Caltech biologists, in collaboration with UCLA's Jonsson Cancer Center, have discovered that brain tumors may be derived from the cells that form the nervous system. These cells, called neural stem cells, may help researchers understand how this cancer begins.

The study, published in the *Proceedings of the National Academy of Sciences*, suggests that pediatric brain tumors develop from cells that have many of the same characteristics as neural stem cells. However, these cells also have an abnormal ability to grow and change.

"We want to understand the transformation process from a normal stem cell to a cancer cell," said Houman Hemmati, the paper's lead author and an MD/PhD student in the UCLA-Caltech Medical Scientist Training Program. "Recent work has shown that some cancers can arise from abnormal cells that are like stem cells, in that they self-renew while at the same time producing the different kinds of cells that make up a tumor. This is a new way of thinking about the fundamental origins of cancer."

"This study demonstrates a previously unrecognized connection between stem cells and pediatric brain tumor–derived cells. By viewing tumors as a type of embryonic cell gone awry, it opens up new possibilities for diagnosis and treatment," said Marianne Bronner-Fraser, the Ruddock Professor of Biology.

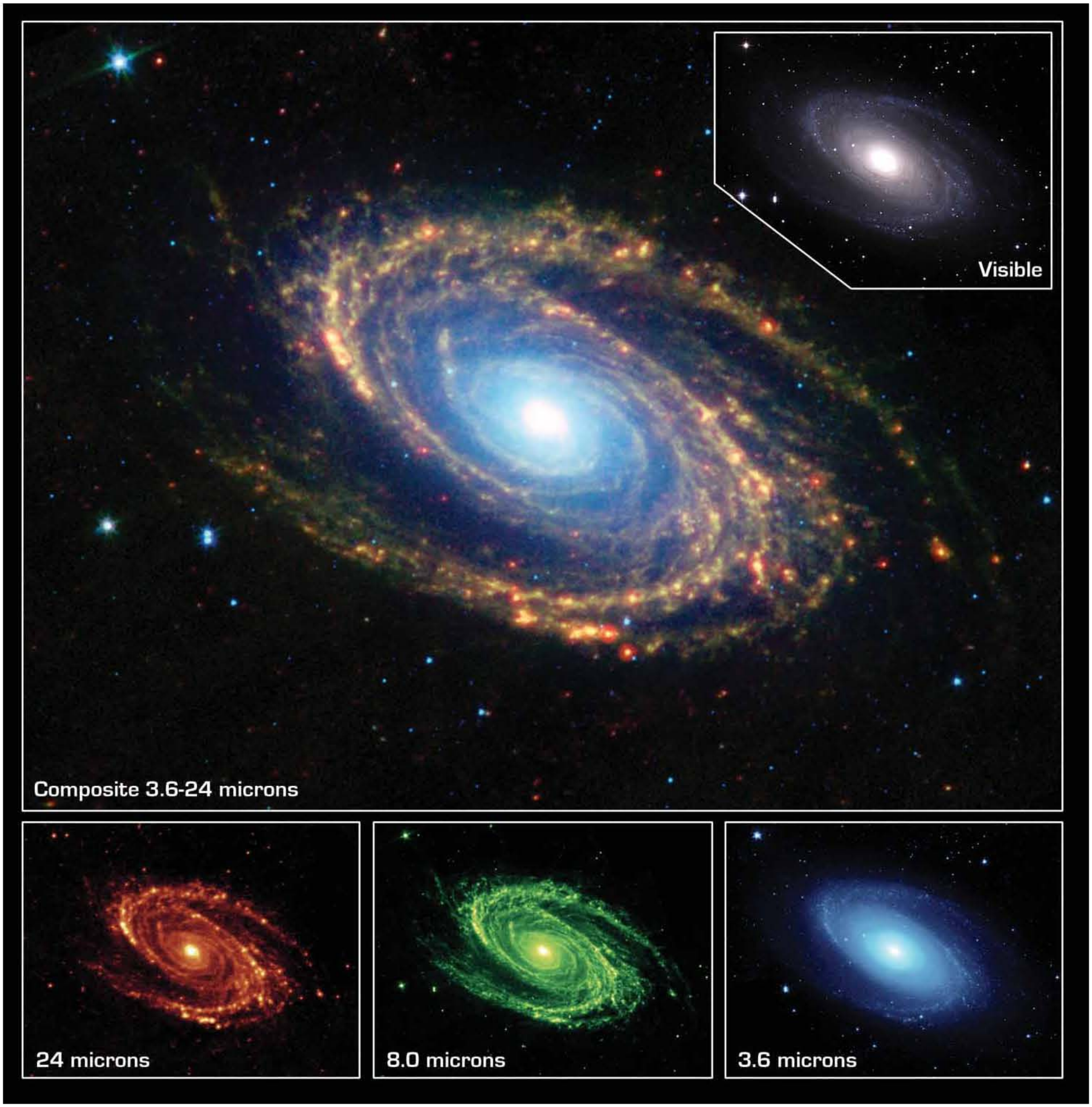


“We believe that neural stem cells, found normally within our brain and spinal cords, could transform into cancer cells,” said Harley Kornblum, a pediatric neurologist, member of UCLA’s Jonsson Cancer Center and an associate professor of molecular and medical pharmacology and pediatrics at UCLA.

“This work also demonstrates that major advances can be made by combining different scientific perspectives—tumor biology, stem cell, and developmental biology. The joint UCLA-Caltech program fosters this important and cross-disciplinary discovery,” said Bronner-Fraser. □—*RT*

Above: Familiar galaxies can now be seen in a new light—the ultraviolet—since the December release of the first images and data from NASA’s new orbiting space telescope, the Galaxy Evolution Explorer (GALEX). In the Andromeda galaxy, blue regions of young, hot stars that give out a lot of energy in ultraviolet wavelengths trace out the spiral arms where stars are forming. The central bulge consists of older, cooler stars formed long ago. (Compare the visible-light image from the 48-inch Samuel Oschin Telescope at Caltech’s Palomar Observatory, above left.) During its 29-month mission, GALEX will survey the entire extragalactic sky to give astronomers new insights into the early stages of star formation, how galaxies evolve and change, and how the elements we see around us today originated. The GALEX Science Center at Caltech has overall responsibility for the project, with Professor of Physics Christopher Martin as the principal investigator. JPL built the spacecraft with contributions from universities, scientific institutions, and companies worldwide, and is managing the project. Check out more stunning images at http://www.galex.caltech.edu.

Only in the infrared can one simultaneously see the veil of cosmic dust and lift it to look within.



NASA/JPL-Caltech/K. Gordon (University of Arizona) & S. Willner (Harvard-Smithsonian Center for Astrophysics)

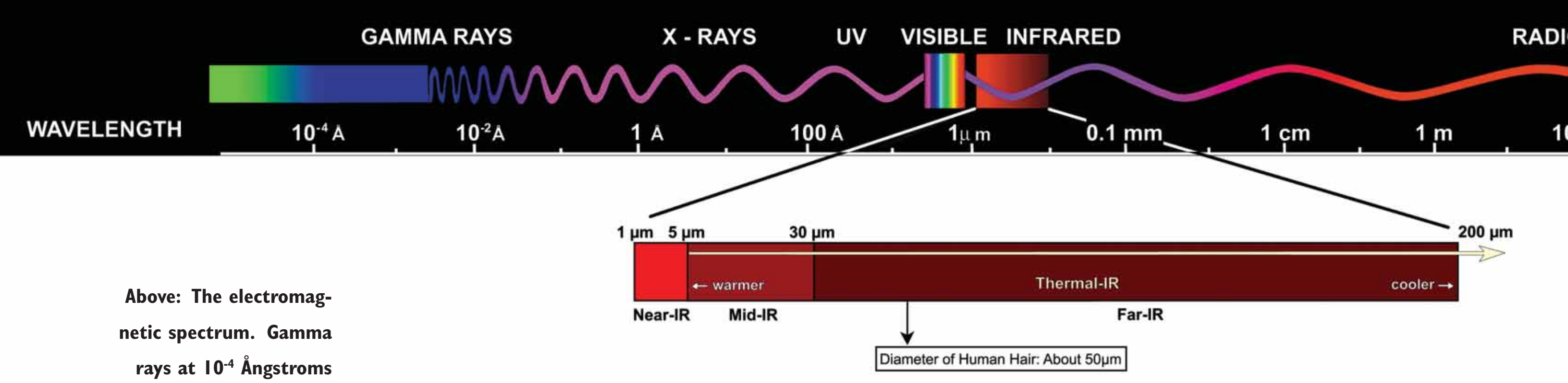
The Far, the Cold, and the Dusty

by Douglas L. Smith

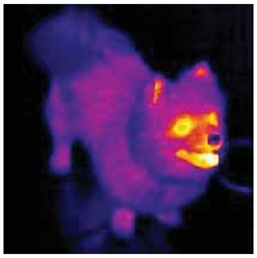
M 81, a spiral galaxy 12 million light-years away, is as big as the full moon and is easily visible through binoculars as a cosmic Fish and Wildlife Service tag on the ear of Ursa Major, the Great Bear. Being so big and near, if M 81 were Paul Newman, the Spitzer Space Telescope could see his nose hairs. In the words of the Smithsonian Astrophysical Observatory's Giovanni Fazio, "for the first time Spitzer allows us to dissect a galaxy like a kid in the biology lab with a frog." Each infrared band (insets at bottom) shows different anatomical details, and the three bands were composited to make the main image. A smooth distribution of mature stars shows up in the near-infrared (blue). Things get clumpier in the mid-infrared (green), and the spiral arms where the young stars live become more prominent. In the far-infrared (red), we see dust clouds heated from within by these stellar adolescents; the bright jewels are stellar nurseries. Besides gritty silicates chemically similar to beach sand, the dust contains organic molecules called polycyclic aromatic hydrocarbons, which, says Fazio, "are the black stuff on your toast and the burnt crud on your barbecue grill." The Spitzer can tell the difference between the two, as well as how much of each is where, and can survey the stellar demographics. Combining this with gas maps from radio astronomers will give us a much better understanding of how stars form. The visible-light image (inset, top right) is courtesy of Nigel Sharp of the Kitt Peak National Observatory.

The Spitzer Space Telescope, né the Space InfraRed Telescope Facility (SIRTF), has just released its first batch of pictures, including the stunning view of M 81 at left. The name change honors Lyman Spitzer, Jr., the Princeton astrophysicist who proposed putting a telescope in space in 1946 and who was the first to recognize that the inky interstellar dust clouds that annoyed other astronomers were worthy of study in their own right as the birthplaces of stars. The Spitzer is the fourth and final of NASA's "Great Observatories," each of which looks at a different portion of the electromagnetic spectrum, and the new name rounds out an astronomical Mount Rushmore that includes the Hubble Space Telescope, the Compton Gamma Ray Observatory, and the Chandra X-ray Observatory. The Spitzer Space Telescope is managed for NASA by Caltech's Jet Propulsion Laboratory, and the Spitzer Science Center, which will run the mission's scientific program and process and disseminate its data, is located on the Caltech campus.

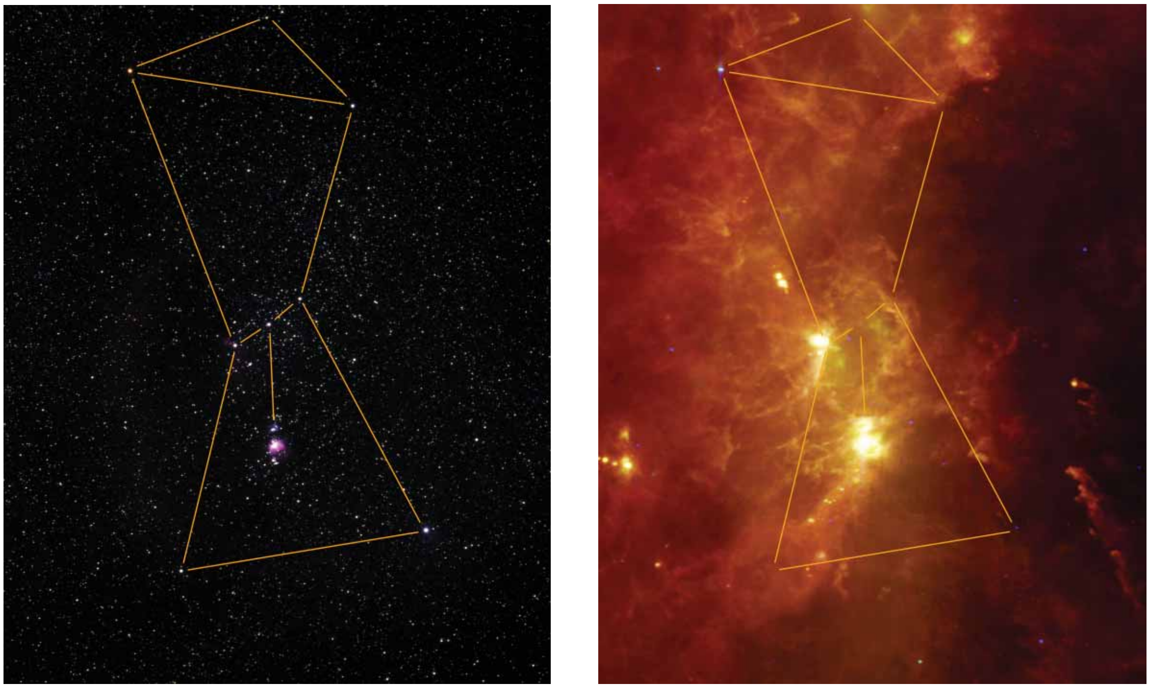
Space is the place for infrared astronomy. Most infrared light never makes it to the ground, but gets absorbed by water vapor and carbon dioxide in Earth's atmosphere. And because infrared radiation is actually heat, it's just too darn balmy here—yes, even in the Antarctic—to see much. As the University of Arizona's George Rieke remarked, "Observing in the infrared from the ground is like trying to observe in the visible with the lights still on in the dome." The telescope is looking at signals measured in quadrillionths of a milliwatt—so faint that the warmth from the tiny trickle of electrons through the camera chips themselves would mess things up, were it not instantly whisked away by the liquid-helium cooling system that keeps the detectors at a frosty 1.5 Kelvins. (Room temperature, 25°C, is 298 K; absolute zero, at 0 K, is as cold as it is theoretically possible to get.) Spitzer is not the first cryogenically cooled infrared observatory in



Above: The electromagnetic spectrum. Gamma rays at 10^{-4} Ångstroms have a wavelength about 10 times the diameter of a proton, while radio waves can run hundreds of times Earth's diameter; the infrared portion (inset) lies comfortably in the middle.



Above: Because infrared radiation is heat, things look very different. Rusty appears cold because of his nice, thick, insulating coat. But his eyes and open mouth betray his body temperature. And he's healthy—look how cold his nose is!



Right: Similarly, Orion's body has bright stars at the neck, shoulders, belt, and knees, plus two bright stars and a fuzzy blob in the sword. And infrared picture from IRAS (far right) reveals vast dust clouds from which stars are coalescing; that fuzzy blob is merely the bright nucleus of one such cloud.

space—a 1983 mission named IRAS had that honor—but it is by far the most sensitive.

Why bother? Because only in the infrared can one simultaneously see the veil of cosmic dust and lift it to look within. The dust is transparent at wavelengths beyond some 20 microns, or millionths of a meter, so you can see right through it to the nascent sun within. That's because the longer an infrared wave, the colder its source. The stuff from which stars and planets condense is very cold and radiates in the far infrared. Temperatures from a couple of hundred Kelvins up to about 1,000 K correspond to the mid- and near-infrared, say 20 to three microns; the exact spectral boundaries, like the dust clouds themselves, are fuzzy. (Your eye begins to see red light at about 0.78 microns.) The Spitzer can see suns whose visible and ultraviolet light is blotted out by the dust, and can also see brown dwarfs—stellar wannabees bigger than Jupiter but too small to start burning hydrogen.

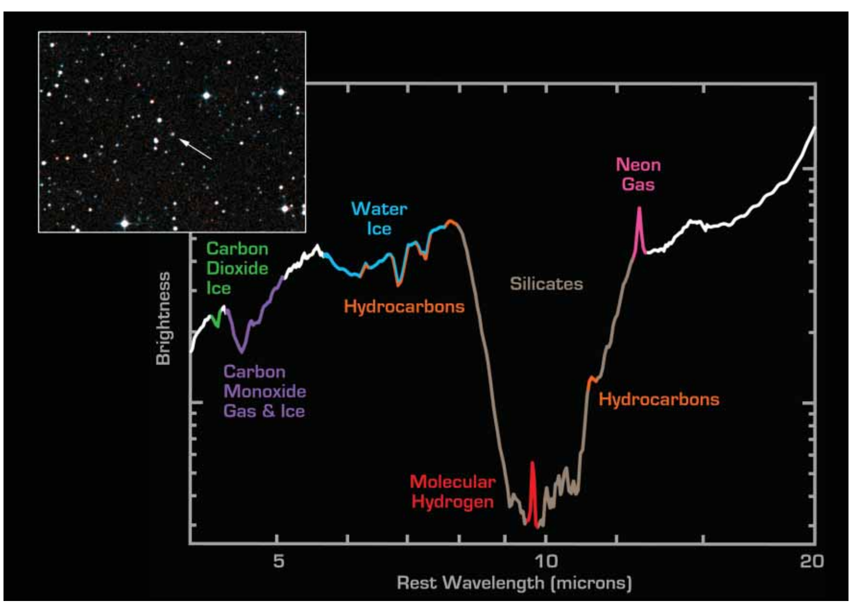
So that's the cold and the dusty. The "far" comes in because the universe is expanding, stretching the light that passes through it. Thus the light from stars in young, faraway galaxies gets redshifted down to where the Spitzer can see it. (The infrared light from their dust, meanwhile, just becomes infraredder.) And since light travels at a finite speed, looking outward in space is equivalent to looking backward in time. Galaxies close at hand also shine brightly in the near-infrared, says JPL's Michael Werner, the Spitzer project scientist, "because much of their light is produced by cool, red-giant stars. Even though a star doesn't spend much of its life as a giant, while it does, it's very luminous." By comparing galaxies at different distances and therefore ages, we can trace their life cycle.

Among the oddities to be spied on by the Spitzer are ultraluminous infrared galaxies, several hundredfold brighter in the infrared than the visible, each of whose "total energy output is

The spectrum revealed that those burnt-food hydrocarbon molecules—essential precursors of carbon-based life as we know it, in the immortal words of Mr. Spock—existed there at the same time they existed here.

Below: Spitzer's infrared spectrum, or chemical fingerprint, of the 3.2-billion-year-old galaxy IRAS F00183-7111 (the arrowed dot in the visible-light inset, from the Palomar Digital Sky Survey) shows a big dip where silicate dust absorbs most of the light from the stars embedded in it, revealing its presence. Hydrogen- and carbon-containing molecules called hydrocarbons can be seen at slightly shorter wavelengths, and as a "shoulder" in the silicate peak. Other carbon-containing molecules and various ices are also visible, none of which were visible before. And the purple peak is light emitted by singly-ionized neon, which is used to calculate star-formation rates.

This galaxy is 1,000 times more luminous than our own, rivaling quasars in its prodigious energy release. But because it's so dust-choked, something like 99 percent of its short-wavelength light gets absorbed by the dust and re-emitted in infrared.

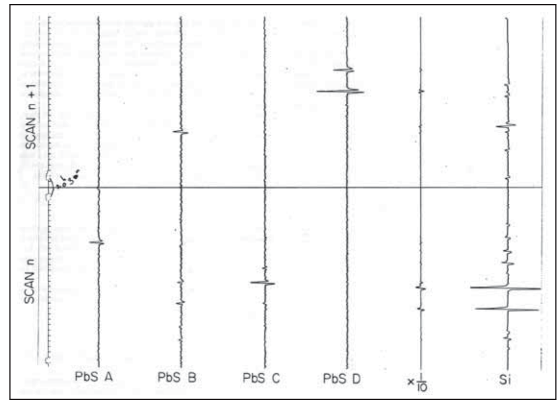


NASA/JPL-Caltech/Lee Armus (SSC/Caltech)

hundreds to thousands times that of our own galaxy," says Werner. "This energy is generated in a very tightly confined space, less than a few hundred light-years across [our own galaxy is about 100,000 light-years in diameter], and emerges in infrared wavelengths, presumably because there's some embedded energy source heating the dust. We don't really know whether that energy source is a dense starburst, a black hole, or some combination of both." Werner hopes that the Spitzer will be able to tell the difference by examining the makeup of the gas near the energy source, and in the process "study the balance between the universe's two fundamental methods of energy release that we know of: nuclear burning—the conversion of hydrogen to helium—and gravitational collapse."

The biggest science news from the Spitzer's holiday gift pack wasn't an image at all, but a spectrum of a galaxy 3.2 billion light-years away known as IRAS F00183-7111. Earth is about 4.5 billion years old, so this light started toward us around the time when terrestrial life was beginning to gel from the primordial soup. The spectrum revealed that those burnt-food hydrocarbon molecules—essential precursors of carbon-based life as we know it, in the immortal words of Mr. Spock—existed there at the same time they existed here. (Every atom and molecule absorbs or emits light at a set of characteristic wavelengths, as identifiable as fingerprints.) The European Space Agency's Infrared Space Observatory had spent a couple of hours collecting a mid-infrared spectrum of IRAS F00183-7111 in the mid-1990s. But, says Lee Armus, a member of the professional staff at Caltech, "ours is much, much better—more signal and less noise—and has a more complete wavelength coverage." And the Spitzer took only 14 minutes to collect it—one can only imagine what we'll find when the telescope *really* stares hard at something!

Whether a civilization in IRAS F00183-7111



Above: The late Robert Leighton sculpts the 62-inch-diameter epoxy mirror for the first infrared telescope in 1962. He cast it in the back of his office in Bridge Lab. The telescope, once the second largest at the Mount Wilson Observatory, was used for the Two-Micron Sky Survey (*E&S*, 1998, No. 4) and is now in the Smithsonian Museum in Washington, DC.

is looking out at us and wondering if they're alone in the universe is, of course, an open question. As James Houck, the spectrograph's principal investigator, said, "We see a bunch of bolts, screws, and maybe a horn button. That doesn't mean a car will appear soon; it just means we have found some things that are characteristic of cars."

Astronomy has come a long way since the first infrared survey, begun in 1965 by two Caltech physics professors. Gerry Neugebauer (PhD '60) and the late Robert Leighton (BS '40, PhD '47) used a simple array of eight lead-sulfide photocells to sweep the roughly 70 percent of the sky visible from nearby Mt. Wilson Observatory, collecting the data as squiggles on a strip-chart recorder. The resulting Two-Micron Sky Survey, published in preliminary form in 1969, contained 5,612 infrared sources, the vast majority of which had been previously uncataloged. One project member was an undergrad named Thomas Soifer (BS '68), now himself a Caltech physics professor and director of the Spitzer Science Center.

The photocells were surplus from the defense industry; they had been developed for the Sidewinder missile's heat-seeking guidance system. Says Soifer, "The infrared has been sort of a poor stepchild to the optical in terms of photon detection, and the major funder of infrared-sensitive chips over the past decades has been the military. But their interests stop halfway through the wavelength range we're interested in, and they don't care about the kind of very-low-light-level detection that we need. A battlefield is pretty bright, even on a dark night, and jet exhaust shows up at fairly short wavelengths."

Says Werner, "We invested a lot of time, money, and brain power in building on the infrastructure provided by the military to develop Spitzer's detector arrays. For example, previous missions' infrared spectrographs have had a small number of detectors and a lot of moving parts, so that different portions of the spectrum had to be dropped successively on the array. Our spectrograph, built by Ball Aerospace under the guidance of Jim Houck and his team at Cornell, has *no* moving parts and gets the whole spectrum at once, so we observe all of the spectrum all of the time. It's extraordinarily powerful." The multiband imaging photometer provided by the University of Arizona's George Rieke has three cameras, including what Soifer calls "the first true camera at 70 microns. It has 32 by 32 pixels, or a thousand individual sensors." At lower resolution, the instrument can see out to 160 microns. And the camera provided by Giovanni Fazio at the Smithsonian Astrophysical Observatory provides four simultaneous images at 3.6, 4.5, 5.8, and 8 microns. Each of its arrays has 256 by 256 pixels, which is not particularly large any more—technology has marched on, and ground-based infrared telescopes today have cameras in the 2,000 by 2,000 pixel range. But, says Werner, there hasn't been a corresponding increase in per-pixel efficiency—the newer chips just have more of them. And the vantage point of outer space more than makes up the difference. Says Soifer, "the cold background gives you *so* much more sensitivity. Our sensitivity is at least a factor of 10 better, and often more, than Keck at any wavelength where we take the same kind of measurement."

So it's a really good thing that the Spitzer got built, because it almost didn't. It was originally conceived in the 1970s as the Shuttle InfraRed Telescope Facility, or SIRTF—the space shuttle, remember, was going to stay aloft for up to 30 days at a time, with forty-some launches per year. In May 1983, NASA issued an "Announcement of Opportunity" for SIRTF as a multi-instrument payload-bay package to be managed by NASA's Ames Research Center up near San Jose and expected to take its first flight in 1990. (Werner, who had joined Caltech as an assistant professor of physics in 1972, had left for Ames in 1979 to

Left: A portion of the Two-Micron Sky Survey data. The eight photocells were arranged in a 2 × 4 array oriented north-south, with each pair feeding a single pen (A-D) on a strip-chart recorder. All four signals were added together and divided by 10 on the fifth channel, in case a really bright source was found. The sixth pen (Si) recorded the signal from a photocell sensitive to light at 0.84 microns, just to the red of visible, in order to see if the source would appear on photographic plates from previous surveys. The ticks along the chart's left edge mark each minute of right ascension, or celestial longitude. At the end of each scan, the telescope automatically clicked poleward by 15 minutes of declination, or celestial latitude, and reversed its direction. So the star that shows up on Channel A near the end of scan *n* reappears in Channel B at the beginning of scan *n* + 1. The position and brightness information was digitized by hand and fed on paper tape into an IBM 7094, a transistor-based computer designed for large-scale scientific calculations that could perform a whopping 100,000 multiplications per second.

become Project Scientist in early '80s.) In retrospect, this was not a great idea, as the 12.5-centimeter InfraRed Telescope (IRT), also built by the Smithsonian Astrophysical Observatory and flown on the *Challenger* in 1985, showed that the shuttle flew in its own cloud of vapor and small particles that, while not as bad as Earth's atmosphere, was still pretty tough to see through.

In any case, SIRTF got scooped. The InfraRed Astronomical Satellite (IRAS), a joint project of the US, the UK, and the Netherlands, was launched in January 1983. In the 10 months before its 127 gallons of liquid helium ran out, it scanned more than 96 percent of the sky at 12, 25, 60, and 100 microns. It logged some half-million infrared sources in what was, at the time, one of the largest data sets ever assembled. IRAS was so successful that in September of the same year, NASA broadened SIRTF's scope to include the possibility of a free-flying spacecraft, and, in 1984, selected Fazio, Houck, and Rieke to build the instruments for what was now the *Space* InfraRed Telescope Facility. This proved to be prescient when the *Challenger* exploded in 1986, grounding the shuttle fleet. The observatory had dodged a bullet, but the firing squad was just warming up.

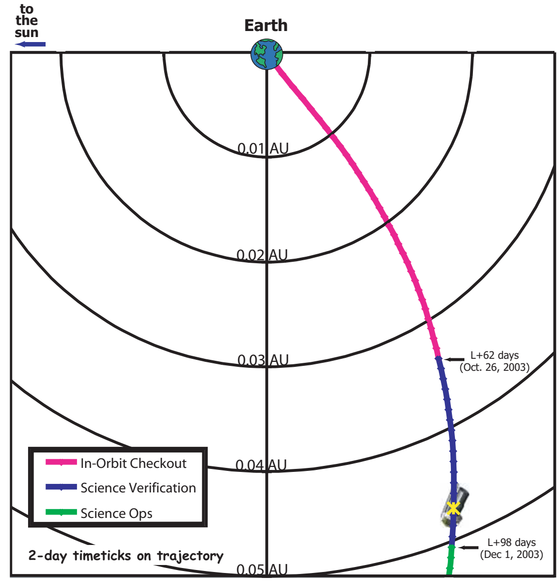
Meanwhile, back at Caltech, a special facility was being set up to digest and catalog IRAS's flood of information. JPL managed IRAS for NASA, but it made sense to move the data analysis to campus because of JPL's access restrictions and because of the intense scientific interest. It didn't hurt that Neugebauer was the American cochair of IRAS's joint science working group, and that Soifer had overseen the development of the data-processing software that turned pixels of light into catalogs and atlases. Caltech's Infrared Processing and Analysis Center (IPAC) and the Hubble Space Telescope Science Institute would serve as the model for the Spitzer Science Center.

Then in April 1990, the Hubble Space Telescope was launched; the flaw in its mirror was discovered in June. "That was our darkest moment," Soifer recalls, "because we were about to begin the Phase B study, which is a serious commitment by NASA to industry to do the project. The Hubble spherical aberration was announced maybe a week or two before our request for proposal was to come out, and that just stopped everything in its tracks." At that point, SIRTF was a $2.2 billion mission carrying 3,800 liters of helium, and, with a launch weight of 5,700 kilograms, would have "strained the capabilities of a Titan IV/Centaur launch, which costs another $400 to 500 million," says Werner. That same year, NASA moved SIRTF (and Werner) south to JPL.

This second slug would probably have been fatal if not for the Bahcall report. Commissioned by the National Academy of Sciences as a road map for astronomical research for the coming decade and printed in November 1991, it was named for Princeton's John Bahcall, the committee chair. It called the '90s the "Decade of the Infrared," where answers were most likely to be found to the compelling questions of how galaxies, stars, and planets form and evolve, and how matter and galaxies are distributed in the universe. It went on to designate SIRTF the highest-priority mission for American astronomy in the 1990s. It was enough to keep the mission alive.

Even so, "SIRTF went into hibernation for two or three years," Werner recalls. It was jolted awake when a third shot rang out that splintered the headboard: in August 1993, JPL lost contact with the Mars Observer just as it was preparing to enter orbit around the red planet. As a result, NASA adopted the "Faster, Better, Cheaper" mantra, and a six-ton observatory—or even the smaller, Atlas-launched version that had been developed in the interim—didn't stand a snowball's chance. "We got out of the doldrums in the fall of 1993 when two things happened. The scientists realized that we had to take the situation into our own hands, so we had a couple of retreats in which we developed this 'warm-launch' idea put forth by Frank Low from the University of Arizona. We also hit upon the idea of focusing on a very small number of science objectives tied into the Bahcall report—anything that wasn't required to do them was no longer going on board."

SIRTF's luck was indeed turning, because that fall Larry Simmons, who had led the team that had successfully refurbished Hubble's Wide-Field/Planetary Camera, became the project manager. Says Werner, "He came just at the right time, and helped us turn things around a lot. He brought with him a very good team from the wide-field camera, and he really operated Spitzer as a team. That's an easy thing to say, but it's not so easy to do. He encouraged a lot of interaction within the project, and developed a culture of openness that made it easier to deal with problems when they arose. It all paid off, because he built a reservoir



Above: Spitzer undergoing final assembly at Lockheed Martin's plant in Sunnyvale, California in 2002. The solar panel, which runs the length of the spacecraft down its shiny side, is not yet in place. The telescope proper fits into the narrow upper part of the barrel, which also contains two more heat shields. The cryostat lives in the bulge in the lower part of the barrel. The eight-sided box below the barrel contains the instruments' electronics, the power systems, and the equipment that aims the telescope and communicates with Earth, and is the only warm part. Above, right: Spitzer's location on November 24, 2003. The spacecraft is now over 8,000,000 kilometers away. An AU, or Astronomical Unit, is the mean distance from Earth to the sun, or 149.6 million kilometers.

of goodwill, and then when things got tough, we could draw on that reservoir."

And they would get tough again—the project took one last hit in 1994. "Larry kept open books so everybody knew how much money everybody else was getting. So when we had to descope, *again*, everybody knew where we were, and where we had to get to, and we were able to come to agreement on how our rather skimpy reserve was to be allocated." The result led to what actually got launched—a $700 million mission that rode a Delta, carried 350 liters of helium, and weighed only 850 kilograms. "And here we are," says Werner. "*With* our original three science instruments, much modified by the passage of time. All through these delays, we were improving the core technologies. So we have a system with the same size telescope that costs, in as-spent dollars, only a quarter of what the earlier concept would have cost in 1990 dollars." Simmons's management style was so effective, says Werner, that he's been asked to write it up for future missions.

Many technological advances kept the Spitzer alive, but Low's warm-launch idea was the key. Previous infrared observatories had put the telescope as well as the camera equipment in a huge cryostat, or cold chamber—basically a giant Thermos bottle—which was chilled to operating temperature before launch. This took a big, heavy flask and a tanker truck full of liquid helium. But only the instruments really need to be kept cold, said Low, so why not launch everything else at room temperature? (This also makes the testing of the launch process a lot easier.) So the Spitzer's cryostat is just big enough for the multi-instrument chamber, where the infrared chips live, and the helium tank. After launch, the spacecraft simply loses heat to the bone-chilling void of space until it reaches the ambient temperature of about 35 K. Meanwhile, valves on the tank open at launch, allowing the liquid helium to begin evaporating and sucking any stray heat out of the

Left: The telescope itself. The primary mirror is 85 centimeters in diameter. Below: Not frat boys praying to the beer god, but technicians mounting a mock-up of the telescope on the cryostat for a vibration test. The cryostat's rounded top houses the Multi-Instrument Chamber, which is only 20 centimeters, or about two handsbreadths, high. The helium tank fills the rest of the keg.

cryostat. The coolant lines run between the telescope's heat shields as well, so once outer space has done its part the helium chills the superstructure to 5 K. It's like popping open a soda can—which are the main products of the Ball Corporation, which built the cryostat—and when the soda goes flat, the mission is over, unless a couple extra years of near-infrared work can be eked out in a "lukewarm" mode. The telescope also hides behind its own solar panel, which doubles as a sunshade, and a spiffy two-tone paint job of silver and black (any Raiders fans on the project?) reflects heat off the shiny sunward surfaces and radiates heat from the shadowed side.

The Spitzer also travels in an innovative orbit designed to conserve coolant. Why snuggle up to a nice, warm planet, asked JPL engineer Johnny Kwok, when there's an infinite deep freeze just beyond? So the observatory was set adrift, as it were, into an orbit around the sun that's slightly larger, and therefore slightly slower, than Earth's own. The spacecraft is gradually falling behind us—it's now more than 8 million kilometers away, far enough that its radio signals take nearly half a minute to reach us. When its coolant runs out in five to six years, it will be some 150 million kilometers away, and in about 60 years, we'll overtake it. Not that there would be any point in trying to retrieve it, unless perhaps the Smithsonian wants it—if detector technology has advanced so far in the last couple of decades, who knows what we'll be able to do by then?

The telescope—mirrors, supports, light baffles, and all—is made entirely of lightweight beryllium, as was IRAS's telescope before it. The slightest warping would throw the optics out of alignment, and different materials contract at different rates as they cool. "Beryllium has favorable cryogenic properties," explains Werner. "It cools down repeatably, if not predictably. So to get the mirror to the shape we wanted, we had to cool it down, watch it deform, and then polish into its surface the inverse of the deformation, so that when it cooled down next time, it would end up in the desired shape. This is called cryo-null-figuring, which had never before been done to such a high level of precision." In fact, it took two cycles of cryo-null figuring, plus a fine-focus adjustment once in orbit, to produce the razor-sharp images we're receiving.

Because of its distance from Earth, the Spitzer is being operated like a deep-space mission. The Hubble Space Telescope is in a low-Earth orbit, and we are in more or less continuous contact with it through the Tracking and Data Relay Satellite System, which also handles communications with the space shuttles and a whole flotilla of other nearby craft. But Spitzer is on its own. It gets its observing instructions once a week, and once or twice a day it disgorges the results—up to eight billion bits of data; for comparison, the Mars Global Surveyor's camera has 11 million pixels of memory for a day's worth of pictures—in 30 minutes to an hour of talking to JPL's Deep Space Network. It's like the Voyagers' visits to the outer planets, says Werner, "but for Spitzer, every day is an encounter. We're working 24 hours a day, seven days a week." This store-and-dump data-transmission system is likely to become standard operating procedure for future observatories.

JPL sends the data to Caltech's Spitzer Science Center, where about 100 people work, for processing and distribution. (The center also manages the selection of the winning proposals for instrument time and programs their execution.) The data and its ancillary pointing and calibration information goes into one of seven "pipelines," depending on the instrument and its observing mode. The pipelines, which took five years to create, are written as modular code, so that they can easily be updated or modified as needed. Each pipeline automatically transforms the raw numbers into images or spectra, removes cosmic-ray hits, attaches the supporting information, and so on. The center processes 10 to 20 gigabits per day on a "farm" of some two dozen high-end workstations, says Member of the Professional Staff Lisa Storrie-Lombardi, "and the drones write their output to the 'sandbox,' which is six terabytes of online disk space, for a human to look at it before it goes to the archives." A terabyte is a trillion bytes; 6 terabytes would store about 13 million snapshots from that cool little digital camera you got for Christmas.

Half of the first year's observing time—more than 3,000 hours—will go to six so-called Legacy Projects organized around the themes of the Bahcall report. These projects are large surveys—sets of atlases, really—that will be published on line immediately for all to use. In a radical departure from standard astronomical practice, Soifer eliminated the proprietary period during which only the scientists who did the work get to look at the data—usually for a year after it's been processed and delivered. Furthermore, the Legacy teams have agreed to repackage all the data into large mosaics, label each celestial feature by its position and brightness, catalog it, cross-reference it to previous catalogs, and generally make the work as useful as possible.

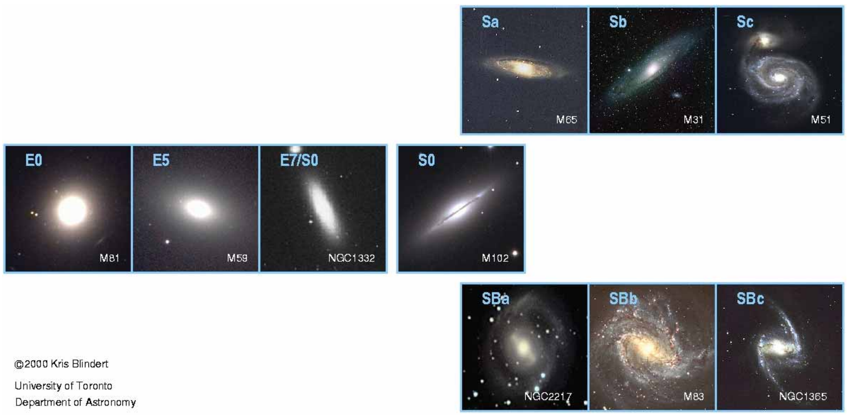
So why would anyone want to clean the stables when everyone else gets to ride the horses, too? Replies Soifer, "That's a very good question, and one that I had to struggle with in order to make these projects attract really good people. I found two answers. Number one is the chance to be in the driver's seat, defining the program—as you know, all of us astronomers believe that we have the best ideas and know best how to advance the field. And the other motivation is that these projects are well-enough funded to not only do the service work of producing these refined, processed catalogs, but also to hire grad students and postdocs and do breakthrough science along the way. We expect that. We understand that. We *want* them to do the science that motivates the service work."

About 1,000 hours' worth of Legacy data should be on line by May, and the balance six months later. Here's a quick look at each project, starting with the farthest reaches of the universe.

The Great Observatories Origins Deep Survey, or GOODS, led by Mark Dickinson at the Space Telescope Science Institute, will peer out to the limits imposed by the telescope's diameter. GOODS will revisit the region near the Big Dipper that Hubble stared at for 10 consecutive days back in 1995 to make the so-called Hubble Deep Field image. Chosen for its apparent emptiness, it proved to contain hundreds of galaxies, from 2.5 to about 12 billion light-years away. In the southern celestial hemisphere, GOODS will look at the Chandra Deep Field, where the X-ray telescope fixed its eye for 278 hours and which Hubble has since surveyed as well. The GOODS observations will be combined with ground-based ones to trace how galaxies evolved from the relatively small aggregations of stars we see beyond about eight billion light-years to the giant galaxies like our own that we see today. Says Werner, "We can't follow a single galaxy, but we can look at different redshift slices to learn how galaxies grow and age, which is not yet very well understood. At almost all epochs we can see what appear to be fairly mature and well-developed galaxies coexisting with obstreperous infants."

In the middle distance, the Spitzer Wide-area InfraRed Extragalactic survey, SWIRE, led by IPAC's Carol Lonsdale, will do "what for Spitzer is a shallow survey," says Soifer. "But it's still far deeper than anything else that has ever come about." SWIRE will go out to a redshift of 2.5, or about 10 billion years ago, encompassing the universe's peak star-formation period, says Soifer. "Most of the action happened between now and back to a redshift of about 2, or nine billion years ago. This will complement work by Professor of Astronomy Chuck Steidel [PhD '90] and others, who are looking at redshift 3 and beyond, before star formation slipped into high gear." Like GOODS, SWIRE will collaborate with telescopes on the ground. SWIRE will cover about 50 square degrees, or roughly 250 times the area of the full moon, and is expected to reveal some two million new galaxies, or a staggering 40,000 per square degree.

Locally, SINGS, the Spitzer Infrared Nearby Galaxies Survey, helmed by Robert Kennicutt Jr. of the University of Arizona, will take extreme close-ups of 75 large, nearby galaxies, like the shot of M 81 at the beginning of this article. These intimate portraits were chosen to represent all parts of the Hubble sequence, which is sort of a periodic table of galaxies. SINGS will also collect detailed spectral data with anatomical precision, inventorying what chemicals are present where and in what quantities, and mapping the dust distribution and measuring how brightly it shines. "We'll examine places that are in different stages of the star-formation cycle to try to identify what distinguishes each phase, and learn how the dynamics of the process work," explains George Helou, deputy director of the Spitzer Science Center and a SINGS team member. By looking at a collection of face-on galaxies, SINGS hopes to figure out how bursts of star formation propagate—do they get triggered by something and then radiate like the ripples from a pebble dropped in a birdbath, as is thought to happen in the arms of spiral galaxies? Or do stars just break out all at once all over the place like that birdbath freezing up, as may happen in ellipticals? And what factors inhibit the process, or even shut it down? "Why do some galaxies experience one big burst of star formation," Helou asks, "then go to sleep for the rest of the ages? Why do others experience repeated episodes, and others yet a more steady rate?"



Left: A portion of the Hubble Deep Field. Almost everything you see is a galaxy—the two things that look like starbursts are, in fact, foreground stars in our own Milky Way. The entire Deep Field covers a patch of sky the diameter of Roosevelt's eye on a dime held at arm's length.

Above: The Hubble sequence was invented in 1936 by Edwin Hubble, who based his classification scheme on a galaxy's apparent shape—elliptical, spiral, or irregular (not shown). Elliptical galaxies go from E0 (almost spherical) to E7 (very flat). Lenticular galaxies (S0) are intermediate between ellipticals and spirals. Spirals range from Sa to Sc as their arms become less tightly wound and their central bulges become smaller. Hubble also distinguished between normal spirals and barred ones (SB) that have a prominent bar through the central bulge to form shoulders for the spiral arms. (Graphic courtesy of Kris Blindert.)

In our own galaxy, the Galactic Legacy Infrared Mid-Plane Survey Extraordinaire (GLIMPSE—"They really worked hard to get an acronym," observes Soifer), with the University of Wisconsin's Edward Churchwell in charge, will answer an age-old question once and for all by counting all the stars in the Milky Way. Well, most of them, anyway—the Spitzer can't look directly at the galactic core, says Soifer, "because it's just too bright, even with our very shortest integration times." But in the portion of the galaxy that they will see, GLIMPSE will inventory every last star in all stages of life, from dusty fetuses to dying cinders—over 100 million sources are anticipated, which will map the Milky Way in unprecedented detail. Even though it's our own galaxy, we're still unclear on such basic questions as how many spiral arms it has, or whether there's a bar in the central region. At visible wavelengths, we can't see through to the other side for the dust in the middle, and previous infrared surveys weren't always fine-grained enough to distinguish between nearby things and ones along the same line of sight but on the far side of the galaxy.

The final two Legacy projects will look very close to home. They will follow, with unprecedented acuity, the process by which a cloud of gas and dust collapses, turns into a star surrounded by a disk of material, and eventually evolves into a solar system. The dividing line is basically at the birth of planets: Neal Evans from the University of Texas heads a project called From Molecular Cores to Planet-Forming Disks, and Michael Meyer of the University of Arizona runs one called Formation and Evolution of Planetary Systems. Geoffrey Blake (PhD '86), professor of cosmochemistry and planetary sciences and professor of chemistry, and Professor of Astronomy Anneila Sargent (MS '67, PhD '77) are members of the

Evans team, which is examining embryos up to about three million years old, such as Herbig-Haro 46/47, at right. And Assistant Professor of Astronomy Lynne Hillenbrand is on the Meyer team, which picks up from there and runs out to a billion years or so. Fomalhaut, bottom right, is an example—the ring of dust surrounding it suggests that planets have already formed in the hole.

But first things first. Soifer has an allotment of what's known as Director's Discretionary Time, and he's called dibs for the First Look Survey. The idea is to find out what the Spitzer's sharp eyes can see, so that other folks can plan their own observations. So in the first two weeks of December, Storrie-Lombardi's team aimed the telescope for 60 hours at four square degrees in the constellation Draco, about midway between the dragon's beak and its belly, in a kind of mini-SWIRE. Like SWIRE, First Look is collaborating with ground-based observers to get as much correlated information as possible, with telescopes at Kitt Peak and Palomar, and radio dishes at the Very Large Array, pitching in. There's a First Look at our galaxy as well, in which a group led by Member of the Professional Staff Alberto Noriega-Crespo took a sweep across the galactic plane in order to examine the galactic halo. They also probed a molecular cloud—a dense region of hydrogen, helium, and other gases from which stars condense—named L1228 that lies between Draco and Cepheus. And Victoria Meadows' group of First Lookers joined ground-based observers on an asteroid hunt.

The entire endeavor has been an excellent example of cooperation between JPL and Caltech, says Werner, "which is something that everybody recognizes as being a good thing in the abstract, but you can't just have [JPL director] Charles Elachi or [Caltech president] David Baltimore get up on a soapbox and say, 'There Shall Be Cooperation Between Caltech And JPL.' It only happens when there's a project like Spitzer that brings out the best in both organizations." Adds Helou, "The Spitzer Science Center will be crucial to the mission's ultimate success by making large-project resources accessible to the small-science researcher. Spitzer will reveal a new universe and rewrite the astronomy books, and it's appropriate for Caltech and JPL to lead a project that represents NASA at its best." □

PICTURE CREDITS:
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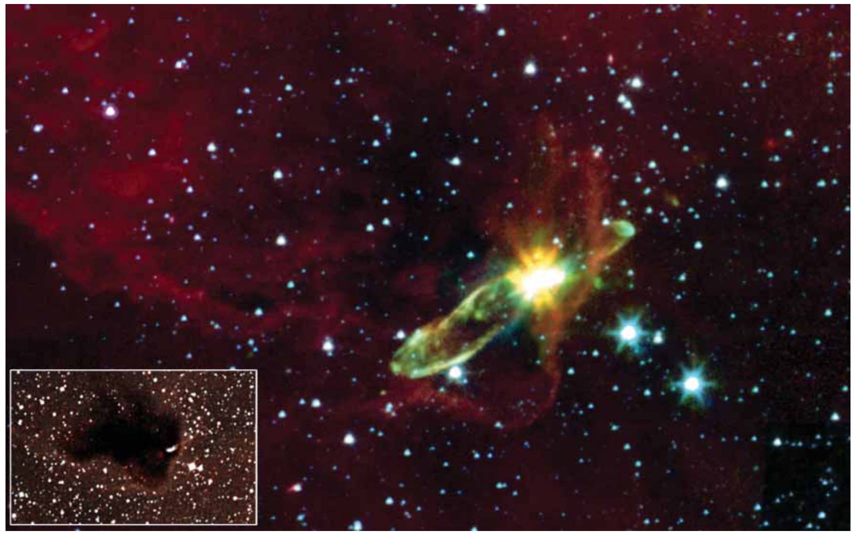

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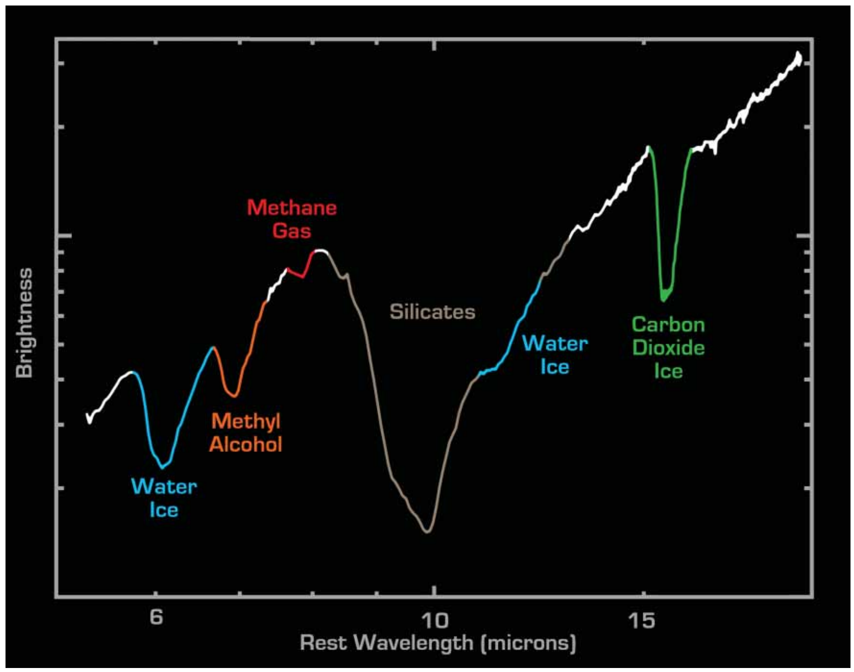

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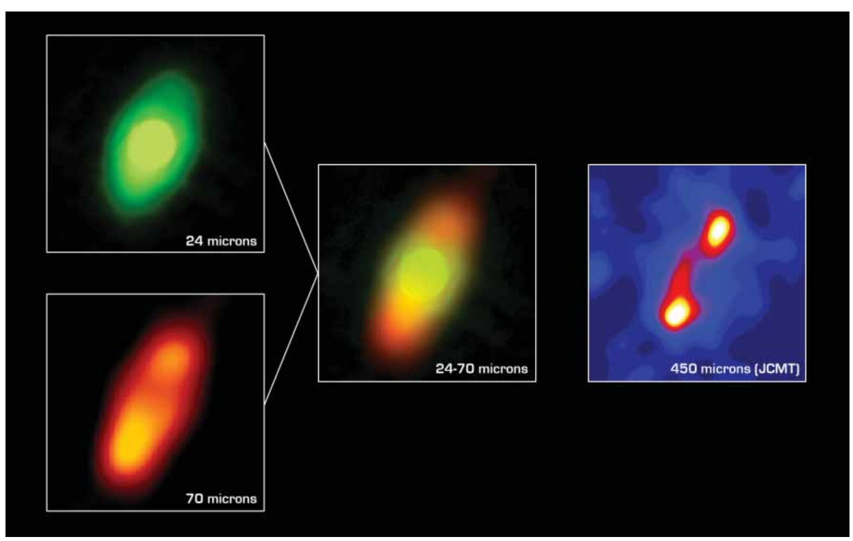
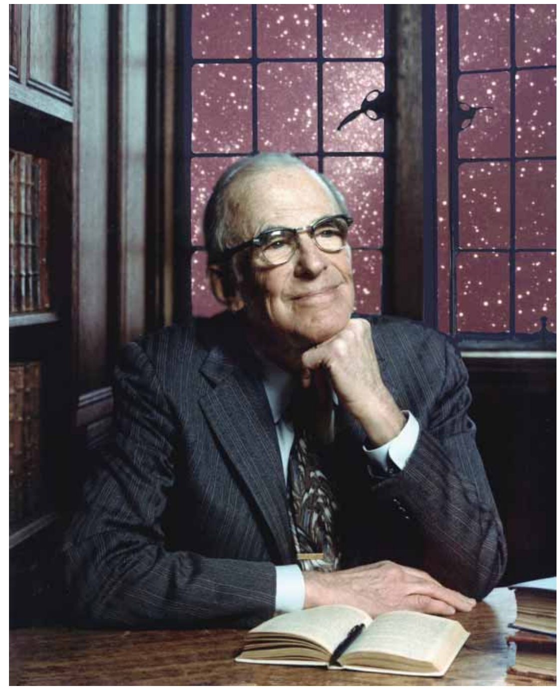


NASA/JPL-Caltech/Karl Stapelfeldt (JPL)

Top: Herbig-Haro 46/47 is 1140 light-years away in the constellation Vela, the Veil. In visible light (again, from the Palomar Digital Sky Survey) all you see is inky crud, which to Spitzer's eye at eight microns becomes a wispy cloud (red) marking where supersonic gas ejected by an embryonic star collides with the interstellar medium. The near-infrared reveals two previously undiscovered jets of gas (yellow-green) shooting out in opposite directions from the protostar. These jets emerge from a star's poles as part of the same processes that create a planet-forming disk around its equator—our sun probably had a similar pair once upon a time. In this composite image, 3.6-micron light is blue, 4.5 and 5.8 are green, and 8.0 is red.
Middle: The deep absorption feature for silicates shows the dust cocoon is really thick, and the dry-ice (carbon-dioxide ice) one shows it's pretty cold.
Bottom: Fomalhaut, the 18th brightest star in the northern-hemisphere sky, is only 25 light-years away. IRAS discovered that Fomalhaut was much brighter in the infrared than it ought to be, but couldn't tell if a disk of dust accounted for the excess. Later microwave observations (right) found a dust ring 56 billion kilometers in diameter—nearly five times the size of our solar system—hinting that planets may have already formed, sweeping the inner region clear. Now Spitzer has taken Fomalhaut's first infrared portrait (center composite). At 70 microns (bottom left), the ring's southern lobe is revealed to be one-third brighter than the northern—perhaps the wake of a comet being pulled into the inner solar system, or the debris from a recent collision between two moderate-sized asteroids. At 24 microns (top left), a faint cloud of warmer (dry-ice temperatures) dust fills the ring all the way in to about the orbit of Saturn, and possibly closer. This dust is thicker than our own so-called zodiacal cloud, but may come from the same source: comets visiting the inner solar system. Or it may be the debris of planetary formation. The submillimeter image was made at the James Clerk Maxwell Telescope.



Astrophysicist Lyman Spitzer, Jr. (1914–1997) contributed to stellar dynamics, plasma physics, and thermonuclear fusion as well as space astronomy. He earned his PhD from Princeton in 1938, and returned in 1946 after helping develop sonar during World War II. He spent the rest of his career there.

That same year, more than a decade before the first satellite was launched and twelve years before NASA was formed, he proposed an orbiting observatory that would be able to see a wide range of wavelengths unblurred by Earth's atmosphere. He would work for the next 50 years to make this vision a reality. His efforts led to the ultraviolet-observing Copernicus satellite, which he helped design in the early '60s, and the Orbiting Astronomical Observatory, which he shepherded through Congress (and past a bunch of reluctant scientists, who were afraid the expense would soak up all federal funding for astronomy) in the mid '60s. He would do this again for the Hubble in the early '70s.

*Spitzer was the first to study the interstellar medium—the gas and dust between the stars—and the magnetic fields therein. He literally wrote the book on the subject—*Diffuse Matter in Space*, published in 1968. He was among the first to suggest that the bright stars in spiral galaxies had recently formed from this stuff, and predicted the existence of a hot halo surrounding our galaxy.*

In 1951, Spitzer founded the Princeton Plasma Physics Laboratory. His Physics of Fully Ionized Gases*, published in 1956, is still a standard reference text, and he led Princeton's effort to harness nuclear fusion as a clean source of energy.*

His numerous honors included NASA's Distinguished Public Service Medal and the Crafoord Prize, equivalent to a Nobel in astronomy.

Several French scientists of the day were convinced that the Dendera ceiling was much more reliable than words.

Egyptian Stars under Paris Skies

by Jed Z. Buchwald

One evening in early July of 1822 a group gathered for dinner at the home of the leading figure in French science, the Marquis de Laplace, outside Paris. The guests included five of the most distinguished physicists and chemists of the day: Jean-Baptiste Biot, famed for his experimental work in optics and electricity; François Arago, rapidly becoming an influential administrator of science, the editor of an important journal, and himself a reasonably accomplished experimenter in optics; Joseph Fourier, who had developed the series representation now termed Fourier analysis and whose controversial theory of thermal diffusion had already been widely discussed; the influential chemist Claude Berthollet; and John Dalton, the English protagonist of the atom.

The previous several years had seen remarkable developments in French science, including fundamental discoveries in electricity, magnetism, heat, and optics. Most of the dinner guests had participated in these events, often on opposing sides. Biot and Arago were scarcely on speaking terms, Fourier's mathematics and his heat theory were not well thought of by Biot and Laplace, and Berthollet had little sympathy for chemical atomism. Yet the evening's conversation had nothing to do with physics, chemistry, or mathematics. Instead, the guests discussed the arrival in Paris of a zodiac from a ceiling in the Egyptian temple of Dendera, far up the Nile. Sawn and exploded out of its site by a French archaeological vandal named Claude Lelorrain, the Dendera zodiac roused Parisian salons and institutes to such an extent that for several months it displaced all other topics, attracted crowds of curious admirers, and was soon bought by King Louis XVIII for an immense sum.

Left: Napoleon urges on his troops at the Battle of the Pyramids. (Detail from Antoine-Jean Gros, *Bonaparte haranguant l'armée avant la bataille des Pyramides, le 21 juillet 1798*.) But, while he won the battle, he lost the war. Napoleon left Egypt in 1799; his deputy was assassinated (below: Victor Adam, *Assassination of Kléber by a fanatic, 14 June 1800*); and the English defeated the French in 1801.

This was not the first time that Dendera had ignited discussion. On his return from Napoleon's colonial expedition to Egypt in 1799, the artist Vivant Denon had made available his sketch of what certainly looked like a zodiac. In short order articles appeared concerning the age of what many took to be a relic of antique Egyptian skies. For if the zodiac were literally an image of the heavens, then astronomy might be used to establish its date of production. Since hieroglyphs were to remain unreadable for another two decades, Dendera offered the tantalizing possibility of establishing Egyptian chronology on the basis of something beyond the few Greek and Latin texts that had been carefully studied by Renaissance humanists. Though some of these texts contained words that could be interpreted astronomically, a great deal of speculation and argument was needed. Several French scientists of the day were convinced that the Dendera ceiling was much more reliable than words. Words, filtered through the sieves of human culture and history, were thought by an early cadré of French *savants* known as *Idéologues*—who were concerned with social systems—to be imperfect reflections of external reality. Images seemed to be different, more trustworthy, because they were considered to connect directly to original sensations stimulated by the natural world. Here lay the seeds of a growing mismatch between historical and scientific sensibilities, at least in 19th-century France, and likely elsewhere as well.

The French astronomer and head of the Paris Bureau of Longitude, Jérome de Lalande, heard about Denon's as yet unpublished sketch in 1800. Reports that he read seemed to indicate that the circular zodiac was at least 4,000 years old. Furthermore, a second star ceiling discovered at Esneh seemed to be older still, dating perhaps to 7,000 years before the present era. If Esneh were that old, Lalande concluded, then a claim made by one

Charles Dupuis' *Origin of All Cults* (frontispiece at left), published in 1795, traced all religions (and myths) back to the Egyptians' knowledge of astronomy. Dupuis dated Egyptian astronomy and the zodiac at 14,000 years earlier, about 10,000 years before biblical chronology set the creation of the world.

Charles Dupuis just before the French Revolution concerning the origins of religion, which interpreted myths in astronomical terms, might well be correct. Dupuis had located the birthplace of the zodiac in an Egypt older by far than any chronology based on textual arguments—and especially on the Books of Moses—could possibly allow. (Standard biblical chronology placed the origin of all things at about 4000 B.C.E.*) According to Dupuis, the zodiac, and astronomy itself, was born near the Nile over 14,000 years ago. The Greeks, he insisted, were scientific children compared to the Egyptians, whose knowledge and wisdom underlay all of Western science and mathematics.

The details of Dupuis' argument were new, and its feverish antireligiosity breathed the atmosphere of pre-Revolutionary France, but Egypt had been considered the original source of knowledge as early as the time of Plato. Scholars in the 17th century had provided countervailing arguments. Isaac Casaubon, for example, had demonstrated in 1614 that one group of texts—the influential Hermetic Corpus—actually dated from about 200 C.E. and not, as had been claimed, from Egypt near the time of Moses. Nevertheless, Egypt and the mysteries of its hieroglyphs continued to capture the European imagination throughout the 18th century. Constantin François Chasseboeuf, who had renamed himself "Volney" in admiration for Voltaire and Voltaire's residence, Ferney, produced a widely read account of his travels to Egypt and Syria between 1783 and 1785 that fed directly into this existing fascination. In his well-known works Volney argued that history amounts to a succession of continually reemerging ancient civilizations. This vision influenced Napoleon, who conceived his invasion of Egypt in 1798 as the latest act in Volney's grand historical drama. For Napoleon expected to be greeted as a liberator by native Egyptians, descendants of a wise and graceful past, who had been subjected for centuries to the oppression of the Ottoman Turks and their Mameluke satraps.

*(*B.C.E. is before the common era; C.E. means common era or Christian era.)*

The Napoleonic expedition was, in the end, a military debacle. Native Egyptians had little love for the Mamelukes, but neither did they greet the French invaders as liberators. Revolts and resistance to the occupation were frequent, and the French responded with great brutality. The English fleet under Admiral Nelson destroyed the French armada not long after its arrival at Alexandria, effectively isolating the French army in Egypt. Napoleon returned clandestinely to France a year later, leaving in charge General Kléber, who was assassinated nine months afterward by a Syrian who detested the presence of non-Muslims in Egypt and Syria. The French occupiers were forced to capitulate to the English by the end of August 1801.

The military failure of this first French colonial invasion of North Africa was soon overshadowed by the immense fund of knowledge concerning Egyptian antiquity that the expedition brought back (as well as by effective Napoleonic propaganda). Here, too, French beliefs concerning the course of history influenced attitudes toward Egyptian civilizations, past and present. Napoleon, trained as he was as a military engineer, and considering himself a natural philosopher and mathematician, had brought along on his flagship many of the most famous scientists of the day—his *savants*. Napoleon's military did not get along well with the *savants*; neither did the soldiers exhibit much tolerance and understanding of Egyptian customs. The *savants* (though military men themselves) had much greater sympathy and understanding for both the *fellahin*, or peasants, and the literate classes, but even they expected to find a people debased, or at least mired in ignorance, by centuries of alien oppression and by adherence to what they regarded as religious superstition. Of course, the *savants* thought all religions to be forms of superstition, so in this respect their condescension was ecumenical. They found what they had anticipated, as we can see from the iconography in the drawing (left) by one of the artists who accompanied the expedition.

Egypt as it is (right) and Egypt as it was (below), in the eyes of the early-19th-century French.

Note the attentive, busy artist dressed in French jacket and Egyptian pantaloons, curved sword at his side. He stares intently at an ancient frieze of what appear to be veiled pharaonic-era women. At lower right sits the artist's Egyptian companion, intent on nothing more than his hookah. He clearly has nothing to do with the regal and mysterious image that captures the artist's attention. To see just how far Egypt had fallen from its glorious past, we need only look at one of the magnificent drawings (left, below) through which the French imagined the Egypt of the pharaohs, where we see stately Egyptian priests, dressed like Roman senators, walking with slow dignity through an imposing temple. This imagery, this contrast, together with the complex interactions of the religiously indifferent conquerors with the unhappy and uneasy Muslim populace had profound effects on subsequent French, and indeed European, views of the Muslim world—a world that was sophisticated, erudite, and elegant, though not in ways that even sympathetic Europeans of the day could easily appreciate.

Educated Egyptians reciprocated French disdain. Al-Jabarti, from Cairo, a chronicler of the invasion, had this to say of the French establishment of a *Diwan*, or court, to adjudicate property issues—"In the form of this Diwan the French established a basis for malice, a foundation for godlessness, a bulwark of injustice, and a source of all manner of evil innovations." Moreover, the French Arabists who accompanied the expedition apparently had little sense of the language's character, which greatly annoyed Al-Jabarti, who deplored their "incoherent words and vulgar constructions." Not only were the French linguistic barbarians, they were disturbingly irreligious, for "they believe the world was not created, and that the heavenly bodies and the occurrences of the universe are influenced by the movement of the stars, and that nations appear and states decline, according to the nature of the conjunctions and the aspects of the moon." In Al-Jabarti's world the alternative to divine destiny was mechanical astrology, to which he thought the invading French "materialists" were addicted. We live today in the unfortunate aftermath of early colonial contacts such as these with the Near East.

Admiration, even awe, for Egypt past grew among the French in reciprocal measure to their disdain for Egypt present. The discovery of what seemed to be four ancient zodiacs fit neatly into this vision; all were rapidly assigned to millennia before (as we now know) the Greeks or even the Babylonians had developed astronomy. The zodiacs were first found by General Desaix—two at Esneh and two at Dendera—as he led his army up the Nile near Luxor. The artist Vivant Denon rapidly sketched the most interesting of the four,

Vivant Denon sketched the round zodiac (left) in the ceiling of the Temple of Dendera, publishing it in 1802. Contemporary astronomers and engineers believed it to be a true representation of the sky at the time the zodiac was produced.

Denon.

an intricate circular design found at Dendera; the other one at Dendera, as well as the two at Esneh, were rectangular. Denon's drawing, along with his sketches and a romantic account of his voyage with Napoleon's army, were printed in a massive folio edition in 1802. Smaller-sized printings rapidly followed, and Denon's *Voyage* became a huge best-seller of the day, both in France and in England, where it was translated and published that same year.

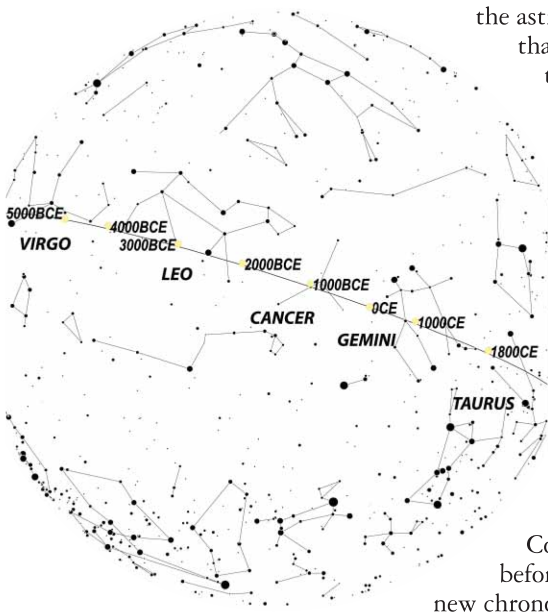
Even a quick glance at Denon's sketch shows what seem to be several easily identifiable zodiacal symbols, such as Taurus (the bull) on the upper right, or Libra (the balance) on the lower left. And the circular form at once suggested to French engineers and astronomers that this must be a planisphere—a projection of the sky done by the ancient Egyptians according to some rule. These, they thought, were not true cultural artifacts. Rather, the zodiacs skipped past the vagaries of human life and society to reflect nature as it truly was when they were produced. But what did they show, and when were they made?

Relying extensively on Dupuis' argument that the zodiac originated in Egypt millennia ago, and that its signs reflect the particular climatic conditions prevalent at the time, the astronomer Johann Karl Burckhardt and the engineer Jean-Baptiste Coraboeuf, both in Egypt as part of the expedition, argued that the Dendera zodiacs were produced about 2000 B.C.E., and that one of the two at Esneh might reach as far back as 6000 B.C.E.

Moreover, Burckhardt and Coraboeuf arrived at such astonishingly antique dates using the precession of the equinoxes, a phenomenon they were convinced was known to the ancient Egyptians.

The earth's axis does not remain parallel to itself as the planet revolves about the sun; it executes a very slow conical motion about the earth's center, called precession. At the end of the 18th century the period for precession was known to be about 25,748 years (as compared to the 36,000 years given by the Alexandrian astronomer Ptolemy in the 2nd century C.E.). Precession affects chronology in the following way: The plane of the earth's orbit cuts a great circle on the apparent sphere of the stars called the ecliptic, along which lie the zodiacal constellations. Since the sun appears to move along the ecliptic, during the course of the year it travels bit by bit through the zodiac. Twice a year the sun lies at the intersection of the ecliptic with the projection of the earth's equator onto the stellar sphere, and at these equinoctial points the hours of day and night are equal. The two points that lie on the ecliptic at 90° to the equinoxes are the solstices, and here the hours of daylight are longest (at the summer solstice) or shortest (at the winter solstice). Because of precession, the position of the sun at the equinoxes and the solstices with respect to the zodiacal constellations changes over time. For example, in about 2000 B.C.E. the spring equinox lay in Libra, and the summer solstice in Leo; whereas by 1800 C.E., the spring equinox had moved to Virgo and the summer solstice to Cancer.

One of the rectangular zodiacs at Esneh had the sign for Virgo at its left end, while the comparable one at Dendera had Leo in the same position. The circular zodiac, Burckhardt and Coraboeuf argued, seemed to spiral in from Leo (a doubtful claim, given Denon's sketch—or even the original). If the first sign in the rectangular zodiacs marked the summer solstice then, precessing backwards in time until the solstice occurred in Leo, the Dendera zodiacs had been produced no later than 2000 B.C.E. Taking the rectangular Esneh zodiac to begin with Virgo, it would date to about 5000 B.C.E. Since even the Dendera representations must have been preceded by at least several centuries of development, it seemed to the astronomer and the engineer that Dupuis' arguments for the extraordinary antiquity of Egypt were now seconded by the most modern of exact reasoning and observations. Coraboeuf went so far as to claim that the zodiacs "bear striking witness to the knowledge that the ancient Egyptians had of that astronomical phenomenon, the precession of the equinoxes."



During the course of a year, the sun appears to move through the zodiac along the plane of the ecliptic. But because of precession of the earth's axis (over many thousands of years), the position of the sun changes over time with respect to an individual constellation at a given point of the year, say the summer solstice (yellow dots). Locating the summer solstice in Virgo in 5000 B.C.E. provided "evidence" of the ancient age of the Egyptian zodiacs.

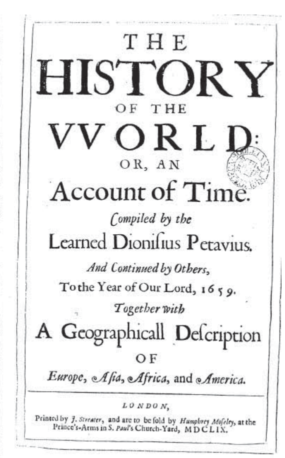
Burckhardt and Coraboeuf, like Dupuis before them, had fabricated a new chronology out of a flimsy tissue of evidence. Why assume that the sequence in the rectangular zodiac begins with the summer solstice? The solstice is, after all, extraordinarily hard to pin-point by observation, and in any case it was known from Greek texts that the Egyptians were particularly concerned with the heliacal rising of the brightest star in the sky, Sirius—that is, with the night when Sirius first appears, just before dawn. In Egyptian prehistory this event certainly preceded the annual flooding of the Nile, which was of obvious agricultural importance. Would not precession have moved Sirius along with the zodiacal stars, eventually decoupling its heliacal rising from the solstice, and so from the annual inundation? We know today that the inundation occurs after the June beginning of the rainy season in Ethiopia, where the Blue Nile rises. And yet Sirius' heliacal rising remained a central marker of the year throughout Egyptian history.

These kinds of objections, which in various forms appeared over the years, are essentially technical. They presume that the zodiacs are reasonably accurate drawings of the heavens as the Egyptians saw them at the time of their creation. For the next two decades many participants in the intense controversies that soon erupted did presume just that. This meant that objectors to the several dating schemes that emerged had either to offer technical counterpoints, or to propose new schemes of their own. Both types of critiques occurred. And, we shall see, the controversy changed in nature over the years with the social and political circumstances of Napoleonic and then Restoration France.

Burckhardt and Coraboeuf's dating became known from remarks printed in a volume describing the pyramids at Ghiza by another member of the Napoleonic expedition named Grobert. Publicized a few years later by the astronomer and ardent atheist Lalande, who nevertheless disagreed with their claims, these early remarks soon produced a powerfully antagonistic reaction. For even the dating of the circular zodiac to no later than 2000 B.C.E. came perilously close to the period assigned to Noah's flood, namely about 2300 B.C.E., as established by such 17th-century chronologers as Dionysius Petavius or Bishop Usher. As one ardent objector named Dalmas put it a number of years later, "Since everything on earth bears witness to a catastrophe similar to the deluge, and since even our incredulous ones believe in it, or at least can't deny it, [to accept their views would mean] to think that, from the moment the deluge ceased, men worked anew to reproduce their settlements on the earth . . . and it seems that a period of 17 to 20 thousand years would be required between us and the deluge—that's where this philosophy takes us."

Mosaic chronology, along with religious sentiment and belief, had long been subject to derision by French *philosophes*. On a visit to Paris in 1774 the English natural philosopher Joseph Priestley, who himself held decidedly unusual theological views, remarked that he found "all the philosophical persons to whom I was introduced at Paris, unbelievers in Christianity, and even professed Atheists. As I chose on all occasions to appear as a Christian, I was told by some of them, that I was the only person they had ever met with, of whose understanding they had any opinion, who professed to believe in Christianity." Dupuis' work, which appeared in book form 20 years later, shortly after the end of the Revolutionary Terror, had grown in fertile ground.

But circumstances had changed considerably by 1802. In July 1801 Napoleon, as First Consul, and Pope Pius VII agreed to reestablish the


THE
HISTORY
OF THE
VVORLD:
OR, AN
Account of Time.
Compiled by the
Learned Dionisius Petavius.
And Continued by Others,
To the Year of Our Lord, 1659.
Together with
A Geographicall Description
OF
Europe, Asia, Africa, and America.
LONDON,
Printed by J. Streater, and are to be sold by Humphrey Moseley, at the Prince's-Arms in S. Paul's Church-Yard, MDCLIX.

The dour Dionysius Petavius (right) dated Noah's flood at 2300 B.C.E.

Catholic Church in France as the religion "of the great majority," though not of the state itself. The agreement contained the provision that worship must conform "to such police regulations as the government shall consider necessary to public tranquility." Napoleon, though himself completely irreligious, wished to avert any faith-inspired insurrections, and he used police power not only to control public worship but also to manage what the press might say about religion. Newspapers were not to print articles that were either critical of religion, or, conversely, that seemed to elevate religious claims above those of the state. Enforced by Napoleon's chief of police, Joseph Fouché, press censorship rapidly dampened critical discussions that had any kind of political tinge.

At this time the zodiac debates were just beginning. Scarcely a week before the Concordat was announced, a priest in Rome named Domenico Testa, acting with the full approval of the Vatican, had produced a long screed on Dendera that vigorously refuted the claims for its antiquity. Also in Rome, Ennio Quirino Visconti, an unsuccessful rival of Vivant Denon's for directorship of the new Musée Napoleon, further attacked Dendera's antiquity on the grounds that the temple showed every sign of having been constructed in Greco-Roman times. Dupuis himself entered the fray in 1806, but by then censorship had taken hold, and he was careful to distance himself from discussions of chronology; he would instead write only about the "nature of the monument," despite his own long-standing belief in the Egyptian origin and antiquity of the constellations. Fouché's secret police were ubiquitous and feared, and Napoleon was by now more than First Consul; he had crowned himself Emperor in 1804.

Fourier.

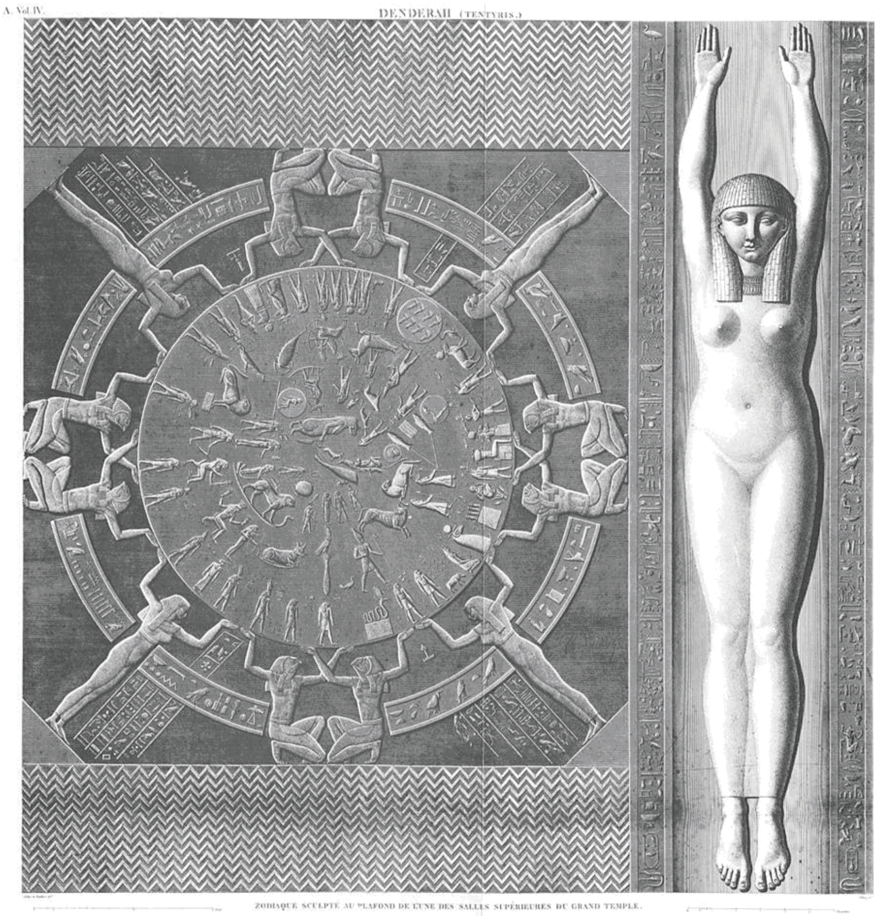
By 1809 the writer Chateaubriand, who dedicated his *Génie du Christianisme* to the dictator Napoleon, had begun infecting a generation with Romantic religiosity and hatred of republicanism. His writings, and those of others like him, cast a pall over skepticism, and certainly over critical historical discussion. That year the first volumes of the magnificently illustrated *Description de l'Egypte* appeared. With an introduction by Joseph Fourier—mathematician, member of the expedition, and now Napoleon's prefect in Isère—the *Description* revived the Dendera affair. Moreover, the *Description* contained a detailed and reputedly accurate drawing of the Dendera zodiac by the French engineers. Thoroughly conscious of the regime's aversion to anything that might offend belief and revive political tensions, Fourier and Edme Jomard only insinuated and hinted at their true views throughout the *Description*. Fourier had convinced himself that the zodiac dated to about 2500 B.C.E., while the engineer Jomard, who had also investigated the metrics of the pyramids, opted for many millennia before that, no doubt following Dupuis' original chronology for the constellations. This politically careful dance did not fool anyone, though it was enough to avoid Fouché's censors, and over time many readers discerned Jomard's and Fourier's opinions.

Jomard.

Arguments for Egyptian antiquity were cast further into the scholarly wilderness by the appearance in 1812 of Georges Cuvier's masterful account of the origins of fossils, and in particular its discussion of the ages of the earth. Cuvier, who had crafted the science of comparative anatomy, argued for the earth's having undergone a series of revolutions or catastrophes, with each one having propelled the globe into a new geological regime. The most recent, he asserted, was the Biblical Deluge, so powerful and all-encompassing that no evidence of antediluvian humanity could possibly have remained. As to chronology, Cuvier was circumspect in general, but not with regard to human history. Surveying with equal distance the records of the Hebrews, Chinese, and Indians, Cuvier concluded that all supported the existence of a massive flood at most several thousand years ago. As for the Dendera zodiac, which he mentioned, claims for its greater antiquity were dismissed. Cuvier, who had also mastered the niceties of patronage, which had led him to a position of power by the beginning of the Empire, no doubt also understood the need for circumspection in matters chronological.

Then, in 1814, after increasingly severe military defeats and social upheaval, Napoleon abdicated and was exiled to Elba. Louis XVIII, brother of the decapitated king, returned with his entourage of embittered émigrés, who found their estates sold, their privileges eliminated, and, perhaps worst of all, their claims to social preeminence usurped by a new class of nobles created by Napoleon. During the year of this First Restoration, Louis XVIII, though certainly no liberal by inclination, forestalled his angry relatives and aristocrats, attempting to create a new social consensus that would not be based on revenge. The properties that had been taken from church and aristocracy and then sold off to political functionaries and Revolutionary profiteers were not to be restored, easing the fears of their now respectable owners, who had been in possession for two decades. Press censorship markedly eased, though the agile Fouché remained chief of police. But Napoleon returned from Elba in the spring of 1815, and the restored monarchy fled in anguish and anger. After Napoleon's final defeat at Waterloo three months later the allies and the re-restored monarchy would brook no compromise, though Louis, evidently conscious of political realities, again remained less punishment-minded than his vengeful aristocrats.

Occupied Paris was infested with English, Russian, and Prussian soldiers. The English Prince Regent, in an effort to break the French spirit once and for all, proposed removing all of the artworks that had been plundered from France's conquered territories for installation in



French engineers made this drawing of the Dendera zodiac still in place on the temple ceiling, before it was blasted out and carted off to Paris. It was published in 1809 in the *Description de l'Egypte*, complete with a goddess and panels of hieroglyphs that did not appear in Denon's sketch—nor, ultimately, in the Louvre (see page 29).

the Louvre. This, perhaps more than any single event of the occupation, deeply angered even those with Royalist sympathies. As one English visitor to the Louvre remarked, "Every Frenchman looked like a walking volcano ready to spit fire." In the event, few works of art were removed, due to clever maneuvers on the parts of Denon and others. Within a few years the Restoration government had undertaken to imitate its Napoleonic predecessor in seeking glory through the theft and purchase of artworks and antiquities.

Newspapers flourished during these years, and the press certainly remained much freer than under Napoleon—though always under suspicion—but the monarchy nevertheless attempted to infuse the nation (or at least Paris, where all important events were thought to begin and end) with a renewed religiosity. It revived the faith-based pageantry of the *ancien régime*, leading to mawkish spectacles in which sanctimonious aristocrats paraded solemnly through the streets of Paris with lit candles—whereas police surveys of the day show that Parisians themselves had at nearly every level of society become more irreligious than ever before. The monarchy's affinity for churchly display, and its hatred for republicanism, was further exacerbated by the dramatic assassination of the only male heir, the Duc de Berri (son of Louis XVIII's brother), at the Opéra in 1820 by an antireligious, anti-Bourbon saddler.

Restoration Paris had its salons, where the real work of politics and social construction occurred. There were of course Royalist salons, but there were Napoleonic ones as well. Vivant Denon, for example, maintained a sort of shrine to the exiled emperor in his, surrounded by relics of the Egypt expedition, among other plundered objects. The most famous and active were the salons of the Duchesse de Duras, Madame de Montcalm, the Princesse de Vaudrémont, the Maréchal Suchet, the painter Baron Gérard (frequented by Cuvier, among other *savants*), and the Duchesse de Broglie. Here elegance mingled with politics as words flew back and forth over the major issues of the day.

In the midst of this febrile mixture of religiosity, politics, and social instability the Dendera zodiac made its physical appearance in Paris. The monarchy was interested in prestigious antiquities and works of art, and by the early 1820s a revived sense of rivalry with England coursed through French veins, especially where Egypt was concerned. Mehmet Ali, an Albanian originally in the employ of the Turks, had by this time gained full control of the country, and he cleverly played off the French and the British against one another in his efforts at modernization. Not overly concerned with antiquities himself, in fact often content to despoil ancient temples for their limestone, Ali would issue *firmans*, or permits, to foreigners for digging and even removal of relics. A man with an avid desire for the competitive (and potentially lucrative) collecting of Egyptian antiquities by the name of Sébastien-Louis Saulnier decided to obtain the Dendera "planisphere" for France. Saulnier had been Napoleon's police commissioner in Lyon as well as his prefect in both Tern-et-Garonne and the Aude. Thrown out of any official capacity during the Restoration, Saulnier occupied himself with literary and scientific matters, and became publisher of two influential periodicals.

How lucky, Saulnier remarked, that the French army under Napoleon had not taken down the Dendera zodiac, for if they had "it would certainly have fallen into the hands of the English, like the Rosetta inscription" (we will shortly return to the purloined Rosetta stone). To realize his dream of possession, the patriotic Saulnier commissioned a master mason of his acquaintance named Jean Baptiste Lelorrain to extract the monument from its home. Special saws, jacks, and large scissors were constructed, and Lelorrain left for Alexandria early in October 1820.

Lelorrain's adventures in Egypt have a certain romantic air about them, if archaeological vandalism can be called romantic. To remove the zodiac, Lelorrain sawed, pulled, and eventually used gunpowder to explode the ceiling out of the temple. At the time this struck several scholars, such as Jomard and the young Jean-François Champollion, as unconscionable. Today it would be both scientifically reprehensible and a likely violation of international law. Yet Egypt had long been treated by Europeans as a quarry for antiquities; many had been brought to Italy under the Roman Empire. In the 19th century Britain, France, and eventually Germany competed with one another on many fronts, not least in the purloining of antiquities. National pride, European disdain for native inhabitants (nicely honed by centuries of colonial experience elsewhere), and pure avarice brought many Egyptian artifacts to London, Paris, and Berlin. The Dendera zodiac, together with obelisks—such as the one visible today in the Place de la Concorde—were among the first. Many justified the removals by arguing that the artifacts would simply have decayed or been destroyed in Egypt, which is not altogether true, since by the 1820s Egyptians had become increasingly aware of the remote past and were seeking to establish their own museums.

To remove the zodiac, Lelorrain sawed, pulled, and eventually used gunpowder to explode the ceiling out of the temple.

Lelorrain and his loot arrived at Marseilles on September 9, 1821. After quarantine (to avoid the very real possibility of plague), the zodiac was offloaded on November 27. Almost at once "a stranger" offered to buy it for a "considerable sum." The patriotic Saulnier resisted. Early in 1822 he wrote a little book intended, in part, to drum up government interest. After discussions over where to put it, the zodiac went temporarily to the Louvre, where it excited tremendous public interest. Salons bubbled with talk about the Egyptian stars, scholars renewed their interest, religious unease reemerged, and a comedy soon appeared in a Parisian playhouse. "Paris has a zodiac from Dendera," a line from the comedy went, "so Dendera should have a zodiac from Paris." Dendera did one day have its zodiac from Paris, but not of Paris skies—a copy of its own ceiling eventually filled Lelorrain's vacant space. Public pressure led Louis XVIII to pay Saulnier the unprecedented sum of 150,000 francs for the zodiac, which was installed in the Royal Library. A good dinner in Paris at this time cost about 5 francs, so this was a huge amount, though Saulnier claimed that he had been offered more by the unnamed stranger. In 1919 the zodiac moved to the Egyptian collections of the Louvre, where it can still be seen.

Comparing the ceiling in the Louvre (opposite page) to the drawing in the *Description* on the previous page, we see that Lelorrain's sawn and exploded ceiling misses the goddess with outstretched arms, as well as the panels to her left and right that are filled with hieroglyphs. If we look closely at the lower left panel by her foot, we can see a hieroglyph drawn within an oval surround, called by the French soldiers a "cartouche" for its resemblance to a cartridge case. Since these panels were left behind at Dendera, and since Denon himself had not drawn them, anyone interested in the hieroglyphs had to rely entirely on the *Description*'s print.

But the hieroglyphs could not be read, or they couldn't be until the summer after the zodiac's arrival—the summer of that *diner chez Laplace* where the zodiac dominated conversation. In fact, Egyptian hieroglyphs had been under intense investigation by an ardent young protégé of Fourier, Jean-François Champollion, a talented republican pamphleteer and superb linguist who was convinced that hieroglyphs could be understood only by someone who had knowledge of life as it was lived in ancient Egypt. These mute symbols, he was certain, would speak only if they were treated neither as cryptographic codes nor as mystical talismans. On September 22 Champollion finished a letter to Bon-Joseph Dacier, the permanent secretary of the *Académie des Inscriptions et Belles Lettres*, where philology, linguistics, and antiquity increasingly mixed and merged with one another. That famous missive explained the essential principles underlying hieroglyphs—that they are fundamentally phonetic, with ideograms used as well, some of the ideograms functioning as what Champollion called "determinatives," or unvoiced

The actual Dendera zodiac, sans the surrounding depictions shown in the *Descriptions de l'Egypte* on page 27, has been exhibited in the Louvre since 1919. The lower image indicates the zodiac figures in red.

signs, which specify what the text is about. Determinatives provided an essential clue to decipherment, and they were what everyone else had missed.

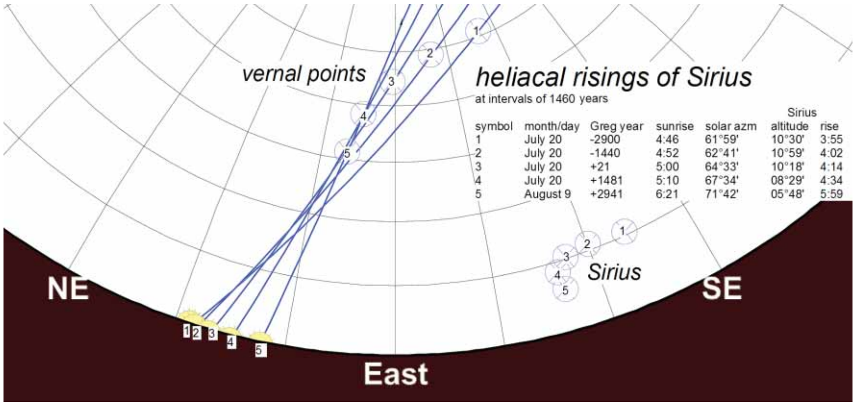
Champollion's was not the only attempt at the time to read the mysterious symbols. The English polymath Thomas Young had also tried his hand. Young approached hieroglyphs almost as though they were a mathematical problem, an issue of cryptographic understanding, and not as a script that was bound to ancient Egyptian ways of thinking. He had however made progress and was the first to suggest in writing that the symbols were essentially phonetic. Both Young's and Champollion's work depended upon their use of the Rosetta stone, which contained the same text in formal hieroglyphs, in the popular Demotic (or what Young called "Encorial")—a late Egyptian script—and in Greek. Discovered by the French early in their expedition, the stone was taken from them (and from Egypt) by the British, when the French were forced to surrender a few years later. As it happens, not only was Young in Paris in the fall of 1822, but he also attended the very meeting of the *Académie des Inscriptions* at which Champollion's letter to Dacier was read. This isn't the place to discuss the complex and increasingly angry dispute between the partisans of Young and Champollion concerning the decipherment of hieroglyphs. Suffice it to say that Young at first thought of Champollion as a junior partner who was following the trail that he had mapped out. Champollion had other ideas, and bitterness soon grew between the two.

Unfortunately for Young, this was the second time within a very short period that a junior Frenchman had apparently bested him. By 1822 the wave theory of light, which Young had developed and espoused two decades before, had been taken to new mathematical and empirical heights by Augustin Jean Fresnel. Though Young remained on friendly terms with Fresnel—in part because Fresnel was much more astute in handling issues of priority than was the fiery Champollion—nevertheless, to have been displaced twice by young Frenchmen, by citizens of a nation so recently and thoroughly defeated by the English, was not altogether pleasant for the foreign secretary of the Royal Society of London.

The lines of patronage, national pride, and scientific politics twisted and turned around these people. Champollion found support from François Arago, who had been Fresnel's major patron and yet a close friend of Young's. Arago later danced nimbly around the conflicts in his obituary of Young. Arago was also close friends with Fourier, whose new theory of heat conduction he strongly supported. That theory, indeed Fourier's entire approach to physics, had long been challenged by physicists associated with Laplace, among whom was Jean-Baptiste Biot. Biot and Arago disliked one another intensely, since Arago felt, with some justification, that Biot had muscled him aside a decade before in new optical discoveries that Arago had been the first to make. This had produced a vicious and very public spat between the two.

In the spring of 1822, just before Champollion's breakthrough, both Champollion and Biot published papers on the dating of the Dendera zodiac. Despite a comparatively friendly warning from Champollion, Biot, like Fourier and other physicists before him, persisted in treating the zodiac as though it were a direct image of nature, untouched by human understanding. He identified what he took to be certain star patterns in it, applied precession, and arrived at a date of about 800 B.C.E. Champollion, now deep into his work on hieroglyphs and approaching the moment of full understanding, warned Biot that the whole business was suspect, but Biot persisted and went into print with his own astronomical dating scheme.

In a first irony, and this story has many, Biot later criticized Fourier for an incorrect application of astronomy to the zodiac. This brings us back to our beginning, to the claims of Burckhardt and Coraboeuf. Recall that they had associated the zodiacs' dates of production with the positions of the summer solstice among the constellations, which entailed that, despite precession, Sirius and the solstice must remain about the same distance in time from one another during most of Egyptian history. Indeed they do, though it's doubtful that Burckhardt and Coraboeuf had thought it through. Because of Sirius' position, and the latitudes at which the Egyptians observed the sky, both Sirius' heliacal rising and the summer solstice remained nearly the same number of days apart throughout Egyptian history even though the



The rising of Sirius, the brightest star in the heavens and important to Egyptians as the signal for the annual flooding of the Nile, was assumed by the French physicists to move with relation to the sun as do the constellations of the zodiac. It does not, however, as we see here. The curved line dividing the lit from the dark regions represents the horizon near Dendera. The blue lines show the locations of the ecliptic with respect to the horizon at five helical risings separated by hundreds of years. The vernal points mark the equinoxes at these times, and the circled numbers on the lower right indicate the corresponding positions of Sirius. Sirius remains about the same distance from the equinoxes—and so from the solstices—throughout these many centuries, despite precession.

zodiac moves slowly around the ecliptic. Fourier, a masterful mathematician but evidently a poor astronomer, just assumed that Sirius would behave like a zodiacal star, making his calculations inherently flawed. Biot did not hesitate to point this out.

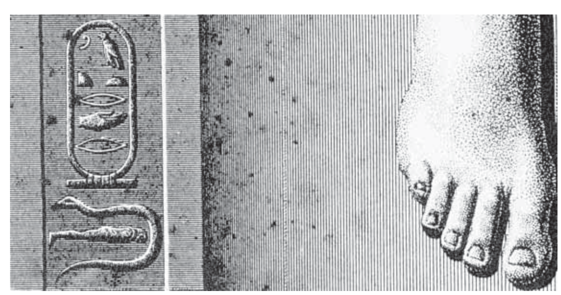
Though Biot persisted in his dating schemes for years, Champollion had already softened the force of his calculations by quickly publishing a refutation. Biot had after all been warned. Champollion's argument seemed to be irrefutable, even though it altogether avoided any claims for the zodiac's putative astronomical significance. For Champollion saw the constellations—like hieroglyphs themselves—as an expression of Egyptian culture. The zodiac was not a planisphere, he believed (correctly, as it turned out), but an astrological chart. In what soon proved to be a major step along his route to the decipherment of hieroglyphs, Champollion conceived that the stars depicted on the Dendera ceiling referred not to the heavens themselves but to the *graphic* itself. They were in fact determinatives, put there to tell the reader that the graphic was about celestial events that guide human destiny. The meaning of Egypt's stars could not be uncovered through calculations done under Paris skies.

How then did Champollion date the zodiac? What told him, as he asserted, that it certainly could not have been made before the Alexandrian conquest, and that it more likely dated to the very late period of Greco-Roman domination in the 1st century B.C.E.? The clue lay not in any image on the purloined zodiac itself, but rather in the side hieroglyphs that had been depicted only in the drawing in the *Description*. At the lower left of the goddess, the print displays a cartouche with (phonetic) signs that Champollion could now pronounce as *autocrator*, which is the Greek word for dictator. What more could one ask? Dendera's Grecian-era birth now seemed to be just as solidly established as Champollion's increasingly impressive readings of hieroglyphs. (And the pope offered the nonreligious Champollion a cardinalship, even though he was married with three children, for having salvaged biblical chronology.)

Debate nevertheless did not end there. Some were to argue that the ceiling might have been designed or built elsewhere and only then brought to its later surrounds, which would still permit the extravagant antiquity that Jomard had insisted upon. Others, like Biot, rejected extreme age but persisted in their astronomical games since, after all, Champollion had not proven irrefutably that the stars *could not* have positional meaning. In fact they don't, though the locations of *planetary* signs in particular constellations may perhaps be telling. Thomas Young himself perceived the folly of housing observations and calculations in the alien environment of words. "The French astronomers still persist in amusing themselves" with the Dendera zodiac, he wrote with evident sarcasm from Paris in late September 1822 to his friend William Hamilton at Naples (British minister plenipotentiary to the Neapolitan court).

Throughout the decade following Champollion's decipherment Parisian newspapers, salons, journals, and institutional meetings brimmed with exchanges about zodiacs. Pamphlets appeared in profusion, scholars attacked one another, and charges of plagiarism were thrown about. Over time the issue subsided, though it continued to erupt now and then. Years later, and especially after the publication in 1859 of Darwin's *Origin of Species*, arguments for the youth of Egypt were occasionally bracketed with arguments against evolutionary descent, each supporting the other.

In 1828 Champollion mounted an expedition to Egypt to see the ruins for himself. The expedition arrived at Dendera in mid-November. Entering the part of the temple that had housed the circular zodiac, Champollion saw for the first time the empty space left by Lelorrain nearly a decade before. He saw something else as well. Turning to look at the surrounding hieroglyphs that had



The critical cartouche near the goddess's foot in the *Descriptions* drawing, whose hieroglyphics led Champollion to the conclusion that Dendera dated from the Greco-Roman era, turned out to be empty when Champollion visited the temple in person.

> The heated arguments that engaged so many people for more than two decades raised the question of who was entitled to speak with authority about antiquity. Was it to be the physicists and engineers, who had one view of evidence, or philologists, linguists, and historians, who had a rather different one?

not been sent to Paris, Champollion froze in dismay. Every single cartouche was empty: there were no hieroglyphs in them at all! The evidence he had so successfully, and influentially, used to date Dendera simply did not exist. Years later the reason became clear. The ceiling had been constructed during the interregnum between the death of Cleopatra's father, Ptolemy Auletes in 51 B.C.E., and the coregency officially established in 42 with Caesarion, Cleopatra's five-year-old son by Julius Caesar. Built during the interregnum, the Dendera zodiac's empty cartouches, like those of every monument constructed during that period, forever awaited royal names. In preparing the plates for publication of the *Description*, some enterprising draftsman had decided to fill the empty cartouches in the drawing with hieroglyphs found in other drawings. How ironic that this very *absence* of hieroglyphs in the cartouches now permits the monument to be dated quite precisely.

Stepping back from the colorful details of the Dendera affair, we can discern a difference among French *savants* that became ever sharper as the century wore on, and that remains with us today. The heated arguments that engaged so many people for more than two decades raised the question of who was entitled to speak with authority about antiquity. Was it to be physicists and engineers, who had one view of evidence, or philologists, linguists, and historians, who had a rather different one? Philologists and linguists, such as the young Champollion, understood the zodiac to be the creation of ancient Egyptian life; it spoke to the beliefs by which Egyptians at the end of the pharaonic era guided their lives. Physicists like Fourier and Biot may have disagreed with one another over which of them could better calculate the past, but both were convinced that the Dendera ceiling was an image of the Egyptian sky essentially unstained by human imagination. Even if it was imperfect, perhaps distorted by the fancies of human imagination or an ancient craftsman's lack of skill in representation, an image might nevertheless shine with evidentiary power just because it could be submitted to numbers, and in numbers alone lay truth. For words are imprecise things, and they have natural truths only as distant and distorted ancestors. Or so men like Fourier, Biot, and Jomard thought. The siren song of calculation deceived them. Al-Jabarti, the chronicler of the French invasion, might have warned them otherwise, for he knew that the sonorities and cadences of Arabic could sway the minds of men. Perhaps ancient Egyptians also beheld the world in speech. And yet Champollion, correct though he turned out to have been, and no friend of numbers, was deceived by the very absence of words he thought to be present. The mystery of Dendera was finally solved neither by numbers nor by the sounds of words, but by a new kind of historical understanding, one in which many forms of evidence—linguistic, artistic, literary, and archaeological—were together weighed and confronted with one another. There never was a Royal Road to the Egypt of the pharaohs. □

Jed Z. Buchwald, the Doris and Henry Dreyfuss Professor of History, came to Caltech in 2001, after 10 years as the Dibner Professor of the History of Science and director of the Dibner Institute for the History of Science and Technology at MIT. He earned his BA in history (1971) from Princeton, and his MA (1973) and PhD (1974) in the history of science from Harvard. From 1974 to 1992 he was a member of the University of Toronto faculty. Buchwald's work focuses primarily on the history of physics from the 17th through 19th centuries (he has written books on Hertz and electric waves and on Fresnel and wave optics) and on related issues in the philosophy of science. But he's also interested in (and teaches courses in) the social and economic history of ancient Mesopotamia and Egypt. Buchwald was a MacArthur Fellow from 1995 to 2000.

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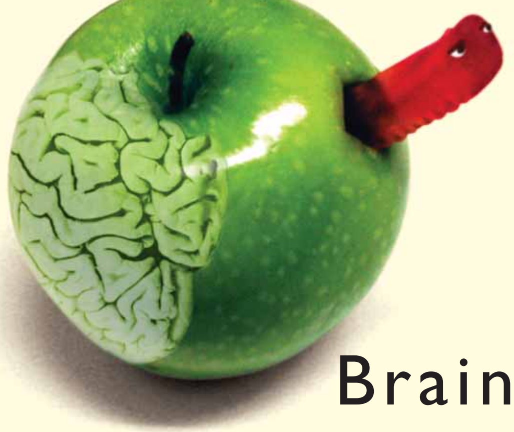


Brain Worms and Brain Amoebas: They Do Exist

by Andrea Manzo

The E&S *staff have selected this article from those written for the Core 1 Science Writing course, which is a requirement for all undergraduates so that they can gain experience in communicating science to the general public.*

Parasites in the Brain?

At a recent evening lecture at the California Institute of Technology, a neurologist was explaining the ins and outs of new brain-imaging technology to an audience composed of Caltech professors, students, and members of the general public. The audience was rather quiet, lulled by the technical tone of the lecture. But when the neurologist mentioned in passing that the disease afflicting one of his patients was caused by a brain parasite, the whole room sat up and made a collective noise of disgust and alarm. *Brain* parasites!

But, in fact, parasites infect us all the time. They live in our bodies, even in our cells, and most of the time we do not even know that they are there. The brain can provide a pleasant, nurturing environment for parasites, because it has structures that prevent many of the immune system's cells from entering, at least in the early stages of infection. Add to that plenty of oxygen and nutrients, and the brain seems like a rather nice place to live.

Despite its seemingly idyllic home, a brain parasite's life does have its hardships. To begin with, the parasite has to find a way into the brain. Invasion of any organ is difficult, but the brain is an especially tough nut to crack due to a protective barrier between the bloodstream and brain fluid, called the blood-brain barrier. This barrier is made up of cells that make a tight seal along any blood vessels so that most stuff from the bloodstream (including brain parasites) can't leak into the brain. If the parasite does manage to successfully enter the brain, it then has to deal with the attack of the immune system. The cells of the immune system act together to rid the body of any foreign organisms. In humans, the immune system is highly organized and efficient; parasites' evasion mechanisms have evolved to be good enough to thwart the immune system, at least for a little while. Unfortunately, the most effective parasites are the ones we really have to worry about.

In fact, millions of people worldwide are infected by these efficacious brain parasites. If you haven't heard about them before, it is probably because most infected people live in nonindustrialized countries, where living conditions are not very sanitary. Many of these brain parasites cause debilitating conditions and sometimes even death. So, in addition to being interesting biologically, brain parasites are also important in the context of human disease.

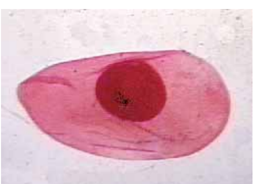
Two parasites with disease-causing capabilities are the pork tapeworm, *Taenia solium*, and the amoeba *Naegleria fowleri*. In addition to their medical importance, these two organisms illustrate the many ways that brain parasites are able to affect their hosts through their methods of invasion and survival.

Tapeworm: From Pork Chops to the Brain

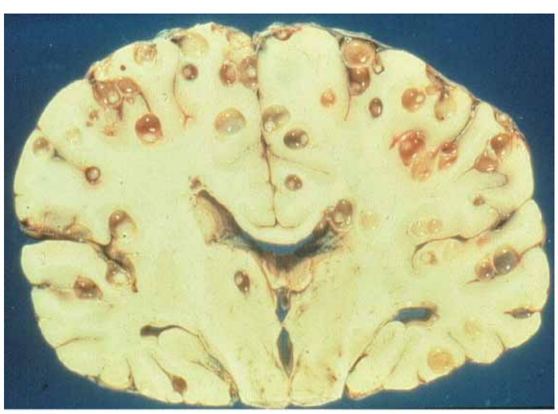
The pork tapeworm is one of the most common disease-causing brain parasites. This parasite infects over 50 million people worldwide, and is the leading cause of brain seizures. It is usually contracted from eating undercooked pork, and once in the gut, it attaches to the intestine, and then grows to be several feet long. Under certain circumstances, these worms can also invade the brain, where thankfully they don't grow to be quite so large.

Why does the worm sometimes attach to the intestine but at other times travel to the brain? It all depends on what stage of its life cycle the worm is in when it is swallowed. In its larval stage, the worm will hook onto the intestine; however, if eggs are swallowed, they hatch in the stomach. From there the larvae can enter the bloodstream and eventually travel to the brain. But in order to reach the brain from the bloodstream, the larvae must traverse the blood-brain barrier. Unfortunately, researchers still don't know exactly how this happens. Many scientists think that the larvae can release enzymes that are able to dissolve a small portion of the blood-brain barrier to allow the parasite to get through into the brain.

Once the larvae reach the brain, they cause a disease called neurocysticercosis, by attaching to either the brain tissue itself, or to cavities through which brain fluid flows. (Brain fluid carries nutrients and waste to and from the brain, and acts as a cushion to protect the brain against physical impact.) Once attached, the larvae develop into cyst-like structures. The location of the cysts determines the symptoms exhibited by the host. If the larvae attach to the brain tissue, then the host often experiences seizures. This occurs partly because the presence of the larvae causes the activity of the brain to become wild and uncontrolled, thereby causing a seizure. On the other hand, if the larvae attach to the brain-fluid cavities, the host experiences headaches, nausea, dizziness, and altered mental states in addition to seizures. These additional symptoms occur because the flow of the brain fluid is blocked by the larvae. Often, the presence of the larvae also causes the lining of the brain-fluid cavities to become inflamed, further constricting the flow of the brain fluid. Since the cavities are a closed system, blockage of the cavities exerts pressure on the brain. This increased cranial pressure forces the heart to pump harder in order to deliver blood to the brain area, increasing the pressure on the brain even more. If the condition is not treated, the heart eventually cannot pump enough blood to the brain, neurons begin to die off, and major brain damage occurs.



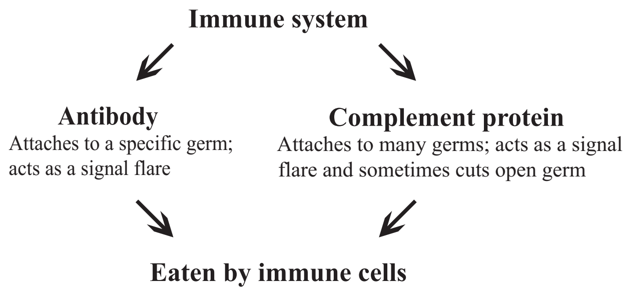
Left: A pork tapeworm (*Taenia solium*) cysticercus, the form in which the tapeworm is found in an infected brain. (Colorized image by P. W. Pappas and S. M. Wardrop, courtesy of P. W. Pappas, Ohio State University.)
Below: *T. solium* cysticerci in the brain of a nine-year-old girl who died during cerebrospinal fluid extraction to diagnose her headaches. This was in the 1970s—if it had happened 10 years later, noninvasive computerized tomography would have given an accurate diagnosis, and the parasites could have been killed with drugs. (Image courtesy of Dr. Ana Flisser, National Autonomous University of Mexico.)



It is interesting to note that some of these symptoms, such as seizures, are caused not only by the presence of the brain parasites, but also by the immune system. In general, parasites do not want to be detected by the immune system, because then they will most likely be eaten and killed. They try to do everything they can to avoid eliciting a strong immune response. Parasites also don't want to do anything that can kill the host. If the host dies, then the parasites die too. For this reason, people can have parasites for years and not show any symptoms at all. But then, as the larval defenses break down, the host immune system is able to have a greater effect, and the symptoms become more obvious. What does the host immune system do to defend against the parasites, and why do its actions elicit harmful effects on its own body?

Defending the Body from Invaders

The main function of the immune system is to make sure that any foreign object in the body is destroyed, including brain parasites. Many of the symptoms arising from brain parasite infection are due to the interactions between the immune system and the parasite. There are two main methods by which the immune system tries to rid the brain of the parasite. First, certain cells of the immune system make antibodies specifically against the parasite. Antibodies are molecules that can attach to a foreign organism and act like a signal flare, telling the rest of the immune cells that this organism is foreign and should be destroyed. There are also other immune cells, called phagocytes, which travel around the body eating anything that isn't recognized as belonging to that body. These cells are much more effective at destroying germs that are labeled by antibodies.



Second, there are proteins in the body that are able to recognize some general characteristics of many germs. These proteins make up the complement system. The complement proteins are able to attach to the germ and also act as signal flares to attract other immune cells that can destroy the germ. However, these proteins are sometimes also able to kill the germ themselves by forming a structure on the surface that can cut the germ open.

Why the Immune System Can't "See" Tapeworm Cysts

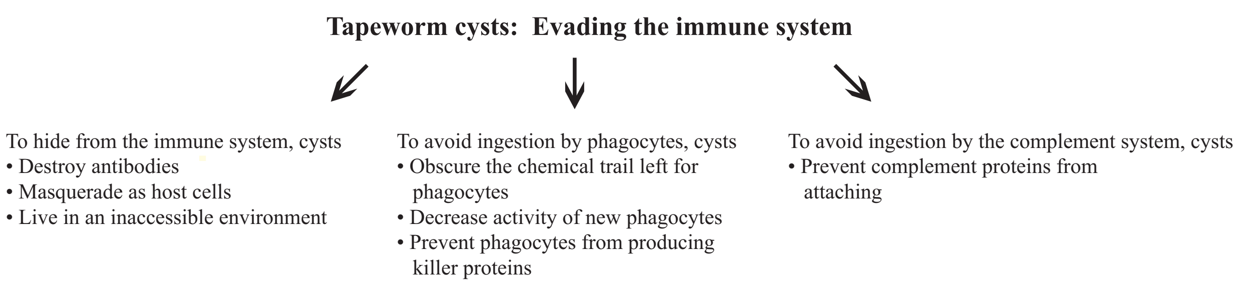
The interaction between the immune system and the cysts is quite amazing; it is a great example of how evolution can produce two complementary systems. The immune system is seeking to find and destroy the parasite, while the parasite is attempting to stay hidden and alive. One way that the cysts are able to "hide" from the immune system is by degrading the antibodies that attach to them. There is some evidence that the antibodies are used as a food source, and that the cysts are able to coax the immune system to make more antibodies. The cysts can even disguise themselves as part of the host's body by displaying proteins on their surfaces that identify them as part of the host—much as Wile E. Coyote hides from Sam Sheepdog in a herd of sheep by wearing a sheepskin. Finally, the location of the cysts is itself conducive to escaping detection by the immune system. The brain is not easily accessible to the cells of the immune system due to the presence of the blood-brain barrier, and so the parasites are partially protected from random encounters with the body's defenders. Only when the immune response is in full swing can the immune cells enter the brain in large numbers.

Besides hiding from the immune system, the tapeworm parasites are able to prevent the immune cells from killing them by using several strategies. For instance, the parasites are able to prevent the complement proteins from attaching to their surfaces. The tapeworms can even release molecules that act as decoys, tricking the killer proteins into leaving them alone. The cysts also release other proteins that are able to protect them from being eaten, although how exactly this is accomplished is still unknown. There is some evidence that these proteins are able to prevent phagocytes from accurately targeting the cysts. One of the ways that phagocytes are able to go to the right place in the body during an infection is by following a chemical trail. This trail is produced by other immune cells at the site of infection. Some of the proteins released by the cysts are able to obscure this chemical trail so that the phagocytes become lost on their way to the infection. Cysts are also thought to release a second set of proteins that decreases the activity of new phagocytes. These proteins affect another group of immune cells that control the activity of new phagocytes; these regulatory immune cells then decrease the number of active phagocytes. Finally, a third set of proteins released by the cysts is thought to be able to prevent phagocytes from producing the proteins necessary to kill the cysts.

Victory?

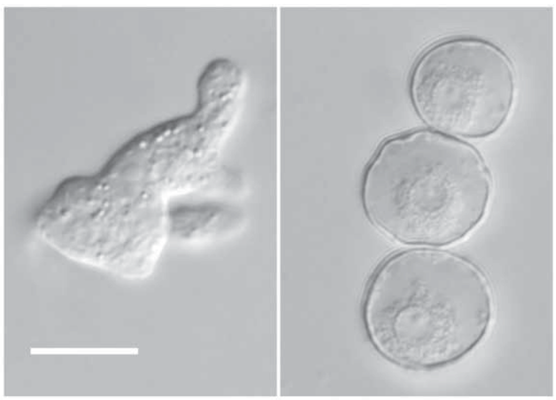
The cysts are very successful in evading the immune system, but they gradually become more and more vulnerable to attack. As the immune system response gains strength, the most common symptoms of infection become more and more obvious. At first, the parasites are simply unable to hide from the immune cells, and cannot pretend to be part of the host's body anymore. Then the full immune system response kicks in, and because the immune cells are able to detect the parasites, the parasites are doomed. More antibodies and complement proteins are released, more phagocytes are born, and more blood and immune cells rush to the parasitic sites. The areas where the

At top: The two main pathways of the immune system response. Below: How tapeworm cysts evade the immune response.



parasites are located become swollen, which often leads to seizures and compression of the surrounding brain tissue. As the response progresses, the cysts are replaced by scar tissue, and finally by calcium deposits. (Calcium deposition often occurs in the body due to the activity of bacteria living in the blood, rather than as a direct effect of the immune system's response.) The scar tissue and calcium deposits are also known to cause seizures. In addition, the immune response causes irreparable brain damage to the areas of the brain around the cyst as the phagocytes ingest the cells surrounding the cysts, which also contributes to the seizures.

In fact, more harm than good often comes out of the immune response to infection of the brain by tapeworms. Against most pathogens, however, the immune response is actually beneficial to the body.



Naegleria fowleri **in the amoeboid form, near right, and in the cyst form, far right. The scale bar is 10 micrometers. Images courtesy of Bret Robinson, Australian Water Quality Centre and CRC for Water Quality Research.**

Foreign organisms often cause lots of damage, and it is important that they be destroyed as quickly and efficiently as possible. Furthermore, the immune system response is generally the same regardless of the identity of the foreign invader; and in most circumstances, the immune response does not have negative effects. Overall, the immune system is actually highly effective at defending the body from foreign organisms.

Of course, the effectiveness of the immune system is largely dependent on the ability of the body to mobilize its defenses. Some parasites act so quickly that the immune system is unable to react before the infection becomes fatal. One such brain parasite is *Naegleria fowleri*, a water-borne amoeba.

Danger in the Waters

If you've never heard of *Naegleria fowleri*, don't be surprised. Unlike the pork tapeworm, *N. fowleri* has only infected about 175 people in the world, causing a disease called primary amoebic meningocephalitis. But out of those 175 people, only six have survived, giving a mortality rate of 97 percent. For this reason, it is quite an important parasite to study, as there are no current treatments that have proven effective against it.

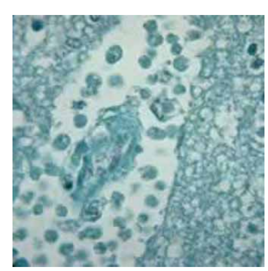
Fortunately, natural infection by the parasite is very rare, although *N. fowleri* is ubiquitous in the wild. It lives mostly in warm freshwater lakes and ponds, but can even thrive in heated swimming pools. Furthermore, *N. fowleri* is actually a free-living organism, which means that it can survive without a host. This explains why *N. fowleri* attacks are so rapidly fatal—since hosts are not necessary to its survival, the parasite does not have to take pains to avoid killing them.

Part of the reason that *N. fowleri* can survive in such numbers and in so many different places is because it is an amoeba. Amoebas are single-celled creatures that resemble sacks of fluid gelatin surrounded by a greasy membrane. Because of their small size and few requisites for survival, these organisms are found everywhere. In addition, the amoebas can form cysts in harsh conditions like extreme cold; in this form, they are protected against the environment.

Attack of the Amoebas

When an amoeba invades a person, it is normally in its active, reproductive phase. Invasion occurs when the amoeba attaches to the inside of its host's nose and then travels up the nose to the brain. The amoeba follows the path laid out by the olfactory nerve, although sometimes it can also use the bloodstream. Several enzymes released by the amoeba are able to dissolve the host's tissues, giving access to the brain. Once in the brain, the amoeba causes damage by actually eating the nerve cells. As you can imagine, this is very harmful to the host, and is the main reason why infection by *N. fowleri* causes such rapid death. The amoeba is able to eat neurons because it has surface proteins that allow it to cut a hole in the covering of the cell. The contents of the neuron leak out, and the

Brain tissue infected by *Naegleria fowleri*. The dark dots are the amoebas. Notice the empty space around the dots; this space used to be tissue before the amoebas digested it. Image provided by the Division of Parasitic Diseases, Centers for Disease Control and Prevention.



***Naegleria fowleri:* Evading the immune system**

To hide from the immune system, amoebas
- Destroy antibodies
- Live in an inaccessible environment

To avoid ingestion by the complement system, amoebas
- Prevent complement proteins from attaching
- Shed portion of membrane containing complement proteins

How *Naegleria fowleri* amoebas evade the immune system.

amoeba can feed on the nutrients it contains. The amoeba even has proteins on its surface that tell it where the best food sources are. These proteins are able to sense the presence of certain nutrients, and then send signals to the rest of the cell indicating in which direction the amoeba should move to eat those nutrients. Finally, there are other proteins on the amoeba's surface that direct it to the most vulnerable areas of a neuron.

In addition to causing direct brain damage by ingesting neurons, the presence of *N. fowleri* amoebas can cause inflammation of the brain-fluid cavity linings. Similarly to infection by tapeworm, blocking the brain fluid can cause increased pressure on the brain. However, this effect is usually only secondary to the much more destructive digesting action of the amoebas.

Fighting the Invader

The immune system, however, is not completely idle while this invasion and destruction is occurring, although for the most part its efforts are in vain. The amoebas use several strategies to stave off the immune cells. Many of these strategies are similar to those used by tapeworm cysts. For example, the amoebas are able to internalize antibodies on their surfaces, although they don't need these antibodies as a food source. Other proteins on the amoeba's surface prevent the attachment of complement proteins. If the complement proteins are able to bypass these surface proteins, the amoeba is able to collect them in one area of its membrane. Afterwards, the amoeba can shed that piece of the membrane. The shed membrane acts as a decoy, attracting more complement proteins that would otherwise attack the amoeba.

Why are these strategies effective in shielding the amoebas, but not tapeworms, from the immune system? The reason is that an amoebal infection is rapidly fatal. The immune system does not have time to fully mobilize its immune cell armies before the brain damage is so extreme that the organism dies. Since these amoebas don't need the host to survive, it's not a big deal if they kill him or her off. Tapeworms, however, die when the host does, and so they try very hard to keep from being detected by the immune system. And in fact, they do a fairly good job at that, since most tapeworm infections aren't noticeable until many years after the tapeworms get into the brain. The immune system is only able to have a big effect on the infection when the tapeworms start to die, often from old age.

Parasite Evolution

These two parasites offer only an inkling of the many organisms that can infect the human brain. While the two seem to differ greatly, the molecular weapons they use for defense and invasion are really very similar. For instance, there is evidence that both parasites use enzymes to penetrate the blood-brain barrier, and both use a decoy strategy to deflect the attention of the immune system. This similarity results from evolution, which has slowly altered these parasites so that they are as effective as possible at survival. As new treatments and cures of brain-parasite-related diseases become available, it will be interesting (as well as medically useful) to see how the strategies of these parasites change. □

Andrea Manzo is a senior majoring in biology. She decided to find out more about brain parasites after attending the 2002 Biology Forum, "Gray Matters: Perception, Intention, Memory, and Dysfunction in the Brain," but is currently doing a research project on neural-crest cell development in chick embryos, a subject with a much lower yuk factor, in the lab of Ruddock Professor of Biology Marianne Bronner-Fraser. Andrea is also house secretary and webmaster of Ricketts. Her faculty mentor on the Core 1 paper was Jed Buchwald, the Dreyfuss Professor of History (see page 20), and the editor was Gillian Pierce.

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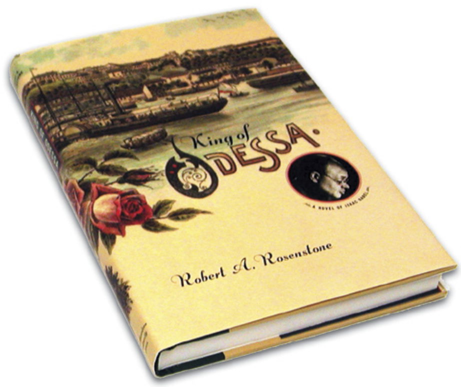


King of Odessa
by Robert A. Rosenstone
Northwestern University Press, 2003
240 pages, $24.95

As the handsome 2004 *Personnel Directory* that recently arrived on our desks reminds us, Caltech is a house divided. Founded, that is, on six academic divisions. The structure stands, nonetheless, very well. When it comes to universities, Lincoln, it would seem, was wrong.

Robert Rosenstone's distinguished career has been one of incorrigible transgression. Not—I hasten to say—of any moral or criminal kind. Rosenstone has consistently overridden the formal subdivisions within his home division (Humanities and Social Sciences). His project, as a scholar, blurs familiar and comfortable lines of intellectual demarcation. For years now he has taught a course at Caltech entitled "History in Film" (NB, not "History *and* Film"). The two discourses, cinematic and historiographic, interpenetrate. They are indivisible. Is, for example, *Reds* (a movie based on Rosenstone's life of John Reed, the American radical) Hollywood fantasy, biopic, or a history lesson about the emergence of the Soviet Union? All these and more, Rosenstone would maintain. And none cancels out the other.

Rosenstone's *Romantic Revolutionary: A Biography of John Reed* was, when it first came out in 1975, a much more adventurous book ("revolutionary," one might say) than it now appears. What Rosenstone did was to plug those vacant parts of his subject's life about which we could know nothing (because no documentary or oral evidence survived) with fictional reconstruction. Put crudely (and his work is anything but crude), Rosenstone hybridized novel and biography into a new narrative synthesis. It is a technique that has subsequently been debased in works like Edmund Morris's *Dutch* (1999; a candidate for the worst Presidential biography ever written) and exploited admirably in Janet Malcolm's brilliant *Reading Chekhov: A Critical Journey* (2003).

I have often wondered why Rosenstone did not continue as a biographer. He must have had tempting invitations from publishers (his biography of Reed remains the standard work). He was, I suspect, temperamentally disinclined to remain in one subject area. A theme that recurs in his autobiographical writing (notably *The Man Who Swam into History*, 2002) is migration. He chronicles his family history as something irresistibly nomadic—a heritage that has rendered him intellectually restless. There seems to be no obvious mold to his scholarship. The move, for example, to the subject of American interaction with Japanese culture, *Mirror in the Shrine* (1988), was wholly unpredictable. That book, although it contains some of Rosenstone's most carefully composed prose, stands, I would say, as a gallant failure: less a reflection on the author than proof of the impenetrability of Japan. But, whatever else, it witnesses to Rosenstone's constant striving for new lines of approach to his subject. And new subjects.

King of Odessa is described by the publisher as Rosenstone's first novel, which suggests a new departure. It is, in fact, more in the nature of a resumé, or compendium, of themes, techniques, and obsessions (the word is not too strong) that have been long-standing preoccupations.

The plot of *King of Odessa* is easily described. In 1936 the Russian-Jewish author and revolutionary, Isaac Babel, returned to his hometown Odessa for three months. Virtually nothing is known about what he did during this period. His life was increasingly perturbed by his vexed personal relationships with women and family. He was, vaguely, collaborating with his friend the filmmaker Sergei Eisenstein. His health was not good. He is known to have made one visit to the synagogue. He is also known to have been working on a manuscript—believed lost. "But now," the introduction tells us, "more than sixty years after his death and over a decade after the collapse of the Soviet Union, a manuscript has been found in the archives that, internal evidence suggests, seems to be the work Babel was writing in 1936."

The "work" follows. Gullible readers are directed to the CIP (Cataloging in Publication) information on the verso of the title page where *King of Odessa* is officially designated "fiction." Not a bureaucratic category that Rosenstone has much respect for, one might add. This is, as he would put it, "History in Fiction."

Like other writers, particularly Jewish writers (Pasternak, for example), Babel felt a cold wind in 1936, even in the summer warmth of Odessa. Stalin's terror was beginning its vile exterminations. Should he stay in the new Communist state which he had helped create? Or should he save himself by emigrating? He remained. It was the wrong choice. As a bleak afterword tells us, three years later Babel was arrested, interrogated "relentlessly" for two months in the Lubyanka, convicted of conspiratorial terrorism, shot, cremated "and his ashes dropped into a common pit." He was later, by that most cruelly ironic of Soviet cultural perversions, "rehabilitated" as a literary hero of the Revolution. Much good it did his ashes.

The year 1936 is an important date in Rosenstone's historical calendar. That year saw the outbreak of the Spanish Civil War with Franco's uprising and the first military victory for nationalist Fascism in the 20th century. Rosenstone (inevitably) has written one of the standard works on American involvement in that conflict, *Crusade of the Left: The Lincoln Battalion in the Spanish Civil War*. Nineteen-thirty-six was also, with the show trials in Moscow, the historical moment when the Soviet experiment went irrecoverably rotten. Babel was, like Reed, a Romantic Revolutionary. He too saw the future and thought it would work. Nineteen-thirty-six was the year in which he must have realized it wouldn't.

Babel's best-known book is the cycle of short stories *Red Cavalry* (1926). It was inspired by his service in the Russo-Polish war of 1920—as an embedded journalist—with a troop of Cossacks. These horsemen were the Revolution's shock troops; they were indelibly associated with Jewish pogrom and indiscriminate cruelty. They were anything but chevaliers.

Rosenstone's Babel recalls the atrocities that he witnessed with the Cossacks: specifically a massacre at the Jewish village of Zhitomar where they discover a charnel house of mutilated corpses left by the enemy: "forty-five dismembered bodies, heads, tongues, limbs, fingers, and ears scattered like bloody pieces of meat in the yard of the local slaughterhouse."

And what does the captain of the Cossacks do when confronted by this horror of war? With the jovial remark "Who needs all these Yids?" he slits the throat of one of the few survivors in a grisly parody of kosher animal slaughter, and—having done this appalling thing—he reaches for the vodka, "shouts *l'chaim*, laughs, drinks deeply, passes it to the surrounding troops."

Rosenstone's Babel realizes that "this is what people need to know about the Civil War." But . . . "nobody will dare publish such a view of the Cossacks, our new heroes. Some of the incidents can be used. But the overall narrative must have some hint of redemption, something more in keeping with the ideals of the Revolution. Something that says all this horror was only a prelude to a better world. For me to say this is difficult."

This difficulty is, for Rosenstone, both perennial and infinitely fascinating. How can the "truth" be mediated by words—words, that is, formulated into the distorting categories of "genre," "discipline," and traditional "discourse"; not to say the needs of the state and the peremptory demands of the reading public craving entertainment? Poetry, fiction, history, biography, autobiography all engage with truth. And, in its entirety, truth eludes all of them. Rosenstone's ingenious blends of those ways of knowing and telling are original, imaginative and often—in my judgement—brilliant. □

John Sutherland
Visiting Professor of Literature

Origami Design Secrets: Mathematical Methods for an Ancient Art
by Robert J. Lang
A. K. Peters, 2003
585 pages, $48

We all remember it. What 20th-century child has not been exposed to it? The inviting squares of brightly colored paper, the excitement of creating that first crane/frog/fish. Yet how many of us in adulthood can boast even a nodding acquaintance with this intriguing art?

Robert Lang can. He began folding paper as a boy of six, and simply never stopped (even while picking up a couple of Caltech degrees: a BS in electrical engineering in 1982 and a PhD in applied physics in 1986). Further, he did what the rest of us did not do; he combined his love of origami's ordered elegance with his passion for mathematics and science. His new book, *Origami Design Secrets: Mathematical Methods for an Ancient Art*, offers us the chance to renew our acquaintance with the art (and introduce ourselves to the science) of origami—its history and evolution, and its technique, underlying mathematics, and design. For Lang makes it clear that all these aspects of origami are firmly interwoven. The evolution of the art (and the development of the underlying geometry) is, for the aspiring paper folder, the sequential path to technical proficiency; proficiency represents the point at which tech-

Each of the koi on the cover is folded from a single sheet of paper, scales and all. The author writes, "If you work your way through folding the entire model, you can congratulate yourself both on your understanding of the design process and, because there are some 900 individual scales to be shaped, your fortitude."

nique becomes second nature; it is only at this point, when the folder's mind is free to think creatively, that the folder becomes the designer.

If all this sounds a bit ambitious, well, it is. Lang explodes your childhood perception of origami in precisely the same way that your first viewing of olympic table tennis exploded your backyard Ping-Pong game. He gives us a glimpse of amazing possibilities; he also provides the means for realizing them. This is a stunningly comprehensive book, well written and well illustrated.

"Origami is, first and foremost, an art form," writes Lang, who is recognized as one of the world's leading origami artists. "It is the nature of creativity that it cannot be taught directly. However, it can be developed through example and practice. As in other art forms, you can learn techniques that serve as a springboard for creativity." Lang is explicit that this book is neither a cookbook of folding patterns nor a "how-to" for design. Rather, as the title implies, he offers tips from his vast experience, and a wealth of technique.

There have been only a handful of designers in origami's long history. For nearly 1,500 years, origami (literally translated, "paper folded") was largely a static art form, consisting of two to three hundred accepted figures. In the 1920s Akira Yoshizawa (now recognized as the father of the modern era of origami) developed a diagramatic scheme of folding instructions that eliminated the need for language and enabled the art to spread worldwide. Then, in the 1970s origami began to attract the attention of mathematicians, scientists, and engineers; only then did the shape of origami begin, quite literally, to change.

The breakthrough came when three Americans and a Japanese, all working independently, discovered a recurring fold pattern, consisting of an isosceles right triangle with two creases in it. The creases represent two scalene right triangles and an isosceles right triangle that is a miniature mirror of the original. Each of these triangles may be dissected into another grouping of the same (as well as being dissectable into two or four smaller copies of themselves). Conversely, the triangles can be reassembled to form larger triangles and rectangles. The new method was dubbed "technical folding"; it yielded an infinite variety of crease patterns and the potential for greater fluidity of shape. So rapid was the pace of discovery from this point on, that nearly all of the thousands of designs currently in existence were created in the past 50 years.

It is for the aspiring origami *designer* that this book, as a whole, is intended. And yet the book may be sampled quite effectively in parts. There is something for everyone here, whether beginner or expert, left-brained or right, specialist or dilettante. If all you want is to sit down and learn to fold a few simple (well, not exactly *simple*) figures, there are well-written, well-illustrated instructions in the beginning chapters to aid you. If, on the other hand, you require a formal mathematical treatment of applicable tree theory, the entire last chapter is devoted to this. The book can also be enjoyed merely for its history, and Lang's history of origami reads like a whodunnit, a succession of clues and discoveries that builds momentum across 15 centuries.

The sheer beauty and elegance of Lang's designs, illustrated in this handsome book (with step-by-step instructions for 25 of them and blueprints for more) are enough to make any reader want to take on the more complicated figures, like the Black Forest cuckoo clock or the antlered moose (but admiration may be as far as you get). Experienced origamists will find something challenging (often *very* challenging) here. And aspiring designers will have at hand, for the first time, carefully described methods and techniques, as well as the mathematical principles, that will enable them to populate their paper zoos with creations of their own.

Gail Anderson
Manager, Electronic Media Publications

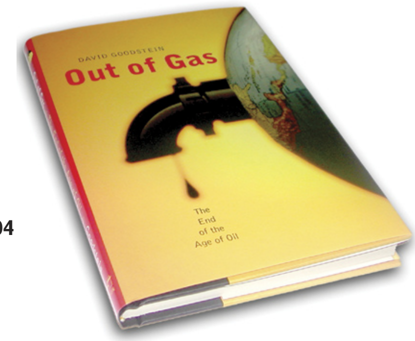
Out of Gas:

The End of the Age of Oil

By David Goodstein

W. W. Norton and Company, 2004

140 pages, $21.95



Ancient Persians tipped their fire arrows with it, and Native Americans doctored their ails with it. Any way you look at petroleum, the stuff has been around for a long time. Problem is, it's not going to be around much longer—or at least not in the quantities necessary to keep our Hummers humming.

To address the choices society will soon face in the inevitable peaking of worldwide oil production, Professor of Physics David Goodstein has written a new book titled *Out of Gas: The End of the Age of Oil*. Goodstein argues that global production will peak sooner than most people think, possibly in this decade—a view held by a number of geologists—and that the peak itself will be the beginning of serious and widespread social and economic consequences.

"Some say that the world has enough oil to last for another forty years or more, but that view is almost surely mistaken," writes Goodstein, whose past forays into the world of science communication have included his award-winning PBS series *The Mechanical Universe*, as well as the best-selling book *Feynman's Lost Lecture*.

Goodstein writes that the worldwide peak will almost surely be highly disruptive, if not catastrophic, considering the difficult American experience of the early 1970s, when U.S. production met its own peak. Since then, U.S. production has been on a downslope that will continue until the tap runs dry.

But even the 1970s' experience would be nothing compared to a worldwide peak, Goodstein explains. Indeed, the country then experienced serious gas shortages and price increases, exacerbated in no small part by the Arab oil embargo. But frustration and exasperation aside, there was oil to buy on the global market if one could locate a willing seller. By contrast, the global peak will mean that prices will thereafter rise steadily and the resource will become increasingly hard to obtain.

Goodstein says that the best- and worst-case scenarios are fairly easy to envision. At worst, after the so-called Hubbert's peak (named after M. King Hubbert, the Texas geophysicist who was nearly laughed out of the industry in the 1950s for even suggesting that a U.S. production peak was possible), all efforts to deal with the problem on an emergency basis will fail. The result will be inflation and depression that will probably result indirectly in a decrease in the global population. Even the lucky survivors will find the climate a bit much to take, because billions of people will undoubtedly rely on coal for warmth, cooking, and basic industry, thereby spewing a far greater quantity of greenhouse gases into the air than that which is currently released.

"The change in the greenhouse effect that results eventually tips Earth's climate into a new state hostile to life. End of story. In this instance, worst case really means worst case."

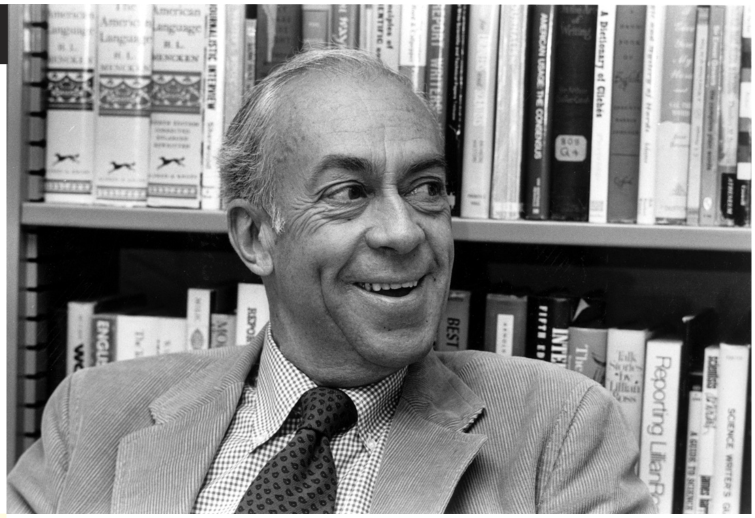
The best-case scenario, Goodstein believes, is that the first warning that Hubbert's peak has occurred will result in a quick and stone-sober global wake-up call. Given sufficient political will, the transportation system will be transformed to rely at least temporarily on an alternative fuel such as methane. Then, more long-term solutions to the crisis will be put in place—presumably nuclear energy and solar energy for stationary power needs, and hydrogen or advanced batteries for transportation.

The preceding is the case that Goodstein makes in the first section of the book. The next section is devoted to a nontechnical explanation of the facts of energy production. Goodstein, who has taught thermodynamics to a generation of Caltech students, is particularly accomplished in conveying the basic scientific information in an easily understandable way. In fact, he often does so with wit, explaining in a brief footnote on the naming of subatomic particles, for example, that the familiar "-on" ending of particles, such as "electrons," "mesons," and "photons," may also suggest an individual quantum of humanity known as the "person."

The remainder of the book is devoted to suggested technological fixes. None of the replacement technologies are as simple and cheap as our current luxury of going to the corner gas station and filling up the tank for the equivalent of a half-hour's wages, but Goodstein warns that the situation is grave, and that things will change very soon.

"The crisis will occur, and it will be painful," he writes in conclusion. "Civilization as we know it will come to an end sometime in this century unless we can find a way to live without fossil fuels."

Goodstein dedicates the book "to our children and grandchildren, who will not inherit the riches that we inherited." □—*RT*



Edward Hutchings Jr. 1912 — 2003

Edward Hutchings Jr., who edited this magazine from 1948 to 1979, died December 8 in Sonoma, California, at the age of 91.

It was Hutchings who made *Engineering & Science* into a vehicle for "understandable science," a rare commodity when he became its editor. The magazine had been born in 1937 as the *Caltech Alumni Review*, managed by alumni. In 1948, with a new name and increased funds from the Institute, a "professional journalist of top rank" was sought to run it, although the character of the reincarnated magazine had not been determined.

Hutchings determined it. He didn't think it ought to be just another alumni magazine: "I always figured that what the alumni—from this kind of a place, especially—wanted to read was what everybody wanted to read," he wrote, years later. "Like the science editor of the *New York Times*, they want to know: What are we doing here? How good is it? Who's doing it? How important is it? They don't want to know that Joe Blow had a baby." And he had a theory for explaining science: "I tried to get people to write so that *I* could understand it."

Hutchings was born in Brooklyn in 1912 and graduated from Dartmouth College in 1933. After a string of Depression jobs (as a bank teller, bookkeeper, and door-to-door distributor of All-Bran samples), he landed in the magazine business and never left. He had published a few short stories, but considered his "career proper" to have started at the *Literary Digest*, where he "developed great respect for good proofreading" by running a department called "Slips That Pass in the Type." He wrote for a magazine called *Tide*, then became news editor of *Business Week*, associate editor of *Look*, and executive editor of *Liberty*, in succession. When Chuck Newton, assistant to Caltech's president, Lee DuBridge, went to New York hunting for a "professional journalist of top rank," he found Hutchings working as managing editor of an experimental magazine called *Science Illustrated*. Hutchings accepted the job offer and moved to Pasadena.

For his unique take on "this understandable science business," Hutchings and the magazine began to collect awards. For several years in the late '60s and early '70s, it ranked among the top 10 alumni magazines in the country. In 1969, a special issue on the environment won the *Newsweek* alumni-publication award for achievement in presenting public affairs.

In an article summing up his work on *Engineering & Science* when he retired in 1979, Hutchings wrote: "The level of understanding at which an article in *E&S* was written has fluctuated from issue to issue—even from article to article. This was inevitable, because every article has been to some extent a compromise. While I have done all I could to direct and edit the article so as to keep it as simple as possible, the author has often gone to great lengths to keep the level of understanding as high as possible. What was finally published represented the point at which any particular compromise reached its farthest limits on each side. Or sometimes, what was finally published merely represented the point at which time ran out on us."

(Hutchings's legacy lives on; this is still true.)

Jackie Bonner, who worked with Hutchings on *E&S* for 14 years and succeeded him as editor, recalled his fascination with words, his flawless taste, and his "perfect pitch." She wrote at the time of his retirement of his belief in "using simple, straightforward language. . . . One of his fetishes is that quotations must be worth quoting and sound as if real people had actually said them." In addition to editing *E&S*, wrote Bonner, "he has also compulsively edited every other piece of written matter that has come into his hands and much of the conversation he has heard. He edits, for example, his own and other people's letters and memos, newspaper headlines and articles, *The California Tech*, manuscripts, transcripts, books, plays; everything his eye happens to light on is grist for his editing mill. Some men are born with a silver spoon in their mouths; Ed must have been born with a blue pencil in his right hand."

After he retired as editor, he stayed at Caltech teaching journalism, acting as adviser to *The California Tech*, participating in musical theater and Playreaders, and swimming religiously. Hutchings also played an instrumental role in making a best-seller out of Richard Feynman. For articles in *E&S*, he had persuaded Feynman, who, Hutchings claimed, never wrote anything, to allow his public lectures to be recorded and transcribed. As Hutchings told it, when he first showed him a transcript, Feynman was appalled, and from then on gladly worked with the editor to "turn his chaotic transcript into a publishable article. . . . *E&S* and Richard Feynman soon became a mutual admiration society, and Feynman got to calling me 'my publisha.'"

Ralph Leighton, Feynman's drumming partner, had also recorded many Feynman stories, but was having trouble turning them into a written version that "didn't change the unique flavor of Feynman's storytelling," says Leighton. "I got on-the-job training from an elegant, cheerful, patient, and supremely talented man who knew how to make a sentence read like you were hearing it spoken to you—even though it started out as two fragments, or three run-ons with no verb-tense agreement."

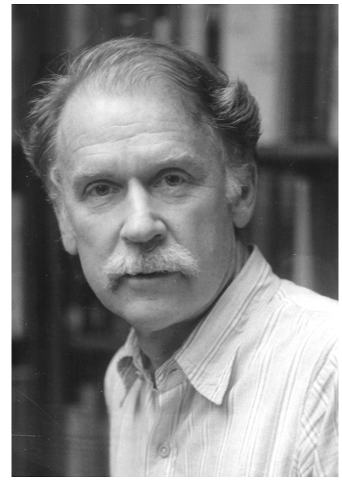
Meanwhile, Ed Barber, then senior editor and now vice president at W. W. Norton and Company, having heard of the physicist's "fabulous stories," had been unsuccessfully pursuing the legendary Feynman for years. "Then a bright editorial angel stepped in," recounts Barber. "I happened to meet Ed Hutchings, a small man in a small office, but large in grace and information." Several more years later, Hutchings called him with a description of Leighton's transcribed stories and brokered a meeting with "the Professor" himself—a meeting in which the joker from Long Island accused Barber (from Mississippi) of being "a city slicker from New York . . . ready to take us to the cleaners." Hutchings smoothed everything over, and the rest, says Barber, "is happy publishing history. The Professor, Ralph, and Ed [Hutchings] produced the best-seller *Surely You're Joking, Mr. Feynman!*, then another, *What Do You Care What Other People Think?*" (Leighton produced a third, *Tuva or Bust!,* after Feynman's death.)

"I shall always be thankful to Ed for showing me how to polish a good sentence and to enjoy a good life," Leighton says.

Hutchings and Barber also remained friends long after their publishing venture. "This gentle man wore his grace, discernment, and good cheer to the very end," says Barber. "I thought him noble—and so much fun."

In 1987 Hutchings retired to Creekside Village in Sonoma, where he originated the Creekside Playreaders and was particularly beloved for his song-and-dance routines in more than 10 years of performing in the Creekside Follies. His wife, Elizabeth, died in 2000; he is survived by his daughter, Alison McAlpine, and son, David. Donations in his memory may be made to the Sonoma Valley Regional Library, 755 W. Napa St., Sonoma, CA 95476.

Bonner quoted a former colleague as saying, "If they don't tie him down, he'll edit his own obituary." Well, he didn't; and I humbly hope, Ed, that there are no typos, factual errors, or infelicities of language here. □—*JD*



PETER W. FAY 1924 — 2004

Peter W. Fay, professor of history, emeritus, died January 18 at his home in Sierra Madre after a long illness. He was 79.

Fay, an authority on China and India, was a member of the Caltech faculty from 1955 until his retirement in 1997. He earned his bachelor's degree (interrupted by service in Italy during World War II) from Harvard in 1947, attended Oxford University as a Rhodes Scholar, and returned to Harvard for his PhD (1954).

Among his books were *The Opium War, 1840–1842*, which won several prizes following its publication in 1975, and *The Forgotten Army: India's Armed Struggle for Independence, 1942–1945* (see *E&S*, Spring 1994). Two years at the Indian Institute of Technology in Kanpur in the '60s, where he helped the humanities program, had shaped his interest in and love for Indian history.

He is survived by his wife, Mariette Robertson Fay; sons Todor, Jonathan, and Benjamin; daughters Jennifer and Lisa Fay Matthiessen; and seven grandchildren. A memorial service is planned. □

Gray Wins Wolf Prize

Harry B. Gray, Beckman Professor of Chemistry and founding director of the Beckman Institute, continues to attract honors the way an azurin molecule attracts electrons from an excited ruthenium complex. He has just been named the sole recipient of the 2004 Wolf Prize in Chemistry for his "pioneering work in bioinorganic chemistry, unraveling novel principles of structure and long-range electron transfer in proteins," and will receive the $100,000 prize in May from the President of the State of Israel, Moshe Katsav, at a ceremony at the Knesset. The Wolf Foundation noted that "his ingenious chemistry, meticulously executed, has given us a real understanding, for the first time, of a biological process of great significance for life."

Gray has also been awarded a 2004 Benjamin Franklin Medal by the Franklin Institute in honor of his work on metalloproteins. And in November, he became an honorary doctor of science at the University of Copenhagen, an event attended by Queen Margrethe II of Denmark. □

Honors and Awards

Deniz Armani, a fourth-year grad student in the research group of Jenkins Professor of Information Science and Technology and professor of applied physics **Kerry Vahala**, has won first prize at the Leading Edge Student Symposium, held as part of the 36th Annual Symposium of the Southern California Chapter of the American Vacuum Society (AVS). The title of his presentation was "Ultra-High-Q Toroid Microcavity on a Chip" and described research on the first ultra-high-Q microresonator on a chip and related applications. Other grad student coauthors on the presentation were **Sean Spillane**, **Tobias Kippenberg**, **Lan Yang**, and **Andrea Martin**, all of applied physics.

David Baltimore, Caltech president and Nobel laureate in physiology or medicine, is the seventh most-cited scientist of the last two decades, according to the top-50 list published by Thomson ISI in *Science Watch*. The rankings are based on the number of times the researchers' papers were cited by their peers between 1983 and 2002 in journals indexed by Thomson ISI.

Barry Barish, the Linde Professor of Physics and director of the Laser Interferometer Gravitational-Wave Observatory Laboratory, has been elected a fellow of the American Association for the Advancement of Science.

Seymour Benzer, the Boswell Professor of Neuroscience, Emeritus, and Crafoord laureate in genetics, has been awarded a 2004 Benjamin Franklin Medal by the Franklin Institute. He is being honored for his work in neurogenetics.

Robert Grubbs, the Atkins Professor of Chemistry, has received the 2003 Pauling Award Medal, which is presented annually by the Oregon, Portland, and Puget Sound Sections of the American Chemical Society. Named after the late Linus Pauling, the medal recognizes "outstanding contributions to chemistry . . . that have merited national and international recognition."

Babak Hassibi, assistant professor of electrical engineering, has been awarded a five-year, $625,000 David and Lucile Packard Fellowship in Science and Engineering.

Michael Hoffmann, the Irvine Professor of Environmental Science and dean of graduate studies, was honored by the University of Toronto's department of chemistry as the 2003–04 A. R. Gordon Distinguished Lecturer in Chemistry.

Fatemeh Jalayer, the Housner Postdoctoral Scholar in Civil Engineering, has been named a corecipient of the Norman Medal, which is awarded by the American Society of Civil Engineers for a paper "judged worthy of special commendation for its merit as a contribution to engineering science."

Alexander Kechris, professor of mathematics, has been selected to give the 2004 Alfred Tarski Lecture at UC Berkeley. Tarski founded Berkeley's Group in Logic and the Methodology of Science.

Bruce Kennedy, facility manager/senior research associate II in the biology division's Transgenic Mouse Core Facility, has received the George R. Collins Award from the American Association for Laboratory Animal Science (AALAS) "for outstanding contributions to the field of laboratory animal technology."

Jeff Kimble, the Valentine Professor and professor of physics, has been awarded the 2004 Lilienfeld Prize by the American Physical Society (APS) "for his pioneering work in quantum optics, for his innovative experiments in single-atom optical experiments, and for his skill in communicating the scientific excitement of his research to a broad range of audiences."

David MacMillan, professor of chemistry, has been selected to receive a 2003 Camille Dreyfus Teacher-Scholar Award from the Camille and Henry Dreyfus Foundation.

Tom Phillips, professor of physics and director of Caltech's Submillimeter Observatory, has been selected to receive the American Astronomical Society's 2004 Joseph Weber Award for Astronomical Instrumentation.

Fred Raichlen, professor of civil and mechanical engineering, emeritus, has received the 2003 International Coastal Engineering Award from the Coasts, Oceans, Ports, and Rivers Institute of the American Society of Civil Engineers "in recognition of his outstanding achievements and contribution to the advancement of coastal engineering through research, education, engineering practice, and professional leadership."

Anneila Sargent, professor of astronomy and director of the Owens Valley Radio Observatory, has been designated by the Council of the National Academy of Sciences and the Governing Board of the National Research Council a lifetime National Associate of the National Academies "in recognition of extraordinary service to the National Academies in its role as advisor to the nation in matters of science, engineering, and health."

Brian Stoltz, assistant professor of chemistry, has been named a Cottrell Scholar by the Research Corporation "for excelling in both teaching and research."

Jeroen Tromp, McMillan Professor of Geophysics and director of the Seismo Lab, **Dimitri Komatitsch**, senior research fellow in geophysics, and **Chen Ji**, associate scientist, together with Seiji Tsuboi of Japan's Institute for Frontier Research on Earth Evolution, have been awarded the 2003 Gordon Bell Prize for "A 14.6 Billion Degrees of Freedom, 5 Teraflop/s, 2.5 Terabyte Earthquake Simulation on the Earth Simulator." The Earth Simulator was used to model seismic-wave propagation resulting from large earthquakes.

Alexander Varshavsky, the Smits Professor of Cell Biology, has been chosen by the Israel Cancer Research Fund to receive its Excellence in Clinical Research Award.

Ahmed Zewail, Nobel laureate in chemistry, the Pauling Professor of Chemical Physics and professor of physics, has been elected a Foreign Member of the Russian Academy of Sciences. □

And Now for Something Completely Different

Steve Koonin, London-bound

Steve Koonin, Caltech's provost for the past nine years, is stepping down from that post February 2 and in March will begin a leave of absence from his faculty appointment as professor of theoretical physics to become chief scientist for BP, based in London. BP, with annual revenues of roughly $200 billion, is the world's second largest integrated oil company and the largest U.S. oil and gas producer.

The new post will provide Koonin with the opportunity to do some strategic thinking about one of the most important problems facing society—energy. Among other duties in his new position, he'll be responsible for scientific and technological input to the company's long-range strategies in an industry that has important economic, social, political, and environmental dimensions. Exposure to business and the private sector is also attractive to him at this point in his career, he says, since he feels he knows academia "pretty well" and has already done a fair bit of advising to government.

Koonin has spent almost his entire academic career at Caltech: from his freshman year in 1968 (he received his BS in 1972) to the present, he has spent only three years away from the Institute—from 1972 to 1975 when he was earning his PhD at MIT. He came back to Caltech in 1975, was named full professor in 1981, and served as faculty chair from 1989 to 1991.

Koonin's departure "will leave a tremendous hole in the Institute's administrative and academic structure," wrote President David Baltimore. "Over the past six years, I have relied on his insight, energy, innate intelligence, and detailed knowledge of Caltech as we have worked to further the Caltech cause."

Edward Stolper, the Leonard Professor of Geology and chair of the Divison of Geological and Planetary Sciences, will serve as acting provost, while the search committee, chaired by Ahmed Zewail (see above), works to fill the position. □

One Good Deed Inspires Another

Gifts made in support of the Institute's "There's only one. Caltech" campaign come from a variety of sources and can be motivated by many things. For example, the inspiration for Robert (PhD '52) and Harriett Owens's recent planned gift to the Institute was the Spring 2003 issue of *Financial Planning Techniques*, describing the retained life estate gift from Robert Sharp (BS '34, MS '35), the Sharp Professor of Geology, Emeritus. Sharp gave his Santa Barbara home to Caltech and to another college.

When Bob and Harriett built their home in the rural Smith Mountain Lake area near Roanoke, Virginia, in 1990, they never dreamed that they would someday decide to give it to Bob's two alma maters, California Institute of Technology and Webb Institute. Upon reading the Sharp article, Bob contacted Caltech's Gift and Estate Planning office for assistance with arranging a similar gift. After deeding a one-half interest each to Caltech and Webb, the Owenses received an immediate income tax charitable deduction, while retaining the right to live in the residence for the rest of their lives.

Bob received a bachelor's degree in engineering from Webb Institute in 1944. Located on Long Island Sound, Webb is a top-ranked undergraduate institution offering only one major: naval architecture and marine engineering. After earning a master's degree in mathematics at Columbia University, Bob came to California and enrolled in another unique institution, Caltech. His doctorate in mathematics from Caltech was awarded in 1952. Bob was attracted to Caltech because of its small size and national prominence as "a school with a great reputation in mathematics." Also, the sunny southern California weather was a welcome change from the cold east coast winters.

The education he received from these two special universities served Bob well in his professional life. He has held various positions at Brown University, the Office of Naval Research, the University of New Hampshire, and the National Science Foundation. Bob served as chair of the Department of Applied Mathematics and Computer Science at the University of Virginia from 1964 to 1974, and remained on the staff until his retirement in 1989.

This generous gift is made all the more valuable by virtue of the fact that it is unrestricted, allowing Caltech to use the funds where they are most critically needed at the time they become available. Moreover, during a campaign, unrestricted giving allows the Institute to maintain the continuity of its current activities while building resources for future endeavors. □ —*Carolyn Swanson*

For more information on Caltech's strategic priorities and the campaign to support them, visit the web site at http://www.one.caltech.edu.

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