BERKELEY science review

Fall 2008 Issue 15

Advancing music

Neglected diseases

Flight of the hummingbird

Planetary birth • *Cannabinoids* • *Student solutions* • *T. rex* and the Crater of Doom • *Beams away*

Dear Readers,

While the Democrats and Republicans are duking it out in Washington and on the campaign trail, UC Berkeley researchers are getting along quite well, and even getting some work done while they're at it. In this issue of the *Berkeley Science Review*, we are highlighting a few of the many collaborations on campus. So if you are sick of all the bickering on TV and in the papers, I invite you to enjoy the 15th issue of the *Berkeley Science Review*, a refreshing look at the scientific progress that emerges when different schools of thought unite.

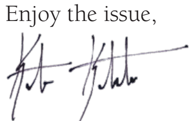
It might seem that chemists, architects, business students, engineers, and law students would rarely have occasion to talk, never mind work together. Not so at Berkeley, as Sharmistha Majumdar tells us in her article about the Berkeley Energy Resources Collaborative. Not only are students venturing out of their labs and buildings to talk, they are also having conversations about topics in the forefront of the minds of voters and politicians alike, including energy efficiency and weaning ourselves off fossil fuels (p. 28). However, energy is just one of the many global issues that teams of scientists are delving into on campus. On page 33, Niranjana Nagarajan tells us how UC Berkeley researchers are banding together to prevent and treat tropical diseases.

All of this conversation between departments is not the only noise on campus these days, as Meredith Carpenter describes in her article about the bridging of science and music at UC Berkeley's Center for New Music and Audio Technologies (p. 23). Meanwhile, on page eight, Greg Alushin tells us how a hummingbird seduces his mate with his own music. And don't miss James Walker's explanation of how those chattering squirrels around campus can remember where they buried their dinner (p. 14). Finally, in her brief about the effect of wine country development on salmon habitats (p.11), Liza Ray may make you think twice about sitting down to a grilled salmon dinner paired with a glass of Chardonnay.

It has been a joy working on this issue of *BSR*. The magazine would not be possible without the hard work and dedication of the student volunteer editors, writers, photographers, graphic designers, and artists. If you are interested in joining us, please send us an email at sciencereview@gmail.com. And if you don't have the time, or are too busy following every move (and gaffe) of the presidential campaign, please consider a financial donation so that we can continue to make our work available to the campus community at no cost. The *BSR* is a non-profit organization, so your gifts are tax-deductible.

I would like to thank both the new and returning staff on our current *BSR* production team. Thank you to Meredith Carpenter, Jackie Chretien, and Matt Mattozzi for gracefully handing over the reins to me, Managing Editor Rachel Bernstein, and Art Director Tim De Chant. And now, without further ado, please enjoy our continued tradition of highlighting the cutting-edge scientific research at UC Berkeley.

Enjoy the issue,



Kate Kolstad

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Cover: The male Anna's huminngbird, seen here hovering for a fast-motion camera, spreads its tail feathers to produce a chirp at the bottom of a dive. Scientists think the sonic dive is used in courtship displays. Photo by Christopher Clark and Anand Varma.

Berkeley Science Review

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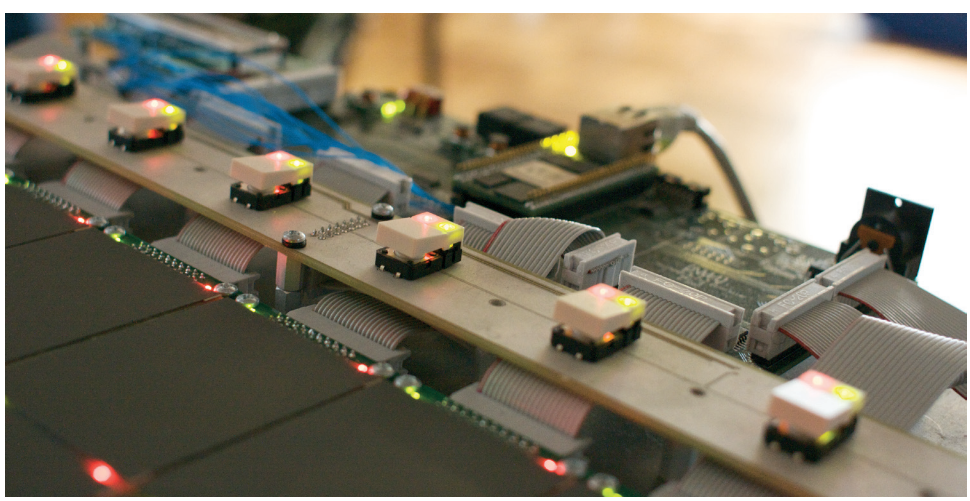
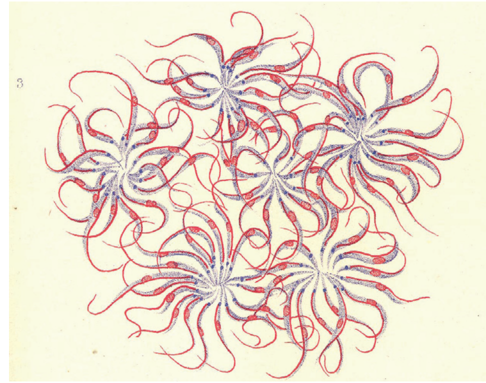
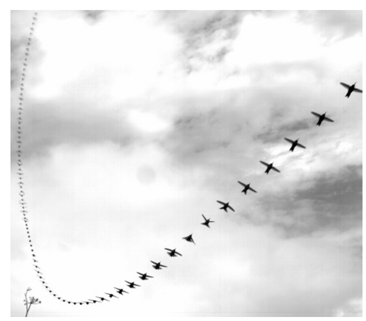
Features

University





Current Briefs



Departments

Image courtesy of *The American Naturalist*

There's a Fruit in my Bug

An unprecedented finding has further tangled the complex web of parasite-host interactions: a parasitic worm that lays hundreds of eggs in an ant's abdomen, turning it bright red to create the appearance of a ripe berry. Robert Dudley of the Department of Integrative Biology and colleagues hypothesized that this dramatic color change fools ordinarily ant-averse birds into thinking they are eating a juicy red berry. Why such an elaborate scheme? Due to a meshwork that prevents the parasites from entering the ant's digestive tract, worm eggs cannot infect an adult ant when eaten. Instead, they must be consumed by the ant larvae as they are fed bird droppings by their foraging parents. Once ingested by the larvae, the worms can hatch and grow, migrate into the ant's abdomen, mate, and lay eggs, turning the abdomen red to hoodwink the next unsuspecting bird. To test the theory that birds are more likely to nosh on an infected ant, the research group secured healthy and infected ants side by side on branches in the forests of Panama and Peru. They found that the abdomen of the unlucky infected ant was more likely to disappear—presumably into the stomach of a bird—than that of its healthy counterpart. To further explore the birds' color preference, the scientists arranged differently colored clay balls along a branch and checked them daily for signs of a bird attack. They found more beak marks on the pink and red balls than on the rest of the colored balls combined, confirming that birds are attracted to berry colors. As further evidence of birds' role in mediating the parasite life-cycle, the research group showed that the droppings of chickens that had eaten infected ants were laden with worm eggs. Says Dudley, "It's the first documented case of transkingdom mimicry: a parasite inducing a morphological change in its animal host to make it look like fruit."

— Jasmine McCammon

Caught in Translation

For the last six years, three UC labs have been working together to accomplish a seemingly impossible feat—watching a single ribosome as it translates an RNA molecule into a functional protein. The results of this heroic collaboration between the labs of professors Carlos Bustamante and Ignacio Tinoco here at UC Berkeley and UC Santa Cruz professor Harry Noller were published last spring in the journal *Nature*. The researchers used optical tweezers, which are focused lasers used to hold macromolecules like protein and DNA, to measure the nano-scale motions of these molecules. The optical tweezers were used to monitor a single ribosome, a protein complex 20 nanometers in diameter, as it moved along a specially designed RNA fragment. The team was able to measure the ribosome moving three bases at a time, a distance corresponding to the stretch of RNA that encodes one amino acid of a protein. Essentially, the researchers were observing the ribosome "read" the genetic code in real time. Strangely, the ribosome's movement was occasionally interrupted by pauses lasting up to minutes. While the authors offer some potential causes for these prolonged delays, the mechanistic details remain a subject for future study. "What this paper really shows is that it's possible to get a system as complicated as the ribosome working in the optical tweezers set-up," says biophysics graduate student and co-author Courtney Hodges. "It also gives us something to explore for the next ten years."

— Katie Hart

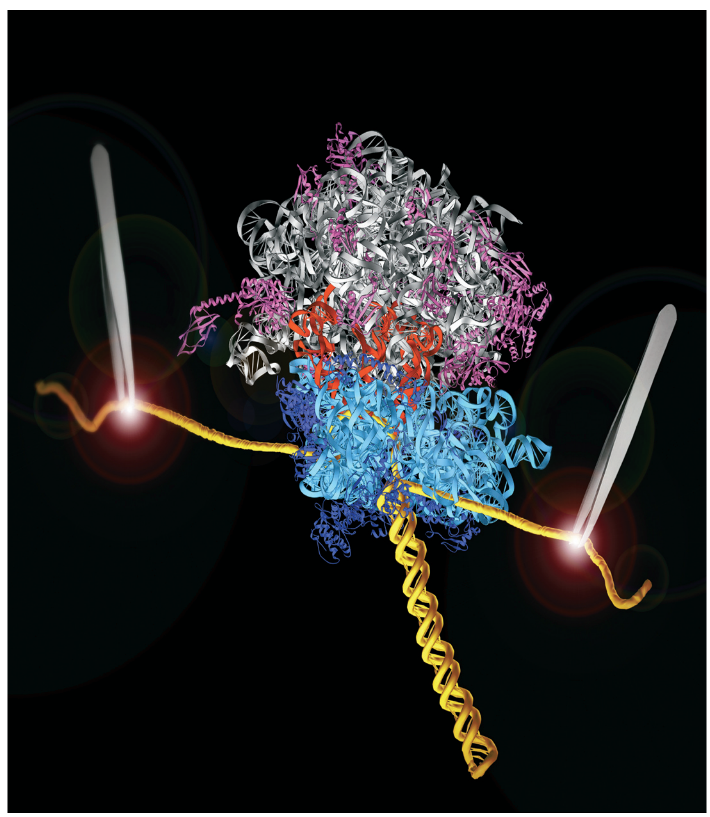


Image courtesy of Courtney Hodges and Laura Lancaster

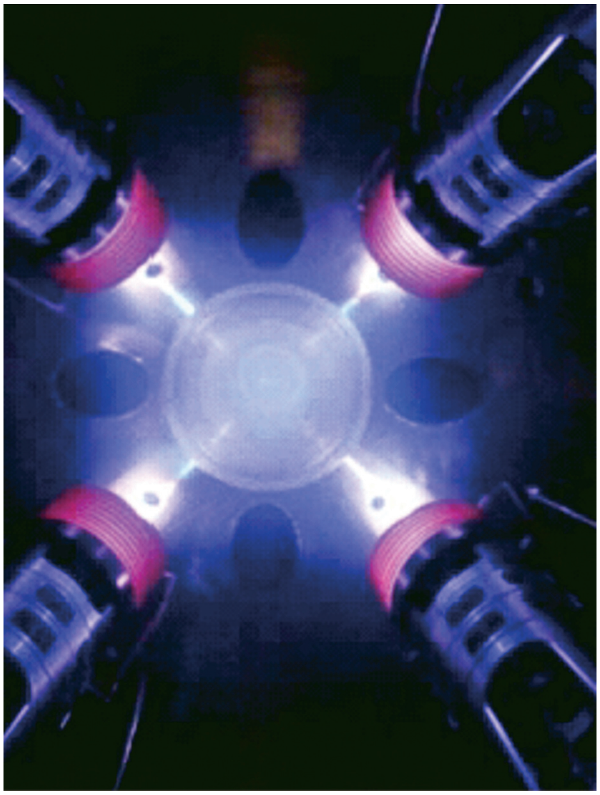


Image courtesy of B. Grant Logan and Frank Bieniosek

Beams Away

Nuclear energy is often touted as a low-carbon method of electricity production. Yet nuclear fission, the process that powers today's nuclear plants, is not without its drawbacks. Researchers at LBL's Heavy-Ion Fusion Virtual National Laboratory are researching an alternative type of nuclear power—nuclear fusion. This process, which powers the sun and other stars, generates tremendous amounts of energy by combining small atoms, usually hydrogen, to form heavier elements such as helium. Fusion uses the readily available hydrogen isotopes deuterium and tritium as the fuel and doesn't generate greenhouse gases or large amounts of radioactive waste, unlike conventional power sources. However, extremely high temperatures are needed for fusion to occur, and the development of efficient and economical systems to generate such conditions is a huge challenge. To address this problem, Heavy Ion Fusion Program Director B. Grant Logan and his colleagues are investigating inertial confinement fusion, a technique that uses high-powered beams of charged particles (plasma) to induce fusion. By intensely focusing and compressing the beams, the researchers are able to create the high temperatures necessary for fusion to occur. The team has made breakthroughs in beam compression and is now able to focus the beams to deliver 700 times more than the initial beam energy. "With further improvements," says Logan, "we expect to increase compression to over 10,000 in the next few years, and we are assessing how these techniques apply to low cost fusion energy."

— Robin Padilla

Investing in Children

Can you give parents money to take better care of their children? That's the idea behind Conditional Cash Transfer (CCT) programs. These programs give low-income families money—up to 30 percent of the family's income—if they provide their children with regular medical check-ups, nutritional supplements, and meet certain school attendance requirements. In contrast to other similar programs, there are no restrictions on how CCT money can be spent.The hope was that the cash would be used on more nutritious food, a day off from work to take children to the doctor, or on school supplies, but families could also use it for rent or anything else they wish to purchase, including cigarettes or alcohol. Public Health professor Lia Fernald and colleagues recently investigated the effects of these programs in Mexico. The researchers showed for the first time that the amount of cash recieved by families is associated with improvements in cognitive, motor, and language development in young children. Families receive different amounts of money based on family size and the length of time they have been enrolled in the program. Fernald's group exploited these differences and used statistical methods to determine the effect that the quantity of cash had on a child's health and mental skills. Doubling the amount of money received resulted in increased height for age, lower average body mass index (BMI), and improved performance on cognitive, motor development, and language tests. Mexico's CCT program served as the model for programs now in place in over 20 countries, including one launched last year in New York City.

— Orapim Tulyathan

Images courtesy of Adrian Mealand /The World Bank

current briefs

Image courtesy of Christopher Clark and Anand Varma

A Musical Tail

Hummingbirds seduce at high speeds

With his wings frantically flapping fifty-six times per second, the male Anna's hummingbird ascends one hundred feet into the air before plummeting downwards, zooming along at over sixty miles per hour at the base of his dive. What could be the reason for this garish display of bravado? Why, to impress a lady of course, although he will also dive for other males and even people, perhaps simply for the sheer joy of it. But this bold acrobat does not seek to entice with dazzling visual effect alone. "Swooping over whatever it is that they are diving to, which is often a female hummingbird, they'll make this 'BEEP!' at the bottom of the dive," explains graduate student Christopher Clark of the integrative biology department at UC Berkeley.

The mechanism by which the bird produces this sound has been a matter of controversy. Biologists had posited that the diving chirp of the hummingbird is mechanically produced by its feathers during the dive, although more recently, others had rejected this notion, citing the striking similarity between the pitch of the sound and the bird's song. Clark and undergraduate Teresa Feo definitively settled the matter: the Anna's hummingbird uses his tail feathers to chirp. Their result is one of the first documented cases of non-vocal sonation—the act of communicating by sound.

Clark's interest in hummingbird physiology provided the motivation for this discovery. His research focuses on how the shape of hummingbird tails are optimized for the mechanics of flight and other functions like attracting mates. He decided to study the Anna's hummingbird because of its peculiar tail feathers. "The males in particular have outermost tail feathers that are somewhat narrow. And they are sexually dimorphic; the two sexes are different," he says. This clue pro-

A male Anna's hummingbird swoops down from on high, flipping its tail at just the right moment to make a "beep," an impressive visible and audible courtship display meant to attract the opposite sex.

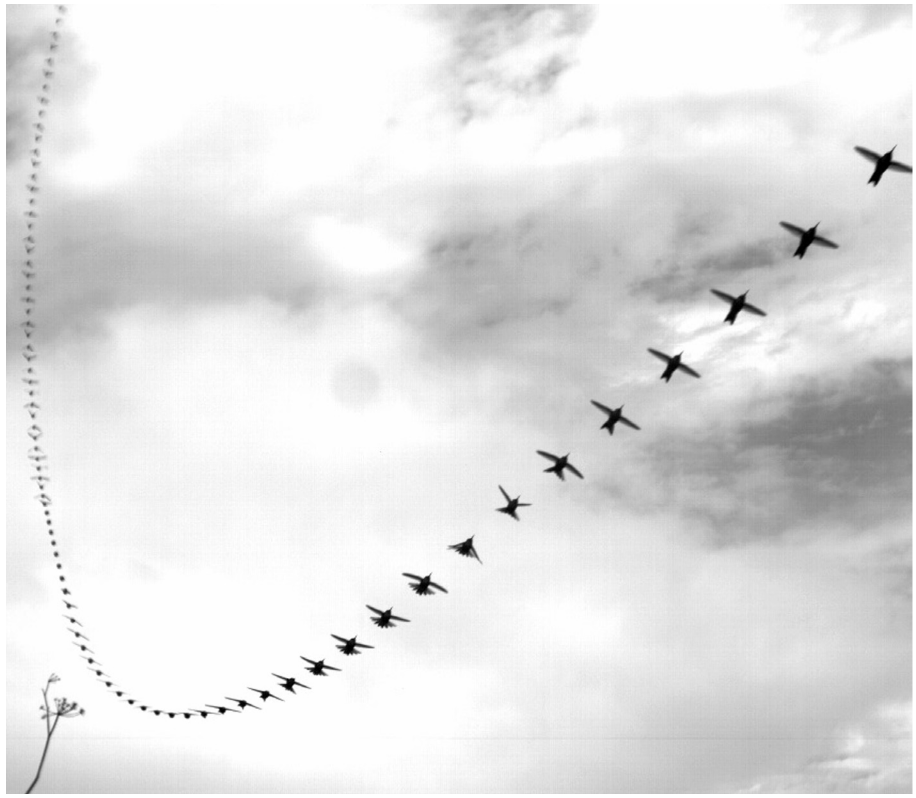


Image courtesy of Christopher Clark and Anand Varma

vided an indication that the shape of the tail feathers might be linked to a function specific to one sex, which Clark hypothesized was the diving chirp of the male.

Clark also embraced the opportunity to do fieldwork without the hassle it usually entails—the Anna's hummingbird is a Berkeley native. Indeed, prime specimens can be found zipping up to a feeder mounted in a special chamber built into the window of Clark's lab. (Its presence is not entirely aesthetic or altruistic, as the birds are sometimes captured and harmlessly experimented upon.) All of Clark's field experiments were performed locally in Albany Bulb park, which he says provides its own set of challenges in contrast to those of more exotic locales. "In the Albany Bulb, the problem was the people. My field notebook has lots of pages with big muddy dog prints from dogs running off leash. A guy also tried to steal my camcorder once."

That camcorder provided some of the initial exciting evidence for the tail chirp. High-speed video recordings showed that the hummingbird spreads its tail feathers for a few hundredths of a second at the bottom of its dive, when the chirp is produced. Clark then captured a few birds and plucked their tail feathers (which grow back in a few weeks), thereby eliminating their ability to produce the dive sound. At this point the evidence that the sound was produced non-vocally was compelling, but the actual physical mechanism of its generation remained mysterious.

Clark and Feo decided to get to the bottom of this question with a series of lab experiments. By placing a tail feather into a jet of air, they were able to reproduce the tone of the dive-sound, proving that the sound was produced by that feather. They then put the feather into a wind tunnel, where they could precisely vary the speed of the passing air. The pitch of the sound did not vary with wind velocity, suggesting that the frequency of the sound wave is based on the intrinsic mechanical properties of the feather. This result was confirmed by high-speed video of the feather in the air jet, which showed it vibrating at the same frequency as the pitch of the sound produced.

There is no hard evidence as to why natural selection has looked favorably on the tail chirp, although there is plenty of room for speculation. The dive sound of the Anna's hummingbird is significantly louder than its vocal song; therefore, the ability to dive and produce the sound could signify the fitness of a male. "But this is just a hypothesis," says Clark. "Maybe the females prefer loud sounds at a particular frequency. It is possible that this is because the architecture of their ear is tuned to a particular sound." A number of birds are believed to make tonal sounds with their feathers, although thus far there has been little investigation into whether these sounds are used for communication. Clark believes that many other hummingbirds, in which funny-shaped tail feathers and elaborate courtship displays abound, may also produce similar non-vocal sonations. In the future, he plans to study how those sounds relate to the evolutionary relationships between different hummingbird species. Soon that little 'BEEP!' may turn out to be just one note in a humming, cavorting symphony.

Greg Alushin *is a graduate student in biophysics.*

Want to know more? Check out:
sciencereview.berkeley.edu/media/15/hummingbird.mov

Of Ice and Men

Cold weather shapes male survival

Choosing your baby's sex is the subject of numerous old wives' tales—eat red meat to have a boy or have sex in the afternoon to have a girl, to name a few. Most of us don't place much stock in these ideas, but there may be more to these tales than just superstition. It was recently shown that the sex of a child can be influenced by whether a mom-to-be eats her Wheaties, as women who ate cereal for breakfast increased their odds of having a boy. Population stressors, including natural disasters and economic and psychological stress, also affect the secondary sex ratio—that is, the ratio of male to female births (the primary sex ratio is the ratio of male to female conceptions). Generally, more stress leads to fewer males. A recent study from UC Berkeley Professor of Public Health Ray Catalano and colleagues found that particularly harsh winters in Scandinavia generated enough stress in the population not only to change the sex ratio, but also increased the lifespan of males in the next generation.

Between the years 1895 and 1914, colder than average winters in Scandinavia were followed by the birth of fewer males. Females, however, weren't as affected; *in*

Scientists have discovered mothers under stress during their pregnancy give birth to more females.

Image courtesy of Sarah Hubbell

utero and beyond, males are more sensitive to stress. "Females are particularly robust to stressors and seem more resilient than males are," says Tim Bruckner, a postdoctoral fellow in the Department of Health Policy and researcher involved in the study. For as yet unclear reasons, "males in general do worse in response to stressors than females across the whole spectrum of life."

For those lucky males who survived, cold stress during gestation also had an effect later in life. The researchers found that those males who made it into childhood tended to live longer than males who were not subjected to the cold stress in utero—on average, 14 days longer than males born after a more temperate gestation. This difference, while statistically sound, is a tiny change over a lifetime and could only be detected with a large data set like the one the authors examined. According to Professor of Global Environmental Health and co-author Kirk R. Smith, it was "a fortuitous combination of the longest temperature records and the longest good demographic set in the world" that allowed the researchers to uncover the phenomenon. Before this study, it was unclear whether stresses that lower the sex ratio do so via a random loss of male fetuses or whether weaker males are selectively terminated. The link between cold stress and increased male lifespan "supports the hypothesis that mothers' bodies aren't aborting just any male fetuses, but are instead aborting the weaker ones," says Smith.

How does a colder than normal winter exert its effect upon the mother's body? The earliest populations in the study were born in the late 19th century, so while they might not have had central heating, they were certainly well-insulated from cold shock in their homes. However, poor nutrition due to reduced food production, depression, or increased exposure to indoor air pollution are all potential sources of stress in harsh winters. Moreover, stress-related hormonal responses in pregnant women have been shown to induce the spontaneous abortion of fetuses, particularly males. Whatever the mechanism, this study indicates that an increase of just 1° C (about 2° F) during gestation predicts that a male's lifespan will be shortened by 14 days. "The human body is closely attuned to the environment and relatively small changes do have an impact," says Smith.

Environmental stressors aren't alone in their effects on the secondary sex ratio. Great tragedies, like the September 11, 2001 attack on New York City, can inflict widespread distress on populations. In another study, Catalano, along with Bruckner and others, explored the effect of the trauma of 9/11 on the sex ratios of populations born soon thereafter. In both New York and California, unexpectedly low numbers of males were born in December 2001, three months after the event, associating the stress of the event with the miscarriage of male fetuses. The reduction in the sex ratio in New York was greater than it was in California (chosen because of its distance from the attack), indicating a dosage effect of stress during gestation.

As humans become more comfortable in our modern lives, insulated from disease, cold, and hunger, it might be easy to ignore how subtle changes in the environment can influence the journey of our species as a whole. However, something as banal as a cold winter can actually alter the composition of the next generation. "We often view human evolution as something that happened in the past," says Bruckner. "But even looking at data from as recent as 1915, we can see that we shouldn't view it as only in the rear-view mirror."

Susan Young *is a graduate student in molecular and cell biology.*

A Night at the Movies

A surprising effect of violent cinema

It's a popular pastime among public figures to decry violence in the media. In recent years, the ire has largely shifted to video games; for example, a recent bill introduced in the US Congress would require vendors to check customer IDs before selling mature-rated games. And after the Virginia Tech violence in 2007, the Federal Communications Commission issued a report calling for greater broadcast content regulation and expanding such regulation to cable and satellite channels. Surely if less violence were consumed as entertainment, violent behavior in society would decrease. Well, not so fast.

UC Berkeley Associate Professor of Economics Stefano DellaVigna, along with economics professor Gordon Dahl from UC San Diego, is working on a study that suggests the effects of media violence aren't so simple. DellaVigna and Dahl found that, on nights when violent movies open to wide audiences, violent crime actually *decreases*. Initally surprised by these results, DellaVigna recalls, "We tried to fix the bug in the data, but there was no bug."

The researchers determined audience size on particular weekends using box office data from the-numbers.com, a free site used by industry professionals to track movie information. They also used kids-in-mind.com, a website that rates movies on a ten point scale along three axes—sex/nudity, violence/gore, and profanity—to separate movies into strongly violent (*Wanted*), mildly violent (*The Incredible Hulk*), or non-violent (*Wall-E*). These were combined with crime data from the National Incident Based Reporting System to study the correlation between violent crime levels and attendance at violent films.

DellaVigna and Dahl found that for every one million theater attendees, violent crime—defined as reported assaults and intimidation—decreases by 1.1 percent for mildly violent films and 1.3 percent for strongly violent films between 6 PM and midnight. The effect per million viewers between midnight and 6 AM (well after the theaters close) was larger: a decrease of 1.9 percent and 2.1 percent for mildly and strongly violent movies, respectively. This equates to about 1,000 fewer occurrences per weeken, and an estimated $695 million saved per year in avoided costs associated with violent crime. No statistically significant effect was observed for attendance at nonviolent movies.

Ideally, a scientist interested in the effects of movie violence might randomly assign half of a random group of people to watch a violent film and the other half to watch a nonviolent one and then observe what happens. The randomness of the groups averages out other possible explanations for any differences in observed behavior. "In the movie theater, we're not randomized. We choose to watch violent movies," explains DellaVigna. This makes analysis more difficult, and other possible influences on the data were considered and corrected for, like occasions of high television viewership (think Superbowl), possible seasonal effects, and inclement weather.

To explain the counterintuitive results, DellaVigna developed a model in which consumers choose between attending a violent movie, attending a nonviolent movie, or doing some alternative social activity. The model, once fit to the data, suggested that violence-prone individuals are disproportionately attracted to violent films, and while in the theater, they are "voluntarily incapacitated." That is, they're watching a movie and eating popcorn instead of engaging in other activities associated with violent behavior, such as drinking at a bar.

That violent crime decreased even more during the late night hours, after theaters are empty, was a more curious result. DellaVigna explains this effect as the result of a "substitution of foregone activities." In other words, even though violent individuals are no longer fixed on the edges of their seats, they have initiated a less raucous evening and may just go to bed after a late movie. And even if they do go out after the film, they simply have less time to drink themselves to belligerence. "It's the difference between drinking from 7 PM to 1 AM and drinking from 11 PM to 1 AM," says DellaVigna.

These findings may appear to dispute evidence from other research that does imply a relationship between media violence and crime. Indeed, laboratory studies in psychology have shown an increase in aggressiveness in individuals upon viewing violent video clips, although these studies don't address actual violent crime. Other studies show that survey respondents who view violent media are more likely to be involved in self-reported violent crime, although the direction of causation in these studies is unclear. DellaVigna himself found evidence supporting the claim that an increase in violent behavior does follow exposure to violent films relative to exposure to nonviolent films; the effect was just swamped in the short run (the evening and night after the movie). DellaVigna explains, "You've got two opposing effects. You have a movie like *Hannibal* causing more aggression, but it's also taking people out of bars. It's the second effect that dominates."

DellaVigna is quick to caution against jumping to political conclusions. Like the laboratory studies, this study cannot comment on the long-term effects of media violence. A better take-home message from the study is that any policy addressing a particular activity must address the next best activity as well. Perhaps violent video games increase aggression, but they also keep a potential offender fixed in his seat. Happily incapacitated, the young ne'er-do-well foregoes his next favorite activity, which could be cow tipping, or worse. "Can we think of activities for youth that are more attractive than committing crimes?" asks DellaVigna. "That's something we should keep in mind when designing policies on entertainment."

Paul Crider *is a graduate student in physical chemistry.*

Image courtesy of Tim Crawford

Land use changes, like the transition from forests to housing developments, threaten wine country salmon.

Swimming Upstream

Wine country salmon struggle for survival

The classic California meal of salmon and Chardonnay may also come with a side of irony. The recent rise of vineyards and country homes in Sonoma County may be contributing to the decline in population of the pink-fleshed fish. Adina Merenlender, of the Department of Environmental Science, Policy and Management at UC Berkeley, is trying to predict how continued development near the Russian River in Sonoma County will degrade native salmon habitat. Merenlender's lab recently developed a statistical model that uses patterns of land use and stream quality from the past ten years to predict how habitat degradation will continue. Sonoma is an ideal place for this research because, as Merenlender explains, "there are lots of immediate pressures on the environment there."

According to Merenlender, water man-

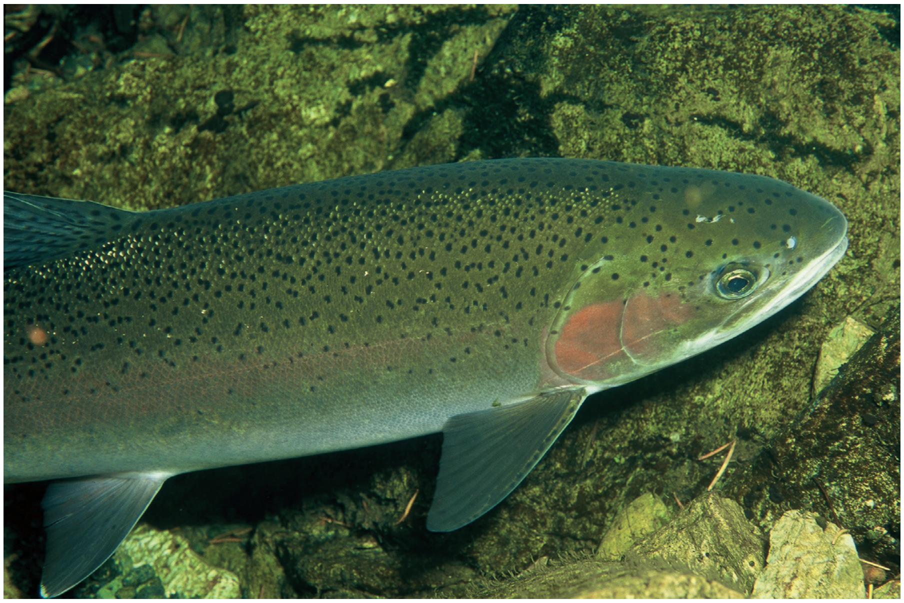


Image courtesy Bill Mitchell

Salmon species native to the Russian River in California's wine country are running out of breath as they swim upstream to spawn. Sedimentation from vineyards is depleting the river's oxygen.

agement and the number and size of buildings, collectively known as the "development footprint," have the greatest influence on the habitat quality of nearby streams. Development footprint includes structures, roads, and other areas where the ground surface is packed so hard that it is no longer permeable to rainfall. The water aggregates and the runoff becomes like a fire hose, accelerating flow and increasing sediment deposition into nearby streams. "The big issue that most do not appreciate," Merenlender explains of vineyards and other types of development, "is the rerouting of water that causes fast moving water can cause excessive erosion." That excessive erosion eventually accumulates in the spaces between river stones where salmon lay their eggs, depriving the eggs of oxygen. As a result, adult salmon have difficulty producing abundant and healthy offspring.

Before predicting how land use will change salmon habitat quality over the next ten years, researchers first had to quantify how land use is affecting salmon habitat quality in Sonoma today. Merenlender and her team, including the lead author and former postdoctoral fellow Kathleen Lohse, and former graduate student David Newburn, used habitat quality and land use data to establish this relationship. Field crews from the California Department of Fish and Game collected habitat quality data from 922 sites in streams and rivers of Sonoma County. The UC Berkeley scientists gathered land use data available from existing county tax assessor records. From those records and aerial photographs, they categorized land use into three types: urban, rural-residential, and vineyard. The researchers classified a piece of land as "urban" if it had at least one building per acre and as "rural-residential" if a single building occupied between one and forty acres. A piece of land was categorized as "vineyard" if at least ten percent of its area was covered by grape vines.

They discovered that all three land use types are associated with degraded spawning habitat. Per unit area, urban development casts the most ominous shadow. But that's old news—scientists proved long ago that dense urban development leads to poor habitat quality for sensitive fish like salmon. What's novel about this research is that it identifies a strong correlation between poor quality salmon habitat and the abundance of nearby rural-residential developments and vineyards.

The researchers used this strong relationship, in conjunction with the mountain of existing evidence about imposing urban developments, to forecast how changes in land use over the next ten years will affect salmon habitat quality. Unlike suburban sprawl, rural-residential development does not grow adjacent to the urban center. Instead, it's prone to "leap frog" all over a region, and like a leaping frog, it is difficult to predict. The researchers in Merenlender's group built a statistical model that included past growth patterns, regional plans, zoning laws, proximity of lands to major employment centers, availability for development, access to sewer and water service, and, most importantly, quality of salmon habitat associated with a given piece of land. They used all this information and more to predict the likelihood that a given parcel's land use will change salmon habitat quality in the future.

Using their model, the researchers predicted that in ten years rural-residential developments and vineyards will cover more than ten times as much land as urban areas. To boot, the model predicts rural-residential developments and vineyards are more likely to occur in places where good-quality salmon habitat remains. Merenlender says of vineyard and rural-residential land owners, it's "not just the flowpaths on their property, but the cumulative effect also." Those cumulative impacts are precisely what the forecast indicates are the biggest threat to salmon habitat.

Merenlender's model is especially useful because it incorporates land value. It identifies parcels that, if conserved, would most cost-effectively preserve salmon habitat. Merenlender explains that habitat conservation groups can help salmon the most by investing in "places that aren't completely degraded but are likely to become degraded."

To curtail the expansion of rural residences and vineyards, Merenlender suggests a shift in supply and demand. She suggests that planners consider the environmental impacts of expanding vineyards and residences, and that people who invest in them consider those impacts as well. Simply put, she says, "You have to get everyone to reduce their footprint. What you want to do is pull everybody in." Creating incentives for high-density development, she says, is essential to saving salmon habitat. Perhaps one day soon, people will envision the ideal development as a place where they can walk around their neighborhood, shop, and stop into a restaurant to enjoy their wine and salmon—without the irony.

Liza Ray *is a staff member in integrative biology.*

Want to know more? Check out:
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and

ispe.arizona.edu/about/people/faculty_details.asp?people_id=684

Blinded by the Light

A distant star signals its demise

The record-breaking stream of energetic photons, having traveled for half the age of the universe, finally reached Earth while Daniel Perley was playing the video game Smash Brothers. Perley, a Berkeley graduate student in the astronomy department working with Professor Joshua Bloom, received an automated message on his cell phone at 11:12:49 PM, initiated by a telescope-laden satellite called Swift. On board Swift, the Gamma Ray Burst Alert Telescope determined the sky coordinates of the photon source and sent another message. Next, Swift's X-ray Ultra-Violet and Optical Telescopes detected the burst and refined their coordinates. Another message. Perley quickly checked his email and read that the event was already hundreds of times brighter than a typical burst. "I thought, 'Wow, okay, this is a big deal,'" he says. "'I'd better get to work!'"

Swift had detected one of the universe's most extreme explosions: a gamma ray burst, or GRB. Gamma rays are photons so energetic that they can break apart atomic nuclei, and a GRB is a flash of these photons from outer space lasting as long as a minute. The flash is followed by an "afterglow," a surge of lower-energy photons that fades in brightness over several hours. Gamma rays are absorbed by our planet's atmosphere, which is fortunate for the atoms in our bodies, but which means that GRBs can only be discovered from space, by satellites like Swift. The X-rays and ultraviolet light of the afterglow are absorbed by our atmosphere as well, but visible and infrared light can be observed from the ground.

Most GRBs are thought to occur in very distant galaxies, an extreme version of the violent death of a star. When a very massive star exhausts its fuel supply, it succumbs to its own gravity and collapses. The collapse, which can produce a black hole at the star's center, leads to a powerful explosion called a supernova that shines as brightly as a galaxy for several weeks. If the original star was spinning very rapidly, the supernova may be accompanied by a GRB millions of times brighter than the supernova. Since the rotation prevents the collapsing gas from falling straight to the center, it spirals inward instead, forming a disk of mind-blowingly hot, fast-moving, magnetized matter pouring into the black hole.

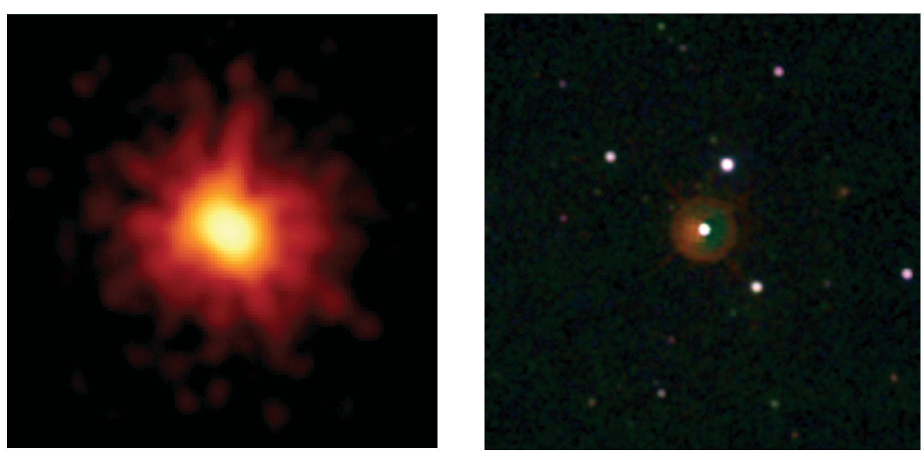
These extreme conditions cause a double-ended jet of material to shoot out along the disk's axis at speeds exceptionally close to that of light. The jet focuses the GRB's power into a narrow beam only a few degrees across, like a flashlight, rather than emitting light in all directions like a light bulb. Most locations in the universe don't get to see a given GRB because its flashlight beam doesn't point at them, but for the lucky ones, it's intense. Violent collisions of matter inside the jet itself release the initial pulse of gamma rays, which the Swift satellite can pick up. The jet then crashes into the ambient gas that fills the galaxy's interstellar space; this collision releases the longer-lived, lower-energy afterglow.

About ten times each month, Swift detects a gamma ray burst and sends astronomers around the world rushing to follow the fading afterglow with telescopes on the ground. Berkeley astronomers use two robotic telescopes, KAIT (the Katzman Automatic Imaging Telescope) at Lick Observatory near San Jose, and Pairitel (the Peters Automated Infrared Imaging Telescope) at Whipple Observatory in Arizona. On March 19, 2008, these telescopes automatically downloaded the coordinates of GRB 080319B (so named as the second GRB discovered that day), just as Perley's cell phone did. They pointed toward it and began measuring the burst's brightness at optical and infrared wavelengths many times each minute. Because the GRB was close in the sky to the day's first discovered GRB, Pairitel managed to start taking data almost immediately.

At the same time, a team in Chile led by Paul Vreeswijk measured the spectrum of the event using the Very Large Telescope. The spectrum tells us how long ago the GRB occurred by assessing how much the wavelengths of light have been stretched as they travel from the GRB to Earth through the expanding universe. This spectrum showed that the burst occurred 7.5 billion years ago, long before the formation of our solar system, when the universe was less than half its present age—and the burst happened so far away that its light only just reached us.

When astronomers analyzed the night's data, they found that the peak optical brightness of the afterglow had shattered records. An explosion halfway across the universe was so powerful that for thirty seconds it could have been seen with the naked eye, had the bright full moon not been close by. Bloom points out the amazing implication, "Our ancestors could have witnessed events from the other side of the observable universe with their own eyes."

The Berkeley team acquired exquisite data of the exceptional event. The Pairitel and KAIT telescopes provided thousands of brightness measurements, spanning a range of optical and infrared wavelengths. Combining their in-house data with public ultraviolet and X-ray data taken by Swift, the team was able to construct the brightness history of the event in detail. "Our decision was, 'We are going to try to get our data out as fast as possible so that other people can use it,'" says Perley. Conveniently, Bloom's group had been planning a retreat to Lake Tahoe the following weekend. While ten feet of snow glistened invitingly in the sunshine outside their cabin,



Super-massive gamma ray burst, GRB 080319B, as seen by the Swift satellite's X-ray telescope (left) and the Ulitraviolet/Optical telescope.

Image courtesy of NASA/Swift/Stefan Immler the team stayed in and worked through their data. Just six days after the burst, they had submitted and posted their paper. “In some ways, it’s like playing poker where everyone can see everyone else’s cards,” says Bloom about studying a publicly announced event. “To make a significant impact, you either have to be quick or have the best cards.” This time, UC Berkeley had both. Their beautiful measurements are helping astronomers refine their models of the physics inside GRBs. One theory proposes that GRB 080319B was off the charts because Earth lay directly along its jet beam’s centerline, rather than in more typical spot closer to the beam’s edge.

Researchers like Bloom are also starting to think about how to use GRBs as tools for understanding how galaxies form. Since GRBs are so bright, astronomers can observe them even in very distant galaxies too faint to detect otherwise. Such galaxies appear to us as they looked long ago, when they were first forming, because of the time light takes to travel to us. The light from a GRB passes through matter within its home galaxy, leaving an imprint that contains clues about the inner workings of that galaxy. Together, these attributes mean that GRBs may make excellent probes of galaxies as they form. And seeing very bright GRBs, like 080319B, “gives us a extra little hope that indeed current and upcoming instrumentation are going to be able to detect these things beyond where any galaxies have been found,” Bloom says.

He adds, “Berkeley is now one of the world centers of gamma ray burst research. There’s a nice confluence of people and resources for the time that is really making this one of the hot beds. I’m very happy to be part of it.”

Linda Strubbe *is a graduate student in astronomy.*

Want to know more? Check out:

Bloom, J. et al. (2008), “Observations of the Naked-Eye GRB 080319B: Implications of Nature’s Brightest Explosion”
arxiv.org/abs/0803.3215

Bloom lab webpage:
astro.berkeley.edu/~jbloom/

The same squirrels seen begging for food on campus are also the subjects of new research in cognitive psychology.

Image courtesy of Caroline Härdter

A Tough Nut to Crack

How campus squirrels find their loot

Anyone walking around campus is sure to notice the antics of our resident fox squirrels, harassing passersby for a handout or digging up nuts from beneath the oaks. However, most may not appreciate the amazing ability of these cute, fuzzy animals to remember where they stored all these nuts, a skill finely honed over millions of years of evolution. Cognitive psychology doctoral student Anna Waisman not only appreciates this ability, but is also studying how the squirrels do it, shedding light on the workings and development of human memory in the process.

Fox squirrels are scatter hoarders—that is, they place each nut they find before the onset of winter in its own well-hidden hole. Each squirrel has thousands of holes scattered in its particular territory. During winter, when the vegetation has changed and snow may cover the ground, the squirrels must rely on their memory to direct them to the exact spot where they buried a nut months before. It was discovered that this ability is based on memory of visual landmarks, which Waisman says “opens up lots of questions as to which [landmarks] are important.”

Previous research on this question of spatial memory has fallen into two categories. The first is concerned with the hierarchy of landmarks (“cues”), which is based on how stable the landmarks are over time and how far they are from the hidden object. At the top are global cues, the most consistent objects in an environment—specific trees or buildings, for instance. At the bottom are feature cues, the potentially variable characteristics of the hiding place itself, like colors and smells. Local cues fall somewhere in between. In a typical experiment, squirrels are trained to find a nut in one of several canisters arranged on a table. In this scenario, global cues are everything outside of the table, local cues are how canisters are arranged on top of the table, and feature cues are characteristics of the canisters themselves. The lab of Lucia Jacobs, where Waisman works, showed that squirrels almost always depend on the global cues first, then local cues. Finally, if no other landmarks are available, they will use feature cues to make a decision.

The second category of spatial memory research involves competition between cues of the same type. For example, if two local cues suggest the nut is in spot A, but another local cue suggests the nut is in spot B, which spot does the squirrel choose? While we might expect squirrels to trust trees as cues more than, say, trashcans or light posts, it seems that most of the time the squirrel chooses the location where the majority of cues are in its favor, no matter what those cues are.

Waisman’s research, as she explains, “marries the two fields.” Her aim was to determine which hierarchy cues would win in the competition test. That is, if the squirrel has three kinds of cues (a global, a local, and a feature), but one of them contradicts the other two, where does the squirrel go? To perform the experiments, Waisman trained squirrels to find a nut in one of four canisters, specifically arranged on a table relative to the different kinds of cues. After the squirrel had learned where the nut was hidden, she changed one or more of the possible cues and watched where the squirrel went to find the nut. Previous research suggested that the squirrels would follow the global cue all the time, but this turned out not to be the case. In general, Waisman found that the squirrels were able to do the math and usually picked the location that had two cues in its favor—regardless of the type of cue. This wasn't true all the time, however, which made Waisman wonder if there might be more going on.

Based on other research in this area, she thinks the squirrels might be weighting different cues according to their relative usefulness. For example, global cues might have a higher weight (40) than local (30) or feature (20) cues. In her original experiments, this weighting would mean that any combination of two cues would beat any single cue. But the squirrels would hesitate or choose the wrong canister more often when the weighting was close (global vs. local and feature, 40 vs. 50) relative to when it wasn't (feature vs. global and local, 20 vs. 70). Waisman's current efforts are focused on statistical modeling of her data to determine if this theory agrees with her observations. She is also designing experiments to measure the relative weights of each cue. If her hypothesis is correct, then the use of spatial cues would be much more complicated than first thought, and might reflect general decision-making processes in the brain. Researchers would then have much more to study, including what attributes influence the weighting, and whether the weighting is innate or learned.

In the future, Waisman hopes to widen the scope of her research by studying how humans, especially children, use spatial cues to make decisions. Like squirrels, preschoolers appear to prefer global cues in hierarchy tests, but this preference goes away as cognitive development proceeds. No one has yet tested competition between hierarchies in young children, an experiment that Waisman is excited to try.

In the end, the ways humans and squirrels think about spatial cues may not be so different. So the next time you walk through campus, go ahead and give that begging squirrel a treat—the study it just participated in might one day help you remember where you put your keys.

James Walker *is a graduate student in molecular and cell biology.*

Image courtesy of Scott Butner

A Reason for Everything

Instinctively making sense of the world

Charles Darwin should be spinning in his grave: more than 40 percent of American adults still don't believe in evolution. Though Darwin's theory has been universally accepted by scientists, public resistance remains remarkably forceful. Meanwhile, creationism and intelligent design enjoy widespread public support.

UC Berkeley psychologist Tania Lombrozo is interested in why people find certain kinds of explanations more or less compelling than others. Her research suggests that some theories, like evolution, may be difficult to accept because they are at odds with a human default for understanding the world in terms of design.

Lombrozo was motivated by the observation that young children often explain the existence of objects and phenomena with reference to their function, a kind of reasoning termed teleological. Ask a three-year old why it rains, for example, and you are likely to hear something like "so that plants have water to grow." Likewise, lions exist "for going to the zoo," and mountains "are for climbing." This tendency of children to infer design suggests an explanatory default: in the absence of competing knowledge, the best explanation for an object with a plausible function is that it was designed to fulfill that function.

Unlike children, most educated adults know that clouds form because water condenses and that mountains exist because of plate tectonics. However, Lombrozo was interested in whether adults would fall back on teleological reasoning in the absence of background knowledge. To address this question, she and her colleagues Deborah Kelemen and Deborah Zaitchik examined a group of adults whose background beliefs were compromised, but who had otherwise developed normally: Alzheimer's patients.

"Alzheimer's patients have some characteristics of adults, and some characteristics of children," says Lombrozo. "Like adults, they have undergone normal development and have presumably gotten rid of any reasoning strategies associated only with children. But like preschool children, they might not have access to the kinds of rich causal beliefs that adults typically have access to."

In her study, subjects were asked to identify the most appropriate answers to a series of "why" questions. For example, for the question "Why does the earth have trees?" they could choose between "because they grow from tree seeds," or "so that animals can have shade." Lombrozo found that like young children, Alzheimer's patients were much more likely than age-matched control subjects to prefer teleological explanations, picking the teleological choice about twice as often as their healthy counterparts.

"The results support the idea that adults and children have the same sorts of cognitive mechanisms at work, and that adults are just overriding the explanatory default with background knowledge," says Lombrozo. They also fit with findings from other studies that show more frequent use of teleological explanations in less educated adults and in educated adults making speeded judgments.

Collectively, Lombrozo says these results may help explain why intelligent design and creationism—teleological arguments that suggest we exist in our current form because we were designed to do so—continue to be so pervasive in today's society. "Many people find it difficult to think that we would be the result of a process that didn't involve design. As a result, intelligent design seems like a much more compelling explanation than evolution. Interestingly, even among those who do accept evolution, many misunderstand it, reinterpreting it as a goal-directed process that occurs at the level of individuals rather than populations."

Why might humans have evolved this kind of a reasoning strategy? Lombrozo has several ideas. "One possibility is that if you look at our evolutionary past or at our experiences growing up, one of the things we did most often was explaining human behavior. And human behavior is generally goal-directed—it does involve intentions and functions. We may be taking the mode of explanation that we're best at and then applying it to other domains," she says. "Another possibility is that it's more effective. We're going to learn more about the world if we go around assuming that things have functions and then sometimes discovering we were wrong, rather than the reverse."

Lombrozo points out that most of the time functional explanations don't do a lot of harm. In fact, they can sometimes help people understand concepts that might otherwise be too difficult. In chemistry, for example, it can be helpful to think about an electron wanting to go toward a positive charge, or, when learning about evolution, that a moth doesn't want to be visible to its predator. On the other hand, says Lombrozo, systematically shaping explanations to what people find satisfying can be bad for their appreciation of science. "Education is most successful when it gets people to undergo something like a theoretical change. Recognizing what kinds of assumptions people come into the classroom with will help in figuring out how to best accomplish this."

Hania Kover *is a graduate student in neuroscience.*

Rock of Ages

Synchronizing geological clocks

Once upon a time, the Earth was an inhospitable place for giant cold-blooded creatures—a meteorite had just blanketed the atmosphere with dust, blocking out the sun and sending temperatures plummeting. Until recently, the date of that extinction event had been placed at sixty-five million years ago, give or take a few million. A team of geologists at Berkeley and the Universities of Utrecht and Vrije in the Netherlands has recalibrated the method used to calculate the date of the dinosaur extinction event. That technique, argon-argon radiometric dating, allows geologists to determine the ages of rocks over most of the geologic past. "We're trying to decipher Earth's history," says Paul Renne, Director of the Berkeley Geochronology Center and a geologist in UC Berkeley's Department of Earth and Planetary Science.

Just how do geologists go about deciphering Earth's history? The sequence of sedimentary rock layers reveals their relative ages. But in order to compare the geologic record to, say, the archaeological record, scientists need to know absolute ages. Says Renne, "Precise and accurate age determinations are critical for causality arguments in geology, paleontology, archeology, and cosmology." Enter radiometric dating: a radioactive element can tell a geologist how old a rock is by how much of the so-called "parent" isotope has decayed into the "daughter" isotope.

In the case of argon-argon dating, the parent is potassium-40, one of three naturally occurring potassium isotopes (each differs in its number of neutrons). Every 1.25 billion years, half the potassium-40 in a sample decays into argon-40. This long half-life means the technique can be used to date rocks over most of Earth's 4.5-billion-year history. "The further you go in the past, the more of the daughter product accumulates in your rock," says Alan Deino of the Berkeley Geochronology Center, a member of the Berkeley team. Measuring the accumulation of argon-40 provides a clue, but to solve the mystery of the rock's age, the original amount of potassium-40 also needs to be known.

Geologists can use the stable potassium-39 isotope to figure out how much potassium-40 was present when the rock formed, because rocks crystallize with a constant amount of potassium-40 relative to potassium-39. But measuring potassium and argon separately requires splitting a sample and using two different measurement techniques, increasing the chance for error. Geologists solve this problem by bombarding their rock samples with neutrons, which converts a fraction of the potassium-39 into argon-39. "The miracle of the 40-39 dating process," says Deino, "is that you can measure potassium in your rock via the proxy of argon-39 at the same time as you measure the radiogenic component, which is the argon-40."

Geologists translate the argon measurements into an absolute age by simultaneously measuring the 40-39 ratio in their mystery rock and in a sample from a standard rock

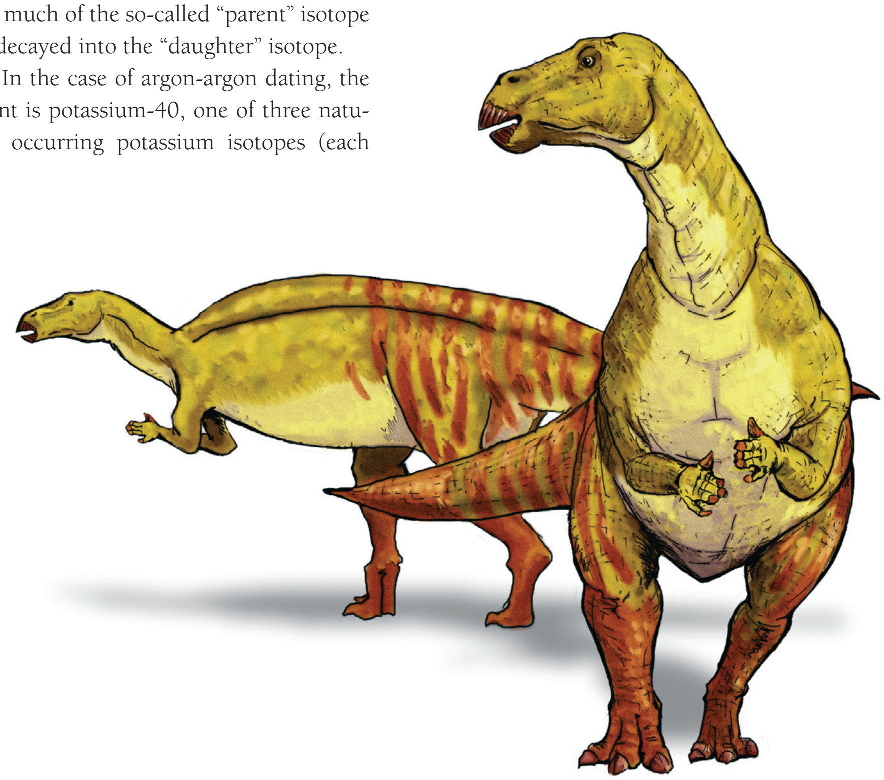


Illustration by Mariana Ruiz

of known age. Comparing the two 40-39 ratios yields an age for the unknown sample. The most widely used standard for the argon-argon method comes from a site called the Fish Canyon Tuff, a large volcanic deposit in the San Juan Mountains in Colorado. Fish Canyon has become the standard because it is a uniform formation that contains many different minerals and is in a location accessible to geologists.

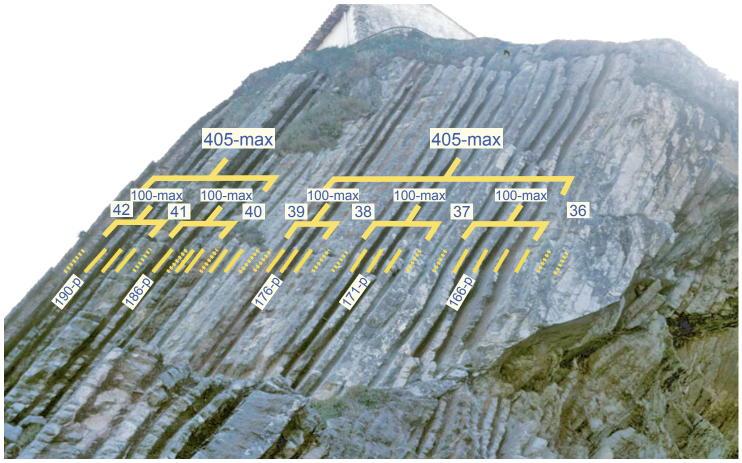


Image courtesy of Frits Hilgen

The sedimentary layers shown here were not explicitly studied for the argon-argon recalibration, but they do show the astronomical tuning particularly well. The dark, narrowly spaced layers are an effect of the Earth's 26,000-year precessional cycle. Every few precessional cycles, the darkened layers become less pronounced, an effect of changes in the Earth's orbital eccentricity (or oval-ness). The eccentricity varies with a 125,000-year and a 400,000-year periodicity, both of which are marked in the image. The precise understanding of changes in the Earth's orbit with time allows geochronologists to measure absolute ages of rocks that formed several million years ago.

The accuracy of the Fish Canyon age dictates the accuracy of argon-argon dating. Previously, that age came from a multi-stage laboratory process that was subject to relatively large errors. A more accurate Fish Canyon age applied to past and future experiments could improve all argon-argon ages. The Netherlands and Berkeley teams have calculated a better Fish Canyon age by linking it to another, independent method known as astronomical tuning.

Over tens of thousands of years, the Earth's orbit around the Sun changes, affecting the intensity of the sunlight at its surface, or insolation. "Astronomers have very carefully measured all the orbital parameters of the solar system and combined them all in models so that you can take a present-day observation of the state of the solar system and say what it was like a hundred thousand years ago," says Deino. An increase in insolation causes heavier rains, increasing freshwater runoff in the Mediterranean basin, and the resulting circulation patterns in the sea cause more organic matter to be present in the sediments that form during that time, darkening them. Identifying those darker sedimentary layers and linking them to astronomical models yields precise ages for the relatively young rocks that formed within the past few million years.

To calculate a more accurate Fish Canyon age, the Netherlands team first found sedimentary layers on the northern coast of Morocco that could be dated astronomically and that also contained the potassium-rich minerals required for precise argon-argon dates. Since the Moroccan rocks could be age-dated by both methods, they would allow the geologists to directly compare the two scales. "If you assume your astronomical clock is the correct one," says Deino, "then you can back-calculate a better age for your standard."

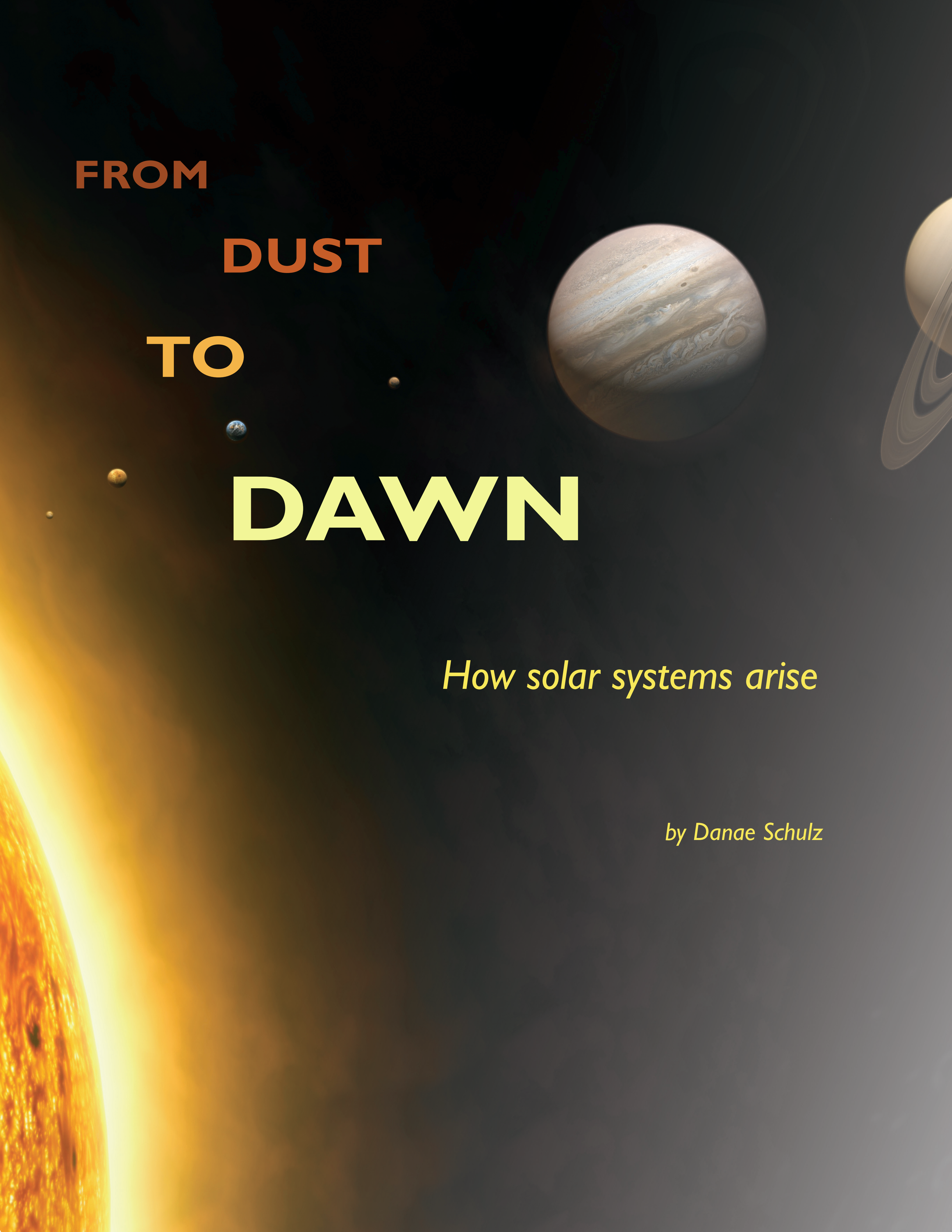
The Netherlands team analyzed the Moroccan rocks and asked the Berkeley group to do the same. "The point of having two laboratories," says Deino, "is a cross-validation of techniques." The two teams independently concluded that the canonical Fish Canyon age was a little too young for the argon-argon clock to agree with the astronomical one. They advocate adjusting the age of the standard in order to synchronize the two. Their new and improved Fish Canyon age aligns argon-argon dating with the astronomical record and increases its precision and accuracy.

There is, of course, more work to be done. To be sure the calibrations are correct, Deino says it is important to go elsewhere in the world to repeat the test. But the higher precision already allows for better absolute ages of much of geologic history. The Netherlands-Berkeley team first applied the new calibration to the layer of rock that formed during the dinosaur extinction: that devastating meteorite impact happened 65.96 million years ago, give or take a mere 40,000 years.

Katie Peek *is a graduate student in astronomy.*

Want to know more? Check out:
A virtual tour of the Argon lab at the Berkeley Geochronology Center
bgc.org/facilities/argon_lab.html

A current outline of rock ages over Earth's history
geosociety.org/science/timescale/timescl.htm
and
earth-time.org



FROM DUST TO DAWN

How solar systems arise

by Danae Schulz

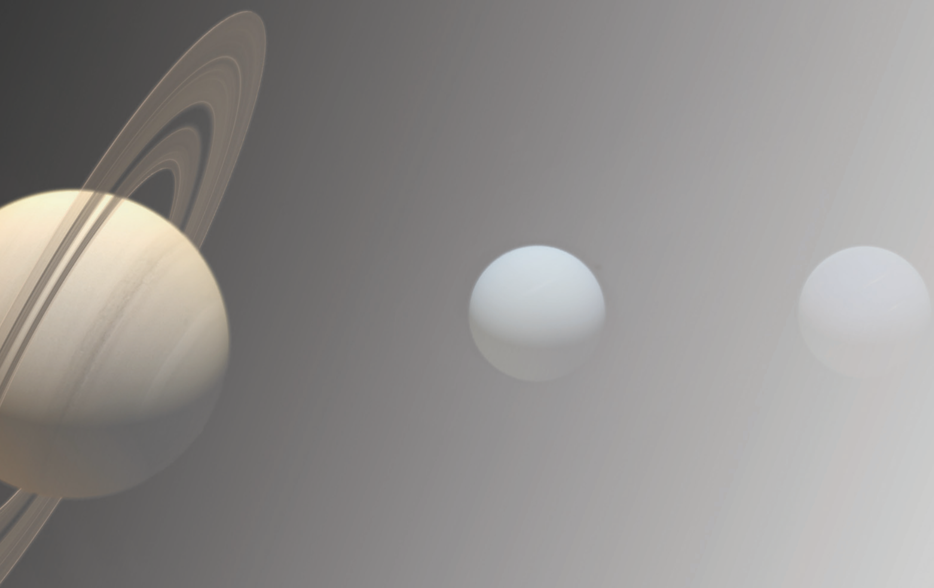


Image courtesy of NASA

A massively dense cloud of molecular hydrogen collapses under its own weight, and a star is born. From this violent beginning, many stars, including our own Sun, go on to exist calmly and happily as energy sources for planetary systems. How does a system transition from its tumultuous formation to a relatively peaceful state? When and how in that process do planets form? To put it simply, how did we get here?

Geologists and paleontologists rely on fossils to learn about our planet's past, but the vacuum of space does not keep the same copious records as the stones of the earth. In the absence of such relics, astronomers are taking advantage of space's vast expanses to search for systems that may be analogous to our own but are earlier in their evolutionary process. Instead of looking at actual remnants of our solar system's past, they hope that putting a mirror up to younger systems will provide insight into our system's formation.

Dusty disks

The journey from new star to mature solar system is long—it may take up to a billion years for a solar system to reach its final, relatively stable configuration—and as yet, not fully understood. However, scientists generally agree on a few basic steps along the way. Every new star is surrounded by a swirling cloud of dust and gas, a remnant of the violent collapse that led to its formation. Under the influence of gravity, this initially spherical cloud collapses to form a disk rotating around the star, rather the same way a ball of dough flattens to form a pizza pie as the baker tosses it into the air. This disk of dust and gas is called a protoplanetary disk, and some of the material within it can eventually become a system of planets orbiting the newly formed star.

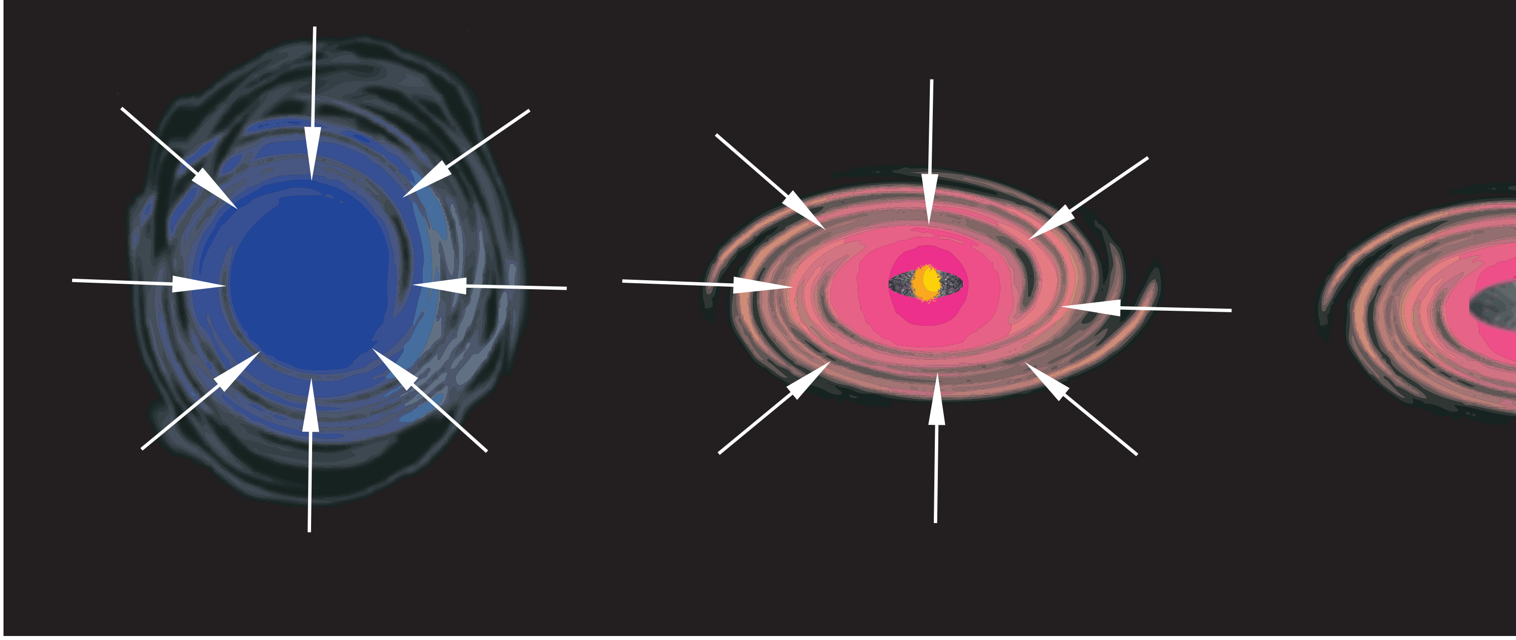
The physical process of building a full-grown planet out of tiny dust particles requires intermediate stages, of which one is the formation of kilometer-sized bodies called planetesimals. It is believed that formation of rocky planets such as our own depends on productive collisions of planetesimals to form larger and larger bodies, but each of these collisions is just as likely to regenerate the dust of the disk. Researchers like Paul Kalas of the astronomy department therefore believe that studying planetesimals could provide insight into the mechanism of planet and solar system formation.

Detecting planetesimals themselves is quite difficult, but it is slightly easier to detect debris disks—rings of dust around the central star that result primarily from planetesimal collisions and are the remnants of planet formation. Our own solar system contains a debris disk in the form of the Kuiper Belt, a collection of relatively large objects traveling in an orbit just outside Neptune's. Compared to newer planetary systems, the Kuiper Belt is a relatively sparse debris disk—sufficient time has passed to allow much of the dust and debris of the protoplanetary disk to clear. Similarly sparse disks are difficult to detect; today's instruments typically are sensitive enough to detect debris disks only of stars younger than our Sun. In the search for the truth about our solar system's past, this condition is ideal.

Kalas and his group are currently searching the galaxy for as many debris disks as they can find. The goal of the project, as described by graduate student Holly Maness, is to "image enough debris disks so that we can begin to draw detailed conclusions about the dynamical structure and evolution of these systems as a whole." For example, once the disks have been imaged, researchers can identify whether it is likely that planets are present by analyzing the gravitational forces on the disk. The distribution of dust can also tell them where in the debris disk planets have formed and how big they are.

Can't see the planets for the dust

Recently, Kalas and his colleagues analyzed a debris disk orbiting the star Fomalhaut using data acquired by the Advanced Camera for Surveys (ACS), an instrument on board the Hubble Space Telescope. The study, focused on optical images, detected a striking ring of dust about 25 astronomical units (AUs, the distance between the Earth and the Sun) wide about 145 AU from the star. In contrast, the Kuiper Belt is about 20 AU wide but is only about 30 AU from the Sun. Interestingly, they found that the belt is not centered on Fomalhaut, but rather on a



point about 15 AU away, indicating that some other body is exerting a gravitational influence on the ring. The inner boundary of the disk is also particularly well defined, and careful analysis indicates that these traits are likely caused by the presence of one or more planetary bodies exerting their influence on the debris disk.

Despite Kalas' success with Fomalhaut, observing distant debris disks is difficult at optical wavelengths because the stars they orbit are very bright, often obscuring the faint signal of the debris disk. However, small (sub-micron sized) particles within a disk reflect some of the radiation emitted by the central star, primarily in the infrared region of the spectrum. A debris disk can therefore be found by looking for a star system with an excess of infrared radiation. Larger particles (approximately millimeter sized) can also absorb the star's energy and subsequently emit their own thermal radiation at longer wavelengths (in the radio region of the spectrum). Observing systems at different wavelengths, from radio to infrared, can therefore provide a relatively complete picture of all the particles in a debris disk. Now that they have identified one probable planetary system, Kalas and his group hope to find more debris disks to study in different systems.

Most of the work done so far on debris disks has focused on detecting smaller particles because the scattering signals at these shorter wavelengths are relatively strong. However, detecting larger particles is particularly important for understanding disk dynamics. Large grains are primarily influenced by gravity and therefore give the most direct information about the presence of massive bodies nearby. Small particles, on the other hand, are subject to additional forces besides simply gravity. Thus, clues about potential planets in their signal can be obscured by other fluctuations.

Unfortunately, the signals emitted at longer wavelengths are very faint and difficult to detect. One solution is to use many small, relatively inexpensive radio telescopes (large dish antenna used to detect these longer wavelength signals) set up in an array, instead of working with one gigantic, and very expensive, antenna. Observers use software to combine the data collected by the separate antennas and generate a map of the debris disk, providing information about both the size and the location of large dust grains and planetesimals within the disk. Two new arrays of antennas, CARMA and ALMA, have recently become available for use, providing exciting potential for new research (see sidebar).

With all these maps, Kalas hopes to further dissect their physical characteristics and identify more potential planetary systems, further developing our picture of solar system formation. But how did these debris disks come to be in the first place?

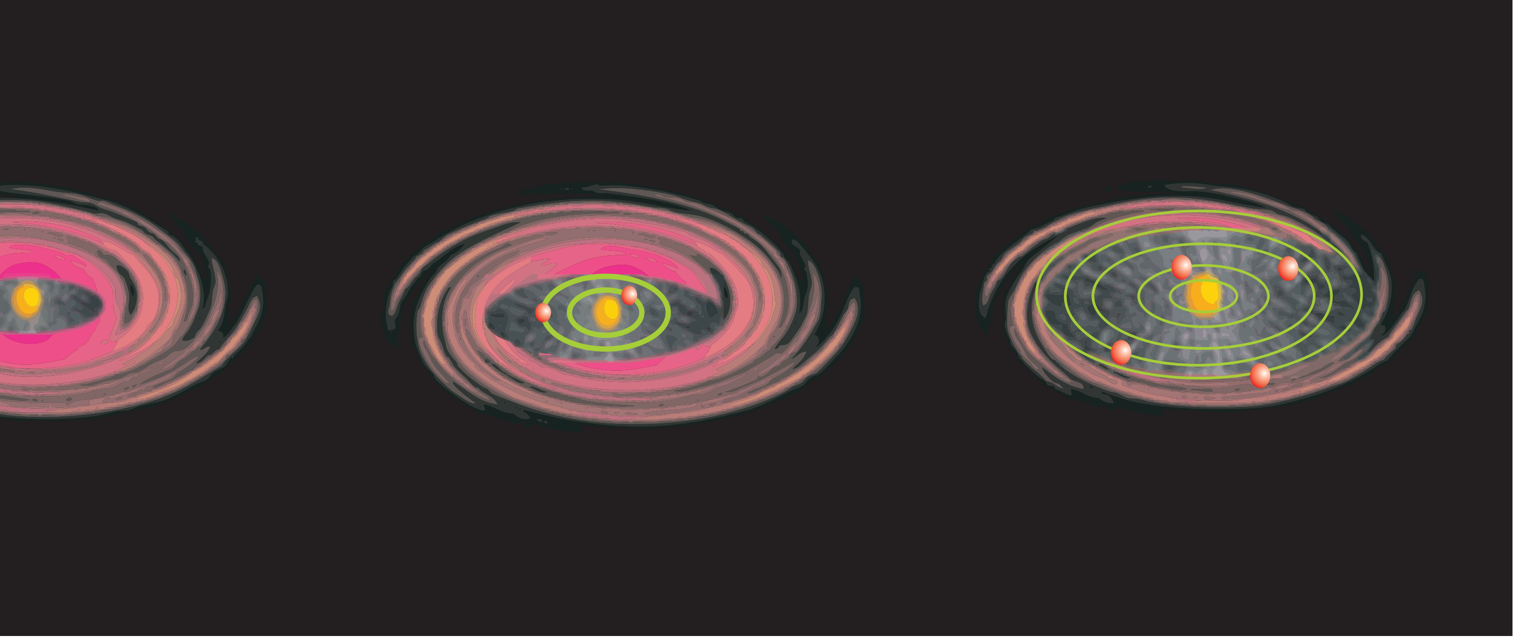
An aging star

On a solar system's journey from an infant protoplanetary disk to a more mature system with a debris disk, it is believed to pass through an intermediate phase called a transition disk. Most stars that have been observed appear to have no disk at all (our own sun would fall into this category). Of the few stars with identified disks of any sort (protoplanetary, debris, or transition), only about 10 percent of them appear to have transition disks. The rarity of observed transition disks is further evidence that they are only a brief stopover on the way to a fully developed star system where all the material from the disk has cleared. The transitional period is also thought to coincide with the time that planets are beginning to form, so understanding them is essential for understanding planet formation. UC Berkeley astronomer Eugene Chiang hopes that studying disks at this point in their evolution can lead to a better understanding of the physical conditions that exist at the time of planet formation and of the development of solar systems in general.

Transition disks arise as the star's gravity pulls in, or accretes, some of the material from the swirling disk of dust and gas that surrounded it at birth. As this process proceeds, it leaves behind a ring of material—the transition disk. Such disks can be identified by a deficit of emission originating from near the star, reflecting the fact that the area around the star is relatively devoid of dust—a hole has formed. These holes can be very large, reaching 10 AU in size (roughly the distance between Saturn and the Sun).

So, how do the holes get there? Chiang has developed a theory that explains why the inner portion of a protoplanetary disk is continuously eaten away, leaving behind a transition disk that eventually develops into a planetary system and remnant debris disk.

Elementary physics dictates that material in orbit around a star should stay in orbit unless some external force causes it to change that orbit. That is, each particle of gas or dust within the protoplanetary disk should just continue to orbit around the star without changing its trajectory. However, temperatures close to the star are so high that the gas surrounding the star can be photoionized: the



A schematic of what is known about the formation of planetary systems. From left to right, the star is initially surrounded by a large ball of gas and dust. Gravity causes this spherical cloud to flatten, giving rise to a protoplanetary disk. Over the next million years or so, the star continues to accrete the gas and dust enveloping it, eating away at the inner portion of the protoplanetary disk and leaving behind a transition disk. Tiny dust particles collide with each other to form planetesimals, which, through more collisions, start to form planets. Planetesimal collisions also create additional dust that can become part of a ring of dust surrounding the star, called a debris disk. After another fifty million years of the gas and dust particles colliding with one another and being accreted by the star, a solar system is finally born.

Illustration by Terry Yen

heat from the star kicks electrons off of gas molecules, giving them a net positive charge. This charge makes the dust particles susceptible to the force of the star's strong magnetic field, which pulls material toward the star.

A challenge to understanding how this process creates transition disks comes when the majority of the dust and gas is far from the central star. In this scenario, temperatures are much too low to allow direct photoionization to occur; thus, it appears that the star should no longer be able to accrete any material, and the protoplanetary disk should never transition fully into a debris disk. Since evolved debris disks are observed, more distant material must be accreted somehow.

Only a small amount of the gas in the disk needs to become ionized to start the process, because charged gas particles can collide with neutral particles and ionize them. So the problem becomes how to ionize enough gas to initiate this domino effect. The solution? The gas is ionized not by the star's heat, but by X-rays emitted from the star. These X-rays contain enough energy to ionize the atoms they collide with, thereby setting off a domino effect of ionization. Chiang and his group are not the first to propose that X-rays, rather than thermal energy, could ionize a disk's gas, but their study was the first to apply this idea to transition disks and show that it creates a viable model of the accretion process.

The X-rays are absorbed by the outermost layer of dust and therefore cannot penetrate very far into the disk. Just as the rain that falls gets absorbed by the Earth's crust rather than traveling to the planet's core, the radiation from the star that hits the rim of the disk never makes it past the first layer of dust. Therefore, only the material on the rim is subject to ionization and subsequent interaction with the star's magnetic field. Once the material at the rim has been pulled to the star, the X-rays can work on a newly exposed layer of material. Thus, the star slowly eats away at the inner rim of the disk, evacuating the material one layer at a time, moving from the inner edge of the donut to the outer edge. This explains how the disk dissipates over time.

Aside from this qualitative understanding of how the disk transition process can occur, Chiang's theory also provides a quantitative relationship between the size of a given hole and the rate of the inward gas diffusion. It turns out that as the size of the hole increases, more and more dust rains down on the star. As the hole grows, the X-rays must travel further to ionize the gas, which could be expected to slow the diffusion rate. However, a larger hole also presents more surface area for the X-rays to interact with, and Chiang hypothesizes that this is the cause of

Are we the only ones out there?

One of the goals of debris disk research is to understand solar system formation. But just how many systems like our own are out there? Berkeley astronomer Geoff Marcy has pioneered this field using high-resolution spectrographs on optical telescopes located at Lick Observatory near San Jose and at Keck Observatory in Hawaii. He looks for very small variations in the wavelength of light emitted from a star over time. As a planet orbits its host star, its gravitational tug causes the star to move toward and away from Earth very slightly, thereby compressing or expanding the light waves the star is emitting. These back-and-forth variations in wavelength over the period of the planet's orbit allow astronomers to detect planets even though they can't be seen directly.

Since it's the planet's gravitational influence on the host star that astronomers measure, massive, Jupiter-like planets are much easier to detect than puny Earth-like ones. In order to search for Earth-like planets, Marcy has headed up a project to construct the Automated Planet Finder, a 2.4-meter telescope with a high resolution spectrograph that will conduct nightly observations of stars within 100 light years of Earth. The advantage of a dedicated telescope is that nightly observations of a star will give Berkeley planet hunters far more data than they can collect from shared telescopes, making the weak signal of an Earth-mass planet easier to detect. Who knows, it's possible that Marcy and his team may be able to provide us all with the prospect of a home (very far) away from home.

Telescope Revolution

Astronomers long for detailed maps of protoplanetary disks at multiple wavelengths to help them dissect the complex processes of planet formation. Creating long-wavelength maps of protoplanetary disks has recently become much easier thanks to a powerful new set of radio antennas called the Combined Array for Research in Millimeter-wave Astronomy (CARMA), located about 50 miles southeast of Yosemite National Park. CARMA originated from a merger of the Berkeley-Illinois-Maryland Association (BIMA) array and the Owens Valley Radio Observatory (OVRO) Millimeter array, built and operated by Caltech. BIMA, founded in the 1950s and located near Hat Creek (290 miles northeast of San Francisco), was started by UC Berkeley as a system of three antennas that rapidly expanded to nine. In 2004, BIMA agreed to merge with OVRO, and over a period of three years, Berkeley and Caltech astronomers orchestrated the movement of the antennas to a single location. They also oversaw development of the software and hardware necessary to begin observations in 2007 using CARMA as a single array. By combining BIMA and OVRO, astronomers were able to make two aging facilities cutting-edge once again.

One of the great advantages of CARMA is its ability to produce high-resolution long-wavelength (radio) maps, allowing for detailed observations of relatively large particles. Holly Maness, a UC Berkeley graduate student in astronomy, is excited by the promise of this new observational resource. "Although there are quite a few debris disk maps at short wavelengths, few long wavelength maps currently exist. In just the last few months, CARMA has contributed three long wavelength maps, doubling the number of successful debris disks observations made in this way," Maness says.

Another exciting development that will allow observers to rapidly generate new maps of debris disks is a project called the Atacama Large Millimeter/submillimeter Array, or ALMA. When completed, ALMA will be an array of 50 to 64 radio antennas located at Llano de Chajnantor Observatory in the Atacama desert of northern Chile. This array, which will cost over $1 billion to build, will be the world's largest and most sensitive array, allowing astronomers to observe systems at three to four different wavelengths, thus generating a large number of detailed debris disk maps with unprecedented speed. The construction of ALMA has been an international effort with partners including the National Science Foundation as well as various organizations from Europe, Canada, Japan, and North and South America. Astronomical research is expected to begin in 2010, with full completion of the facility slated for 2012. UC Berkeley's scientists will have access to the data that is generated there, giving them an invaluable new tool to generate maps of debris disks surrounding newly discovered star systems.

the increased diffusion rate.

A competing theory argues that formation of the holes within transitional disks is the result of a planet evacuating material from the disk as it progresses through its orbit. This theory depends on the presence of a planet to create the hole in the first place. Chiang's theory, however, does not require the presence of a planet to hold true, but at the same time, the presence of a planet would not alter the explanation for how the protoplanetary disk gets eaten away. Because it is unclear whether fully formed planets exist within transitional disk systems, the theorists might have to wait for Kalas and other observational teams to gather enough data to support one theory over the other.

A Life Through the Ages

From protoplanetary disk to emptying transitional disks to dusty debris disks and onwards, forming planetary systems is a long road, and it is just the beginning of a star's, and planet's, known life. Just as physiologists have long since realized that in order to understand the body and its development, one must study it in all its stages, from infancy to old age; astronomers have now come to the same conclusion. Sophisticated technology and complex mathematical and physical studies are beginning to help us understand how our planet and solar system may have come into existence, providing small parts of the answer to the question of how we got here. Still, astronomers are continuing their quest for new phases in a star's development to better understand the life history of our own solar system and all the myriad solar systems that exist within our galaxy, or even the universe.

Danae Schulz *is a graduate student in molecular and cell biology.*

Want to know more? Check out:

Paul Kalas's circumstellar disk learning site
astro.berkeley.edu/~kalas/disksite

CARMA telescope:
mmarray.org

ALMA telescope:
nrao.edu/index.php/about/facilities/alma

Geoff Marcy's exoplanets page:
exoplanets.org

The Sound of New Music

Expanding Technology's Horizons at CNMAT

by Meredith Carpenter

At first glance, the device looks like a futuristic TV tray. The top is covered with a grid of black squares glowing with red and green LED lights, and a patchwork of electronics and wires connects the machine to a nearby laptop computer. Professor David Wessel sits on a stool positioned behind the setup. Hunching down slightly, he begins rhythmically tapping the squares as though typing on a keyboard. While this may seem like the prelude to some complicated experiment—or perhaps a spaceship launch—Wessel is, in fact, playing music. This improvised composition of layered electronic sounds, so unlike a Beethoven sonata or Mozart fugue, epitomizes the genre of "new music."

Wessel, a music professor at UC Berkeley, is Co-Director of the Center for New Music and Audio Technologies, or CNMAT. Founded in 1987 by composer and Professor Emeritus Richard Felciano, CNMAT seeks to foster productive interactions between music and technology. With an interdisciplinary research program that includes music, physics, computer science, psychology, mathematics, engineering, and even architecture, CNMAT's ultimate goal is, according to Co-Director Edmund Campion, to conduct "research that has a musical application at the end of the day." These applications range from new sensor-based technologies for producing music (such as the device described above), to hearing aids with improved capabilities for music listening, to a better understanding of how the brain acquires musical knowledge.

Beyond the blue door

Headquartered in a distinctive blue-doored house on Arch Street in North Berkeley, CNMAT was modeled after the famous Institut de Recherche et Coordination Acoustique/Musique (the Institute for Music/Acoustic Research and Coordination, or IRCAM) in Paris. According to the IRCAM website, the goal of founder Pierre Boulez was "to bring science and art together in order to [develop new instruments] and rejuvenate musical language." In the same way, says Campion, "the notion of bridging the humanities and the sciences is one of the reasons we exist. The goal is to constantly renew, revise, and revisit the materials of music in the hopes of inspiring new music."

According to CNMAT's website, "new music exhibits novelty in its situation, presentation, compositional process, performance practice, or outcome. In some pieces, that novelty is dependent on or derived from the use of technology." Thus, the CNMAT facility contains computer labs as well as classrooms, performance space, recording studios, and offices, and the Department of Music offers several undergraduate classes that teach students to use software developed at CNMAT. In addition, CNMAT offers summer workshops for musicians and artists. Workshops offered this past summer included a hands-on course for creating sensor-based instruments, in which students learned to use conductive and piezoelectric fabrics to create instruments that can be used in musical performance, dance, and art installations. Piezo-

Photo by Korbinian Riedhammer

electric materials generate an electrical signal in response to stress or force, making them ideal for creating new instruments that are activated by bodily movements or gestures.

Musical gestures

These so-called "gestural controllers" are a main focus of research at CNMAT. "I think we're in a kind of renaissance now in engaging the body in interaction with computing devices," says Wessel. "Witness the Nintendo Wii's success." In fact, Wii controllers are used in the workshop as starting materials for new gesturally controlled instruments. According to Wessel, "One of the really critical things we like to do here is to work on these interfaces for control. Laptops and mobile computing devices are pretty powerful, but it doesn't seem quite so interesting to see someone behind a screen on a concert stage—you wouldn't know if he was reading his email or doing office work or what—so we want to have gestural controllers that function more like musical instruments by engaging the body."

Gestural controllers also open up a whole new realm of flexibility that acoustic instruments cannot offer. For example, the keys of Wessel's multi-touch keyboard can communicate both spatial information (where the key is touched in the left-right and up-down dimensions) and pressure information. A computer program then generates sounds based on pre-programmed settings for each key, with variation depending on how exactly the key has been touched. Because the sounds produced and their qualities like pitch, volume, and timbre depend on computer-programmed settings for the controller, the controller itself does not have a characteristic sound. However, its mode of use can impart certain properties; for example, depending on how it's programmed, a Wii controller might allow for more sliding sounds than a controller with keys alone.

Adrian Freed, Research Director at CNMAT and the instructor of the sensor workshop, is CNMAT's resident sensor guru. One of his most recent prototypes is a drum-like controller called "the tablo." To create the device, Freed stretched an electrically conductive silver-plated fabric over an embroidery hoop. He then pulled the taut fabric down over an inverted bowl that he had covered with strips of conductive plastic. Pressing down on the fabric distorts it so that it touches the plastic sensors on the bowl in different places, shorting them out at the point of contact. A microprocessor measures the resistance of the sensors along their entire length and passes the information to a computer that actually produces the sound. The signal changes based on the location of the contact between the fabric and the sensor, allowing for flexibility in how the tablo can be played.

Photo by Korbinian Riedhammer

CNMAT Co-Director David Wessel plays the multi-touch array, an instrument developed at CNMAT.

Conductive fabrics have become one of Freed's favorite materials for building new controllers. "I'm using fabrics partly because I'm in a hurry, because I have to try all kinds of things and work quickly with lots of prototypes," says Freed. "The conventional way of making these kinds of sensors is to make circuit-boards, which take days to come back from the manufacturer. With fabric, I can just take scissors and cut what I need." So why not just clothe yourself in conductive fabric and dance around? In fact, students at this year's sensor workshop did just that. "We had people wanting to build wearable light shows and clothing that makes sound—clothing that can be musical instrument interfaces," says Freed. However, he emphasizes that the source of inspiration for his new instruments is not the technology or the materials alone. "The way we run things around here is that music drives the technology. The technology in a certain way is sort of neutral and empty, waiting for things to need it."

Timing is everything

So why aren't these electronic instruments more popular? "Part of the reason that a lot of people still prefer acoustic instruments to electronic instruments is because the electronics are too slow," says Freed. "They're not accurate enough in communicating gestures. The sensors are pretty good these days, but there's been a long history of not taking time into account." To address this problem, Andy Schmeder, CNMAT's Research Programmer, recently investigated the timing requirements for transmitting gestural information from an electronic instrument's microprocessor to the computer, usually through a USB connection.

"Musical gestures are characterized by the need to transmit information that changes over a very fine time structure," explains Schmeder. "We're looking at the limits of expressive gestures that you can make with your finger, or some other device like a stick or a musical controller, and still transmit the information faithfully." It turns out that the time information has to be highly precise in order to communicate the gestures to a computer without losing any signal quality. "Acoustic instruments already have this, because they don't need to transmit the signal somewhere else. But this is something we need to be aware of if we're going to build a new instrument that's based on these technologies," says Schmeder.

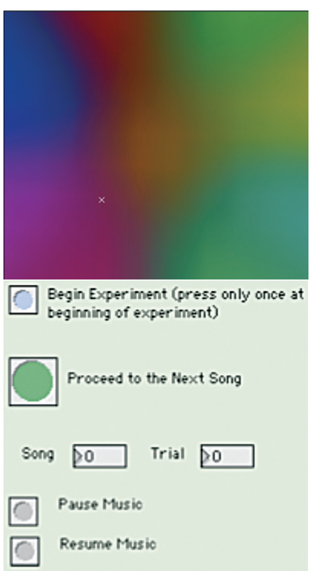
These limitations, of course, are only part of the reason that electronic instruments haven't been more widely adopted. Many musicians are understandably resistant to the idea of abandoning the instruments they've been playing for years. "We are very interested in the skill set of a musician who spent thousands of hours learning an instrument. We don't want to ignore that, so augmenting traditional instruments is also very important," says Wessel. "For example, we worked with Gibson Guitar on various kinds of processing to make the guitar more of a digital device." While some of CNMAT's funding comes from the university and individual donors, it has also participated in numerous collaborations with industry partners like Gibson, Yamaha, and Meyer Sound over the years. These partnerships are encouraged by the availability of UC Discovery Grants, which provide matching funds from the state for money invested by industry in research.

Music to my hearing aid

One current industrial partner is Starkey Laboratories, a hearing aid company with a Berkeley-based research center. CNMAT researchers are working with Starkey to optimize hearing aids for music listening. "People who wear hearing aids complain bitterly that their hearing aids don't sound right, and often they'll just turn them off when they're listening to music," says Wessel, who works on the project. The goal of the current research is to allow hearing aid users to better adjust them for music.

"Hearing aids are really tuned for speech intelligibility, and music is more complicated in many ways," Wessel explains. "First of all, there are a lot of varieties—everything from Gregorian chants to quick-tempoed Balinese music—so the settings that you would use for your hearing aid to best enjoy these different types of music would probably need to be varied." Because hearing aids are generally fitted only by an audiologist, who measures a person's hearing loss and sets the parameters accordingly, additional daily adjustment is not currently an option.

Screenshot by Andy Schmeder



A screenshot from the user-friendly hearing aid adjustment program. Each color represents a group of pre-selected hearing aid settings, creating an auditory "map" that the user can navigate to find his or her optimal settings for music listening.

Eric Battenberg, a graduate student in the Department of Electrical Engineering and Computer Sciences (EECS), hopes to change that with a user-friendly computer program. "The idea is to create an interactive program that allows the user to locate hearing aid settings best tailored to that person's type of hearing loss," he explains. However, hearing aids can have over 70 different settings, which would be a challenge for a user to adjust manually. "You don't want to give people too many parameters to adjust, so it's important to keep the dimensionality of the task very low," says Wessel.

Instead, Battenberg's software starts with just a few combinations of parameters that correspond to common types of hearing loss. The user listens to music with each parameter set engaged and then lays them out on the screen based on their apparent similarity, placing similar sounding sets near to each other and distant ones further apart. These pre-established sets provide landmarks on an auditory "map" that the user can navigate between to find his or her preferred settings. As the user mouses across the screen, the software calculates a set of parameters that is the middle ground between the surrounding sets. When the user settles on a particular location that sounds best, the set of parameters at that location is recorded for subsequent use in a hearing aid.

The researchers wanted to test this technology using subjects with normal hearing, who are accustomed to listening to music on a daily basis, before taking it into tests with the hearing-impaired. To do so, Andy Schmeder created an audio processor that works like a hearing aid. "It basically simulates how a hearing aid operates by amplifying quiet sounds, but without making loud sounds even louder," he explains. "This can be combined with a computerized model of hearing loss in order to give a normal person the feeling of what it's like for the person wearing the hearing aid to be listening to music." Ultimately, the researchers hope to use their technology to augment the fitting of hearing aids. "We don't want to put audiologists out of business, but it'd be nice if people could adjust things on their own," says Wessel. "I could see this happening with an iPhone-like handset with a multi-touch interface, where

Photo by Korbinian Riedhammer

CNMAT Research Director Adrian Freed teaches a workshop on designing and building sensor-based instruments.

you would adjust your parameters from day to day—even while you're sitting in a concert."

Attack of the Martian tritaves

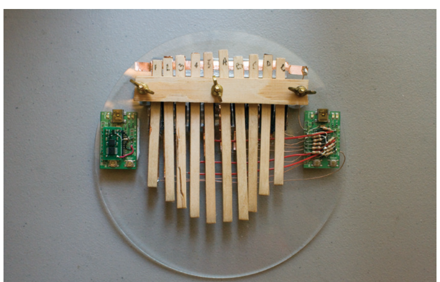
Although some CNMAT thesis projects involve creating a new technique or technology, few PhD recipients can claim to have created an entirely new system of music. But that's exactly what CNMAT researcher Psyche Loui did for her psychology PhD, which she received in 2007. "For my thesis, I asked the question of how humans know what they know about music," says Loui, now a research instructor at Harvard Medical School. Along with Wessel, her thesis advisor, Loui sought to determine how the human brain acquires musical knowledge by studying how people learn an entirely new musical language.

"Most of the music we hear in our everyday lives is composed according to certain rules and principles—for instance, songs belong to a certain key," explains Loui. "And evidence shows that people, regardless of age and musical training, know these rules implicitly." However, is this knowledge a reflection of how the auditory system works, or simply a result of the culture in which you were raised? To address this question, "one could either compare music from other cultures, or look at how old an infant has to be before they demonstrate sensitivity to these musical rules, or you could look at how humans learn a completely new musical system," says Loui. She chose the last option because it allows for tighter control of the experiment—she was able to control the amount of exposure her subjects had to the musical language she created. “My idea was to invent a set of completely new musical rules—‘Martian’ music, if you will—and get people to listen to it, and then test them for what they know.”

To create her Martian music, Loui turned to physics. Most musical systems around the world use the octave scale, which is based on a two-to-one frequency ratio between notes that are one octave apart. Thus, if one note has a frequency of 440 Hertz, the note one octave above is at 880 Hertz, and the note an octave below is at 220 Hertz. Additionally, within the range of an octave, the common Western system has 12 divisions—the notes A through G plus a total of five sharp and flat notes. Loui’s system, however, used a novel scale called the Bohlen-Pierce scale, which is based on a three-to-one frequency ratio between so-called “tritaves.” One tritave above 440 Hertz is three times 440, or 1320 Hertz, and there are 13 divisions within each tritave.

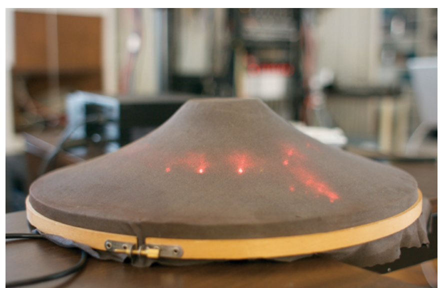
Armed with this new musical system, Loui then had to compose songs to use in her experiments. Fortunately, says Loui, “it turns out that you can compose chords in the new scale and then compose chord progressions by putting these chords together. It sounds unlike any music that anyone is used to, but it still makes sense.” Loui played this music to her experimental subjects (Cal undergrads receiving class credit) for half an hour. She then tested them on what they had heard by playing them the same melodies again, different melodies from the same system, and melodies from the traditional octave system. She was excited to find that, given exposure to a sufficiently large set of melodies, people could not only recognize tritave melodies they had just heard but also identify new melodies that belonged to the tritave system. “Essentially, people demonstrated generalized knowledge of the musical rule, not just rote learning what you played them,” she says. “This suggests that the human brain can rapidly and flexibly pick up on sounds in the environment and learn rules and structures from these sounds.”

Next, Loui examined whether listening to the new musical system elicited the same brain responses as Western music. “Usually, when music doesn’t end the way you expect it to, the brain emits certain electrical signals,” she explains. Loui collected electroencephalograms (EEGs) while subjects were listening to chord progressions in the new musical system. Her goal was to determine whether unexpected chord progressions would elicit the same brain signatures as those from Western music. “We did, in fact, observe the same brain response for infrequent chords in the new musical system, and these responses increased over time,” says Loui. “As subjects sat there listening to the new music, the brain signals became increasingly sensitive to the structure of the sounds, again demonstrating that the brain can absorb the statistics



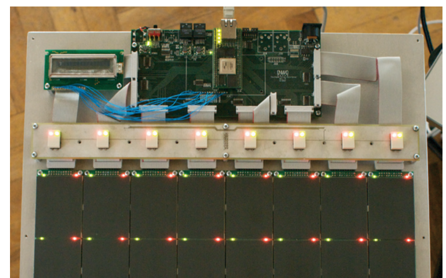
Kalimba
Designed by Adrian Freed

This device was inspired by the African kalimba or mbira, also known as the thumb piano. Typical kalimbas consist of metal or wooden keys of different lengths attached to a hollow box, which amplifies the sound when the keys are plucked. Freed’s device, however, uses wooden keys attached to a round piece of clear plastic. The undersides of the keys are covered with conductive copper tape and piezoresistive fabric that measures how much the player is bending each key. These signals are sent to a computer that creates the sound. Recently, Freed also added a sensor that measures the kalimba’s orientation, allowing the user to change the volume or shift the sound in space by moving the controller.



Tablo
Designed by Adrian Freed

A mathematical curve called the “witch of Agnesi” (a mistranslation), originally studied by the 18th century Italian mathematician Maria Agnesi, was part of the inspiration for this controller. The shape of the device, which consists of electrically conductive silver-plated fabric stretched over an inverted bowl, resembles this curve. The bowl is covered with strips of conductive plastic, so contact between the fabric and the bowl changes the resistance of the strips depending on where the contact occurs. A microprocessor measures the resistance of the sensors and communicates this information to the computer. In addition, pressure-sensitive fabric on top of the bowl allows the device to be played more like a traditional drum. As for the red and green lights shining through the fabric—according to Freed, “they’re thrown in for the Las Vegas effect.”



Photos by Korbinian Riedhammer

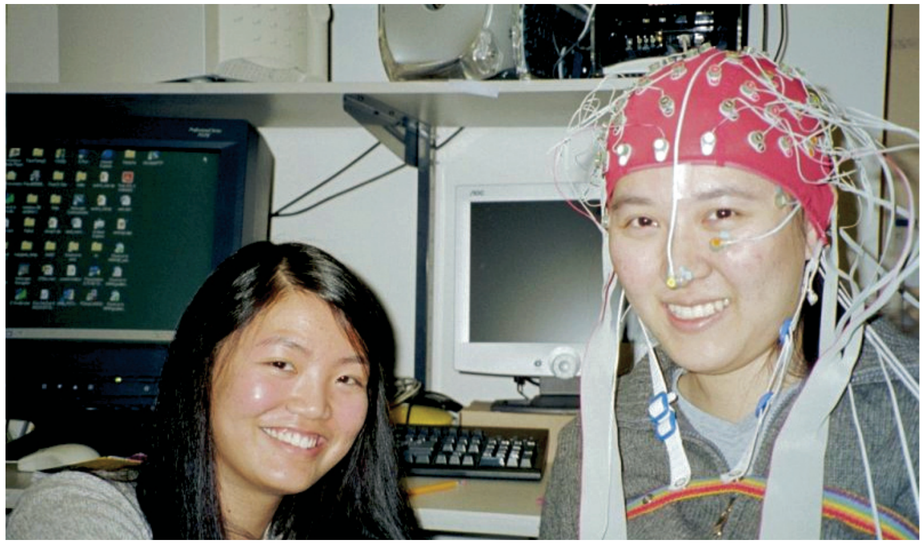
Multi-touch Array
Designed by David Wessel, Adrian Freed, Rimas Avizienis, and Matthew Wright

The multi-touch array consists of a brick wall-like arrangement of 24 square touchpads. Each touchpad allows for a three-dimensional representation of musical material: two spatial dimensions plus a force measurement. The touchpads were created using a similar engineering strategy to the tablo. Each touchpad has four layers: a base, two layers of resistive material oriented perpendicularly to each other, and the touchpad surface on top. When force is applied to the touchpad, the two sensor layers come into contact at the point of applied pressure. This results in a pressure-dependent resistance between the layers at the point of contact and a position-dependent resistance between the point of contact and conductive traces at each edge of the touchpad. By measuring these resistances, it is possible to calculate both the point of contact and the amount of force being applied. This information is sent to a computer, which creates sound based on pre-programmed settings for the x (up-down), y (left-right), and z (pressure) dimensions of each key.

of sounds in the environment and calculate their frequencies."

For her current work, Loui has turned her attention to the neurobiology of "congenital amusia"—otherwise known as tone-deafness. In a recent paper in the journal *Current Biology*, Loui and her collaborators investigated why tone-deaf people, while unable to consciously perceive pitch differences, can nevertheless speak fluently. Her results suggest that the brain has evolved multiple pathways for sound perception and production, such that the pitch information necessary for fluent speech can be acquired separately from the pathways needed to consciously perceive pitch differences.

Photo courtesy of Elaine Wu



Former CNMAT graduate student Psyche Loui (left) and her former research assistant Pearl Chen (right). Loui's thesis project involved taking electroencephalogram (EEG) recordings to better understand how the brain perceives music.

A few final notes

What lies ahead for CNMAT? While most "new music" has yet to hit the Billboard charts, some is now being made available on the CNMAT website, which also holds a library of software for music composition and production developed by CNMAT researchers. "The website is a way of allowing the fruits of what's generated at CNMAT to be shared with the rest of the world," says Campion. "It's there as a trace of our history and demonstrates what we do in both research and creative production." Because all of the software was created using a common programming environment, called Max/MSP, musicians around the world can use the software and even design their own applications to contribute to the website.

Indeed, while CNMAT researchers remain on the cutting-edge of research in a wide array of disciplines, serving the musician remains their primary goal. "In some ways, I'd rather have called it the Center for New Music and Musical Science," says Wessel. "We like to develop technology, but it's really the music that is driving everything. We want to serve composers, serve the musical imagination." And that imagination, it seems, is limitless.

Meredith Carpenter *is a graduate student in molecular and cell biology.*

Want to know more? Check out:
cnmat.berkeley.edu

The Evolution of Music

Walking around the UC Berkeley campus between classes, it seems nearly everyone is wearing headphones. Although tastes may vary widely, we see music everywhere, in all cultures. How did this fundamental part of the human experience evolve?

"There's always been a debate about whether or not music serves any adaptive purpose," says Professor David Wessel, whose background is in mathematical psychology and who is interested in these basic questions about the evolution of music. Wessel disagrees with Harvard psychologist Steven Pinker, who, in his famous book *How the Mind Works*, said music is a side effect of evolution—"auditory cheesecake, an exquisite confection crafted to tickle the sensitive spots of…our mental faculties," but not adaptive in itself.

"In my view, music certainly played a role in how language evolved, and particularly the way emotional states are communicated one to another," says Wessel. "I would also say that music functions in bringing people together and promoting social cohesion." Steven Mithen, professor at the University of Reading and author of the influential 2006 book *The Singing Neanderthals*, also disagrees with Pinker's hypothesis, as do many other researchers in the field. "Mithen pronounced the auditory cheesecake idea as 'daft' at the neuroscience and music meeting in Montreal this summer," says Psyche Loui, a former CNMAT graduate student who studies how the brain processes music. "The audience applauded after the word 'daft.'"

Mithen hypothesizes that music and language both evolved from a common proto-language used by Neanderthals and the ancestors of modern humans. He calls this communication system "Hmmmmm," which is actually an acronym that stands for Holistic, manipulative, multi-modal, musical, and mimetic. Essentially, this form of communication (not yet a "language") was composed of messages rather than words, often accompanied by gestures, and had characteristics of music like pitch and rhythm. Unlike traditional depictions of early human language that consist of words without grammar ("me make fire"), Hmmmmm consisted of phrases with more complete meanings that were later segmented into discrete words. Birds use a similar system of communication, using different calls for different situations—the calls each have meanings meant to manipulate the behavior of other birds, though you wouldn't call them a language.

But that may not be the whole story. As Darwin first suggested, sexual selection may have also been involved (data from Mick Jagger certainly support this hypothesis). "From birds to mammals, song seems to play a role in the whole sexual game and mating," says Wessel, and Mithen agrees that sexual selection could have spurred the evolution of the musicality of Hmmmmm. Other factors, such as the ability of music to pacify infants, may have also played a role. Though many of these hypotheses are difficult to test empirically, people will surely continue to theorize about music's origins for years to come. "As neither the enjoyment nor the capacity of producing musical notes are faculties of the least use to man," wrote Darwin, "…they must be ranked amongst the most mysterious with which he is endowed."

COME

Students power the Berkeley Energy Resource Collaborative

TOGETHER

by Sharmistha Majumdar

Three years ago, a group of graduate students at the Haas School of Business were sitting around talking about energy-related issues. The topic turned to the unique advantages of living in Berkeley—one of the most environmentally aware cities in the United States—and even in California, whose state government has a long history of leading "green" crusades. The Bay Area is well known for its institutions of higher learning and research and its culture of entrepreneurship and innovation. But there did not seem to be an active effort to bring all these people, research, and resources together. The Haas students, led by Will Coleman, decided to take up the challenge of setting up a collaborative, bridging the gap between the venture capitalist and the scientist, the policymaker, and the entrepreneur. BERC was born.

BERC, or the Berkeley Energy and Resources Collaborative, has since grown to become one of the most active student organizations at UC Berkeley. The group unites students from the School of Law, the Goldman School of Public Policy, and the Haas School of Business with researchers and engineers on campus and at Lawrence Berkeley National Laboratories (LBL). Outside campus, BERC strives to connect to the Bay Area's fast-expanding "cleantech" cluster (companies interested in alternative and clean energy technologies) to foster productive applications of university research.

Image courtesy of Sebastian Celis

The student-run BERC encourages collaboration through roundtables, lectures, and an active online discussion forum and increasingly sponsors interdisciplinary projects. The group is also engaged in community outreach through its SEED (Students for Environmental Energy Development) program, which creates activity- and project-based curricula taught at local middle and elementary schools.

BERC's biggest annual event is an energy symposium that brings together leaders in energy from the public and private sectors, the arts, and the sciences. This year's symposium, "Leadership at the Nexus of Science, Policy and Business," featured speakers from UC Davis and Stanford, as well as BP (formerly British Petroleum), Chevron, and Khosla Ventures, a local venture capital firm. Panels and poster sessions covered topics ranging from biofuels, nuclear power, and green building technology to the global dimensions of sustainable energy.

On a day-to-day basis, the members of BERC participate in an equally diverse array of research and public policy programs. In this feature, we profile several projects on campus that have taken advantage of connections made through BERC.

EBI and Biofuels

Jerome Fox, a second year chemical engineering PhD student and BERC member, works at the newly formed Energy Biosciences Institute (EBI). The EBI represents a unique collaboration between UC Berkeley, LBL, the University of Illinois, and BP. BP will support the Institute with a 10-year $500-million grant.

Fox is working on the kinetics of lignocelluose breakdown, the molecule that gives strength and structure to plant cell walls and happens to be most abundant organic material on the planet. Lignocellulose, which is made up of sugar chains and the complex biopolymer lignin, is highly resistant to degradation due to the strong bonds between the sugars and the lignin. However, if it can be broken down to simpler sugars, it has a great potential to be an energy source. The energy would come from the fermentation of those sugars to produce carbon-neutral biofuels like ethanol. This is especially promising, because unlike other biofuel crops like corn, plants with high lignocellulose content cannot be digested by humans, so there is no competition with the food supply.

Fox aims to unravel the difficult problem of extracting simple, fermentable sugars from lignocellulose. He is studying the mechanism of action of cellulase, the naturally occurring enzyme that catalyzes the breakdown of cellulose, the complex sugar portion of lignocellulose. Fox, along with his colleagues, is trying to engineer new cellulase enzymes that are more efficient. They also hope to develop quantitative assays that will allow them to dissect the steps of the cellulose breakdown reaction. If successful, these EBI scientists could help create a new generation of cellulose-based biofuels that have the potential to decrease the over-dependence on fossil fuels in much of the developed world.

—*Want to know more?*
Check out: sciencereview.berkeley.edu/articles/issue12/renewableenergy.pdf

Image courtesy of Jim Frazier

Scientists hope crops like switchgrass can provide a rapid-growing, inexpensive source of biofuel derrived from lignocellulose.

ARUBA in Bangladesh

Arsenic is a well-known poison, which at high doses causes violent stomach pains, vomiting, delirium, and death. At lower doses it is a carcinogen. The groundwater in many parts of the world has very high concentrations of naturally occurring arsenic. Bangladesh is one of the most severely affected countries, with groundwater arsenic levels reaching as high as 1,000 parts per billion (ppb), a hundred times higher than the EPA standard of 10 ppb. This has led to a massive epidemic of arsenic poisoning, affecting almost 70 million Bangladeshis.

For the past few years, scientists at LBL and UC Berkeley have sought simple solutions to this problem. Aided by a grant from the campus-based Blum Center for Developing Economies, a multi-disciplinary team including many BERC members was formed. An international collaboration was also set up with scientists at the BUET (Bangladesh University of Engineering and Technology) in Dhaka, the capital of Bangladesh. Members of the Berkeley group, including Johanna Mathieu, a PhD student and BERC member and Kristin Kowolik, a chemistry undergraduate, both from Ashok Gadgil's group at LBL, visited Bangladesh to investigate the problem firsthand. Gadgil is a senior scientist and Deputy Director (Strategic Planning) of the Environmental Energy Technologies Division at LBL and an adjunct professor in the Energy and Resources Group

Since the arsenic problem was identified, a range of technological solutions have been tried to solve the crisis. Many of these solutions have been effective, but are either too difficult or too expensive to implement on a large scale. Mathieu and Kowolik have come up with a novel solution. Around five years ago, the Gadgil group realized they could exploit arsenic's inherent affinity for ferric hydroxide (an oxidized form of iron, also a component of rust) to remove it from water. The problem then became finding a low-cost surface on which to put the ferric hydroxide. They decided to investigate the potential of bottom ash, a non-toxic waste product of coal mines. Bottom ash is sterile, as the coal is usually baked at 800° C, and, more importantly, is present in abundance in Bangladesh and adjoining India.

Bottom ash turned out to be a great material. Working in their lab at the LBL, Mathieu and Kowolik optimized the conditions for linking ferric hydroxide to the bottom ash. When the material was mixed with arsenic-laced water, the ferric hydroxide bound to the arsenic to form insoluble complexes that could then be filtered out of the water. The arsenic concentration in the filtered water dropped a drastic 250-fold, making the water safe to drink. Since then, the group has modified the process slightly; instead of removing the arsenic compounds from water with a filter, which would eventually clog up and have to be maintained or replaced, they found that safe drinking water could be obtained by simply allowing the particles to settle over time. A device called a clarifier can then be used to allow water to flow from the bottom to the top of the container, thereby ensuring that by the time the water gets to the top it is clear and safe to drink.

The Berkeley scientists named this simple but innovative technology ARUBA (Arsenic Removal Using Bottom Ash). They have tested the power of their material in the field with great success. Currently, they are planning to build a community-based prototype for large-scale filtration of drinking water using the ARUBA technology. Kowolik, who just graduated from UC Berkeley with a bachelor's degree in chemistry, has seen ARUBA grow over the past two years. She says this project allowed her to better understand the "human aspect of a technological problem," as well as gain technical expertise. "It was very fulfilling to put my knowledge to immediate good use," Kowolik says with a smile.

Want to know more? Check out:
arsenic.lbl.gov

Darfur cook stoves

Several members of BERC are working on technology directed toward relieving humanitarian crises using relatively simple technologies. One such crisis was the scarcity of cooking fuel in refugee camps in Darfur, Sudan. Refugees often travel miles from the safety of the camp in search of wood for fuel, facing the constant risk of rape and violence in order to cook dinner. In 2004, the US Agency for International Development called Ashok Gadgil. Could LBL scientists help Darfur refugees make the most of their limited fuel resources?

The members of Gadgil's research team, many of whom are associated with BERC, have a long history of coming up with simple but creative innovations to solve acute environmental problems in the developing world. The Gadgil team set out on a fact-finding expedition to Darfur to investigate the problem. The Sudanese have always cooked in round pots on traditional three-stone fires. These fires, however, are very inefficient, as most of the heat generated by the burning wood does not reach the pot and instead escapes through the sides of the stove. The scientists realized that they could help the Sudanese make better use of their fuel wood by creating a more efficient stove. But the solution would have to be practical in a refugee camp with minimal resources.

Returning to Berkeley, they got busy with the task at hand: building a low-cost, fuel-efficient stove. The aim was to come up with a stove on which the two common sizes of traditional Sudanese pots would fit snugly. This would help maximize heat transfer from the burning wood to the pot and decrease the heat dissipation that was characteristic of the three-stone fires. Moreover, the structure of the stove should contain the flames and ensure that the oxygen supply is adequate but controlled. "We have so much knowledge of science and engineering at our fingertips," Gadgil says, "but many desperate problems of people living at the bottom of the economic pyramid are easily solvable by application of what we have known for years and taken for granted."

The Gadgil team researched the design of various fuel-efficient stoves from other parts of the developing world but had to come up with something that would function best in Darfur's present circumstances. They used basic principles of engineering, their first-hand knowledge of the conditions in the field, and old-fashioned trial and error to make prototype stoves out of scrap metal. After a few months they had a model. Built using a dozen pieces of bent metal and a cast-iron grate, the stove significantly improved combustion and energy transfer and used 75 percent less wood than a cooking fire. The stoves fit traditional cookware and also shielded the fire from strong winds.

The stoves cost about twenty-five dollars, should last at least five years, and most importantly, were an instant hit in Darfur. "We didn't have to discover anything fundamentally new and none of our work involved any breakthrough in basic science or engineering," Gadgil says, "but we have engineered the technology to help this particular population cook their traditional food using locally available fuel."

Image courtesy of Michael Helms

Presently, the Gadgil group is exploring possibilities of large-scale assembly of these stoves in Darfur itself. This would simplify the process of getting the stoves to people that need them and also foster the prospects of income generation for the local population. Using the BERC network, they have set up collaborations with the engineering and business schools on campus. Currently, the group is trying to set up a supply chain for IKEA-style flat-pack kits for the stoves. The kits consist of pre-cut sheet metal parts made with a mechanical stamping press that can be assembled into a stove with hand tools. If successful, production time as well as dimensional errors will decrease significantly compared to the current method of building the stoves from scratch with hand tools.

"One of the biggest lessons we learned was that tackling many of the problems that afflict the developing world is very different from trying to crack, say, the protein folding problem, " Gadgil says. "The solutions need to be practical, scalable, but immediate and affect the present population rather than some futuristic product which could affect the lives of people three generations later."

Want to know more? Check out:
http://darfurstoves.lbl.gov/

Artificial Photosynthesis

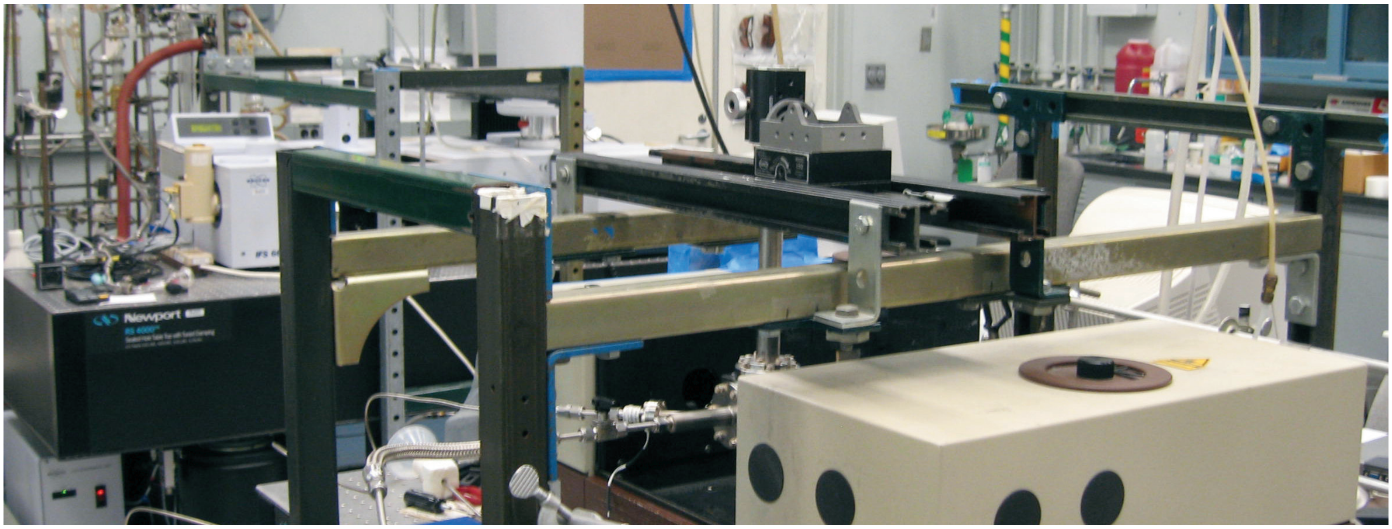


Image courtesy of Heinz Frei

Frei's lab space is a tangle of photochemical and spectroscopic tools tasked with studying the fundamental principles of photosynthesis.

Photosynthesis, one of the most important biochemical processes in nature, allows plants, algae, and some bacteria to convert light energy from the sun into chemical energy that can be stored. Heinz Frei's research group in LBL's Physical Biosciences Division is particularly interested in how this works. During photosynthesis, sunlight is used to convert water and carbon dioxide from the air into oxygen and sugars. Chlorophyll, the pigment that gives leaves their green color, plays a vital role in this process. This molecule has the ability to release electrons when stimulated by light. Those electrons, through a cascade of complex reactions, eventually promote the conversion of carbon dioxide to energy-containing sugars. Chlorophyll, meanwhile, regains its lost electron from a water molecule, which is broken down to release oxygen. The end result is the simultaneous production of life-supporting oxygen and chemical energy and reduction of the greenhouse gas carbon dioxide—the ideal "green" reaction.

It's no surprise, then, that scientists interested in renewable energy have long tried to understand the details of the complex reactions that occur during photosynthesis, with the ultimate goal of recreating the process on an industrial scale. If successful, these artificial photosynthetic units could mimic the natural photosynthesis process and even improve its efficiency. But first, they must answer some basic questions: How do you reduce carbon dioxide? How do you split water to produce the electrons that can be used as fuel? And how do you efficiently combine these processes in a synthetic system?

Frei's group has set out to tackle these questions. Their experimental set-up consists of metal-to-metal charge-transfer (MMCT) units that are made up of two metal atoms connected by an oxygen atom. The metals in the MMCT unit take on the role of chlorophyll in nature, absorbing visible light and releasing electrons. Other inorganic molecules (photocatalysts) in the system accelerate the electron transfer reaction. Both the MMCT units and photocatalysts are assembled on a solid support. The Frei lab has successfully demonstrated units that can oxidize water to oxygen (the Chromium-Oxygen-Iridium unit) or reduce carbon dioxide (the Zirconium-Oxygen-Copper unit) in the presence of visible light.

A major advantage of the MMCT techology is that it is "a flexible and very tailorable method for assembling and coupling photocatalysts," says Tanja Cuk, a BERC member and postdoctoral fellow working in the Frei group. Currently, the lab is synthesizing new MMCT units using a variety of metals and photocatalysts to identify the most efficient combination. Cuk, a physicist by training, is studying light-driven electronic and structural reorganization of the MMCT units. Her studies will be crucial for designing more efficient systems in the future.

Want to know more? Check out:
pbd.lbl.gov/about/people/frei.htm

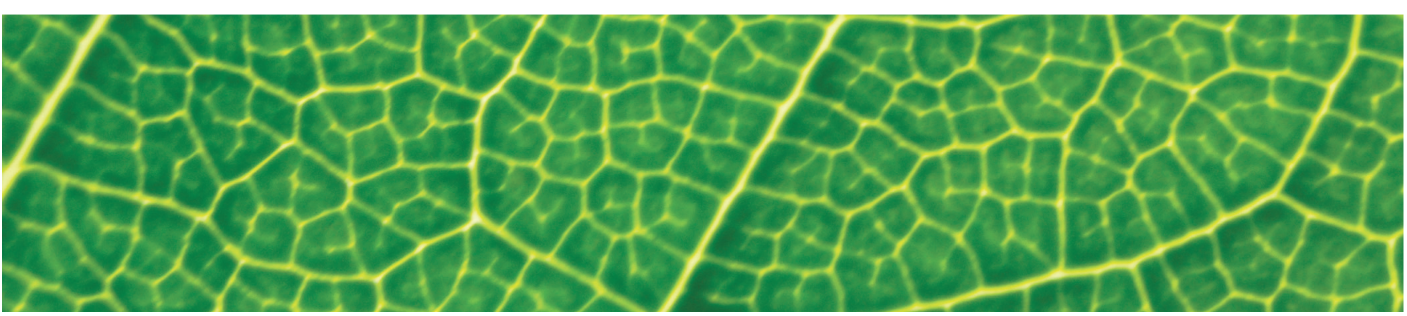


Image courtesy of Dave Campbell

The Road Ahead

BERC has already accomplished much in the few years since it began from a conversation between students. Where, then, does it see itself in a few years? Jit Bhattacharya, a recent Haas graduate and former BERC co-chair, says that BERC "is great at education right now but should definitely concentrate on solutions in the future." The group should help research labs on campus "orient themselves towards more creative solutions," he adds.

He highlights the example of the Photovoltaic Idea Lab, which is a successful collaboration amongst various on- and off-campus groups with a shared interest in developing a new generation of low cost photovoltaic solar cell technologies. Bhattacharya, himself a budding entrepreneur, recently formed a start-up company called Hum Cycles. The company aims to use lithium-ion battery technology to manufacture high-performance electric motorcycles that can run up to 150 miles on a single charge using no petroleum. The Hum Cycles team is made up of a bunch of like-minded engineers and entrepreneurs who met at a local clean-tech conference and decided to take the proverbial plunge after a few brainstorming sessions. In the future, BERC hopes that it can help many more members make the right connections and take off on the best path right after graduation.

The vision, spirit, and enthusiasm of the students who form BERC has lead to significant successes in many areas. In particular, by acting as an umbrella organization, BERC has initiated dialogue between students, faculty, and those in need to facilitate the development of practical, green-technology that can be moved from "lab to land" and ensure a safe and sustainable future.

Want to know more? Check out:
berc.berkeley.edu/ and http://berc.berkeley.edu/?q=symposium

—**Sharmistha Majumdar** is a postdoctoral fellow in molecular and cell biology.

Image courtesy of Cyron Ray Macey

Eran Karmon Editor's Award

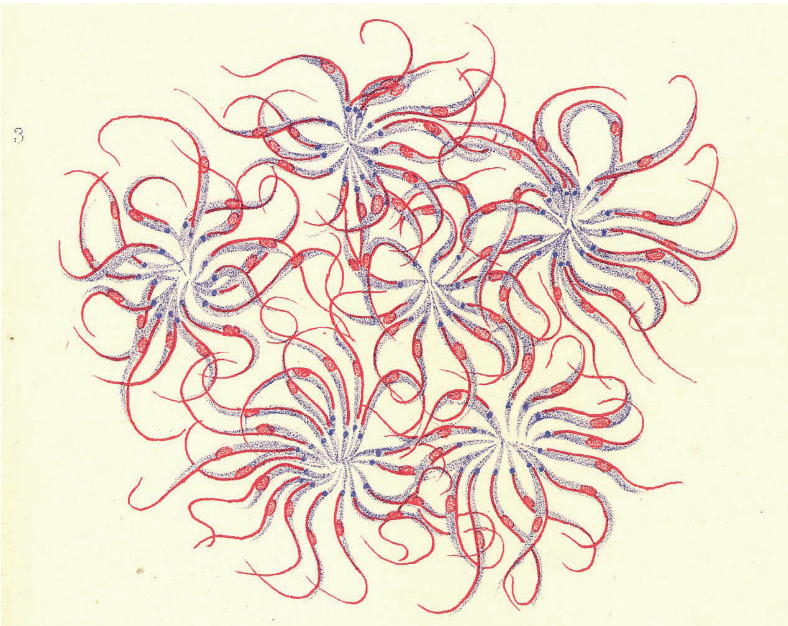
In memory of Eran Karmon, co-founder and first Editor-in-Chief of the *Berkeley Science Review*. This award is given annually to the Editor-in-Chief of the *BSR* thanks to a generous donation from the Karmon family.

Neglected No More:

Tropical disease research at UC Berkeley

by Niranjana Nagarajan

Image courtesy of Laboratoire de Biologie Parasitaire, Paris



An early drawing of trypanosomes by French microbiologist (and Nobel Prize-winner) Alphonse Laveran.

YOU GET BITTEN BY A TSETSE FLY, FALL ILL, THEN FALL ASLEEP AND NEVER WAKE UP.

Sleeping sickness is a scary disease, right out of a horror film. Or somewhere, somehow, you breathe in one bacterium, called *Mycobacterium tuberculosis*, and you're stuck with it for life. It lives inside your body, hiding and protecting itself until the right moment, when it starts to multiply, ravaging your immune system.

Sleeping sickness, or human African trypanosomiasis, affects close to 500,000 people a year in Africa, killing 66,000. In 2006, 14.4 million people worldwide carried tuberculosis; 1.5 million died from it. And still, these diseases are neglected, largely under-represented in the academic world of medical research. UC Berkeley stands out, despite having no medical school, with a host of research programs on campus working on finding treatments and vaccines for neglected diseases.

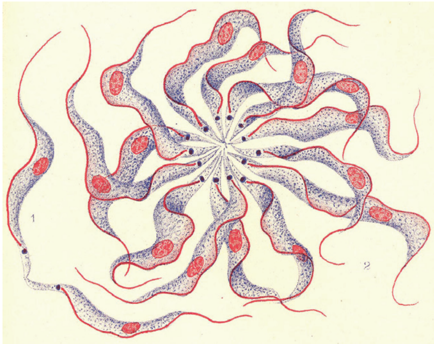
Targeting trypanosomes

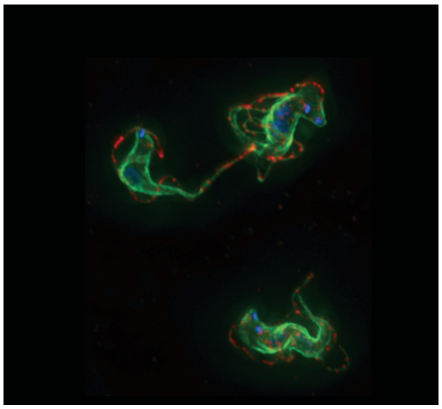
UC Berkeley professor Matt Welch, in the Department of Molecular and Cell Biology, works on identifying new drug targets in trypanosomes, the parasites that cause sleeping sickness and Chagas' disease (American trypanosomiasis, a disease prevalent in Central and South America in which a similar parasite causes damage to the heart and digestive tract). Welch's lab studies the cytoskeleton, a framework of proteins that holds cells together and gives them their structure. A few years ago, Robert Douglas, then a consultant for Cytokinetics, a biotech company specializing in drugs that target the cytoskeleton, approached him about setting up a research program to identify possible drug targets in trypanosomes. "[Douglas] decided that he wanted to work in neglected diseases," Welch says, "and he couldn't do that in the context of the biotech industry," because "that's not something the biotech companies are interested in, because there's no money to be made." As a result, Welch and his lab entered the realm of neglected disease research.

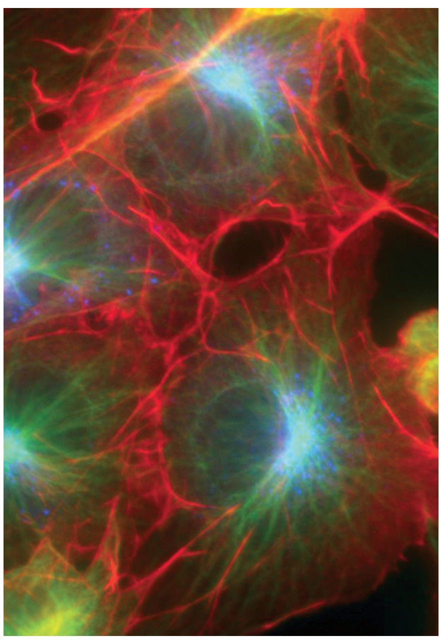
The cytoskeleton maintains cell structure by forming a complex network of interconnected strings of proteins, called filaments and tubules. These filaments and tubules also serve as intracellular highways, along which many essential components move from one part of the cell to another. As a result, drugs that disrupt the trypanosome cytoskeleton could potentially make good therapeutics for sleeping sickness and Chagas' disease. Unfortunately, the major components of trypanosomes' cytoskeletons are extremely similar to our own, so such drugs would be toxic to us. Instead, a sub-family of cytoskeletal proteins, called kinesins, might make better drug targets since they vary a lot more between humans and trypanosomes. If the cytoskeleton forms cellular highways, then kinesins, or motor proteins, are the trucks that transport essential materials via this network.

At the same time that Douglas and Welch began collaborating, the trypanosome genome sequence was released. An examination of the sequence yielded a surprising result: trypanosomes have about 45 kinesins, an unusually large number (almost as many as humans have, unlike yeast, which has six). Together with UC Berkeley professor Zac Cande and then postdoctoral fellow Scott Dawson, they analyzed these 45 genes and were surprised again: while many of the trypanosome kinesins fit easily into previously defined families, some of them appeared entirely unique, and some that Welch and Douglas thought would be necessary for cell division (and therefore good drug targets) were missing.

"So that left us with the more difficult task of trying to identify what kinesins might







Top: *Another early drawing of a trypanosome.*
Center: *A more modern view of trypanosomes taken with a light microscope. The cytoskeleton is stained in green and the nucleus (DNA) is stained in blue.*
Bottom: *The cytoskeletal filaments inside a cell, labelled with a red fluorescent tag.*

be important for the physiology of trypanosomes and that would also represent drug targets," says Welch. The researchers have been going about the process methodically, blocking the production of each of the 45 kinesins one by one and determining which are essential for the trypanosomes' survival. So far, they have found four that affect trypanosome survival and are following up on one particularly promising target.

When this kinesin is blocked, the trypanosome swells and eventually dies, apparently unable to divide. They cut the candidate kinesin into pieces, hypothesizing that it was the actual motor portion of this motor protein that was essential. Neatly enough, Cytokinetics, the company that Douglas consulted for, specializes in making small molecules that target this motor activity and is now screening their chemical libraries for compounds that inhibit this particular piece of the trypanosome kinesin.

Welch believes that this joint venture between his lab and Cytokinetics "speaks to the desire of biotech companies, even when it's not something directly in their product line, to participate in work like this, to try to identify drugs for these neglected diseases, even though they wouldn't be involved in marketing the drugs ultimately. The vision is [that] the company is a collaborator in this process and we've negotiated a situation where there are not a lot of intellectual property constraints on compounds that would come out of these particular studies."

Controlling tuberculosis

Trypanosomes are disease-causing organisms that live outside host cells, making them extracellular pathogens. Intracellular pathogens are disease-causing organisms that enter the cells of our bodies and live there, flying under the radar of the host immune system. "[Intracellular pathogens] are particularly hard to make vaccines against because they hide inside host cells," says Professor of Molecular and Cell Biology Tom Alber, who studies *Mycobacterium tuberculosis*, the bacterium that causes tuberculosis and an intracellular pathogen.

Humans have been suffering and dying from tuberculosis for centuries. One of the enduring mysteries of *M. tuberculosis* concerns its unique life cycle—it infects and lives untouched inside host cells called macrophages, which just happen to be important members of the host immune system. Macrophages are hungry cells, floating through the body and sampling their surroundings by swallowing pieces of whatever is around. Anything the macrophage swallows, including lurking *M. tuberculosis*, ends up in a special compartment called the phagosome. The cell generally fuses the phagosome with another cellular compartment called the lysosome. Lysosomes are centers of cellular destruction, with highly acidic interiors and a plethora of destructive enzymes. Once a phagosome fuses with a lysosome, the contents of the phagosome are chewed, corroded, and cut up into oblivion. *M. tuberculosis* neatly sidesteps all this destruction by blocking the fusion of its resident phagosome with lysosomes.

Lisa Prach, a fifth-year graduate student in the Alber lab, is interested in how exactly *M. tuberculosis* blocks phagosome-lysosome fusion. Her research was inspired by a study from a group at Cornell University that randomly deactivated genes in the bacterium and looked for those that were necessary for phagosome-lysosome fusion. One of the genes identified encodes an enzyme called diterpene cyclase, necessary to make a class of lipids called diterpenes, which seemed out of place in a bacterium. "This is a pretty crazy class of enzymes," Prach explains, "because they are really common in plants, and there's only one bacteria known to even encode this sort of thing. It's really unusual for TB to have something like this." *M. tuberculosis* makes this unique, unusual lipid and also carries out the really unusual function of blocking phagosome-lysosome fusion. Extend the thought to the observation that the enzyme that makes this unusual lipid is necessary for the unusual function of the bacterium, and you may have a big clue to the big mystery of how the bacterium actually blocks phagosome-lysosome fusion.

Prach then noticed that the different strains of *M. tuberculosis* used in the Alber lab, some of which are more virulent than the others, have different levels of diterpenes. She hypothesized that the amount of diterpene produced by the *M. tuberculosis* strains may affect virulence. So she is now in South Africa, with a travel fellowship from UC Berkeley's Center for Emerging and Neglected Diseases, in a lab that studies the epidemiology of tuberculosis. In South Africa, the Van Helden lab and collaborators have collected about 20,000 *M. tuberculosis* samples from patients in clinics outside Cape Town and in other parts of South Africa. They have detailed records of the important properties of the strains they have collected—what specific

Images courtesy of Laboratoire de Biologie Parasitaire, Paris; Robert Douglas; Ken Campellone sub-type of bacteria they are, how they behave in mouse infection, whether the patients cleared the bacteria, and whether the bacteria were drug resistant. Prach wants to find out if she can "correlate the levels of different lipids, specifically diterpenes, in these various strains with disease progression and disease outcomes." Specifically, she wants to know if the diterpenes in *M. tuberculosis* are related to the virulence and drug-resistance of the bacteria.

Other work in the Alber lab deals with how *M. tuberculosis* signals to the host cell to leave it alone in its phagosome home. One of the best-known systems of signaling in mammals is the kinase phosphatase system. Enzymes called kinases (not to be confused with kinesins) add a specific chemical group, called a phosphate group, to proteins, which switches them on. Phosphatases, by removing phosphate groups, serve as off switches. Alber says that nothing was known about these systems in bacteria before his lab started their research. "What we're interested in is, what are the signals the bacteria sense, how does that signal from outside the cell switch on the kinase on the inside of the cell, and once the kinase is switched on, how does it change the physiology of the cell."

So what turns on the kinases? The Alber lab has showed that the kinases themselves, in *M. tuberculosis* and other bacteria, were switched on by pairing with each other. These kinases went on to turn on a number of other proteins in the bacterium, among them some called sigma factors, which decide what genes will be turned on and when. These proteins could be promising drug targets, given that they have functions that are so essential for bacterial life.

Another exciting potential drug target is a sugar export channel in the bacterium. Deleting this channel entirely is lethal for the bacterium, and a partially defective mutant is immediately recognized and cleared by an infected mouse, unlike intact bacteria. Alber points out that of all the proteins in *M. tuberculosis*, "this [channel] is among the 20 that the bacterium most requires the function of." The Alber lab has data that suggest a bacterial kinase may be controlling the activity of the channel. "We're trying to discover, how does the channel change when phosphorylated? What does the channel do? What does it export? And what on the outside controls this export?"

"We're hopeful that they'll support the development of a new drug and we'll see how far we can take it."

How promising is this protein as a drug target? Alber says, "We just made a presentation to the Global Alliance for TB drug development. We're hopeful that they'll support the development of a new drug and we'll see how far we can take it."

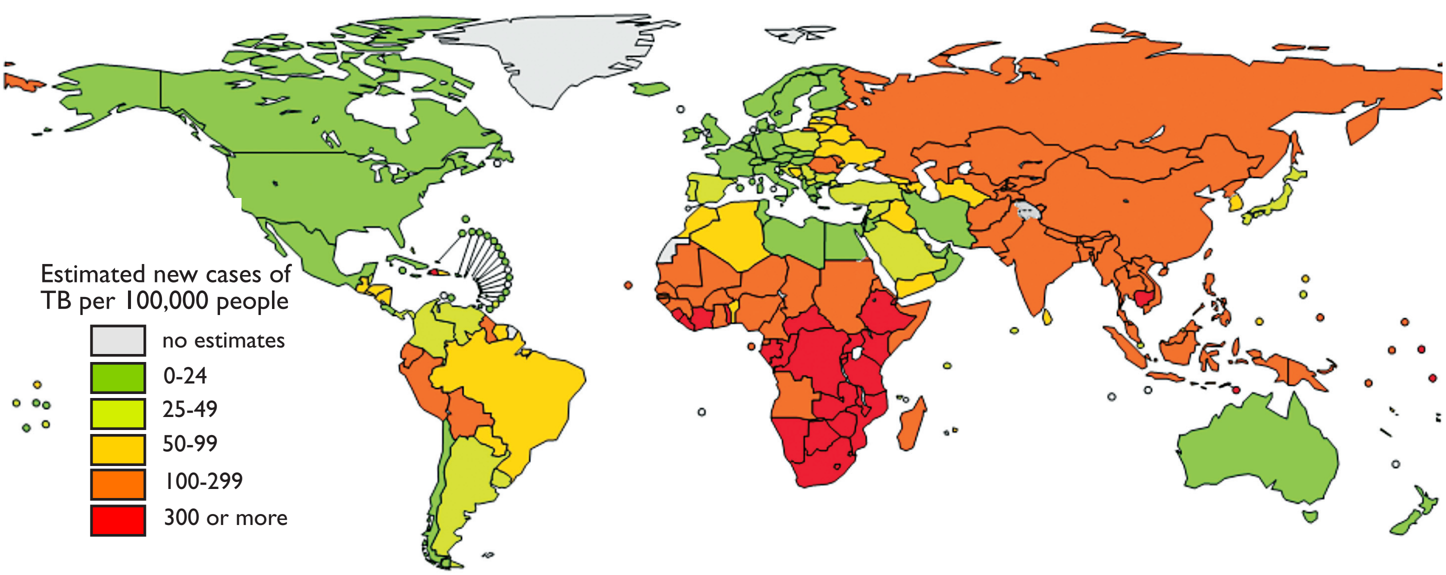
The Center for Emerging and Neglected Diseases

Given that there is such good, relevant research on neglected diseases on campus, it is surprising that UC Berkeley is not very well known for this kind of work. Part of the reason is that many of the labs on campus that work on aspects of neglected diseases are found in different departments and physical locations.

What the UC Berkeley campus needs is a way to enable researchers from different departments, but with shared interests in neglected diseases, to find each other and potentially work together. The Center for Emerging and Neglected Diseases (CEND), which officially opened in May of this year, aims to do exactly that. CEND is a coalition of campus researchers from 12 departments and colleges whose mission is to promote the development of better "health outcomes" for people that suffer from neglected diseases.

The new approach is multidisciplinary. Alber, the director of the new center, explains that CEND's function is "to bring people together that work on different pathogens to look for common mechanisms of disease, common solutions to diseases. And to bring people together from different fields so we can come up with innovative solutions for the problems each person is facing within their research on a specific disease."

Temina Madon, the executive director, tells the story of CEND's origins. In 2005, Professor W. Geoffrey Owen, then Dean of Biological Sciences, set up a series of community meetings with anyone interested in neglected diseases. More people attended each successive gathering, until, Madon says, "eventually they reached a large enough community on campus that it was decided to start



Graphic courtesy of World Health Organization

The World Health Organization's estimated incidence of tuberculosis worldwide in 2005. Colors represent the estimated frequency of new cases of tuberculosis per year.

The worldwide population affected with TB. Of every 100 people worldwide, 32 are carriers of TB (orange), seven of whom will die from it (red).

Graphic by Katie Peek

raising funds for a Center, to identify priorities, programmatic activities, and needs of the research community on campus."

Now, "CEND is bringing big discovery science into global health," says Madon. She says CEND has three primary goals: stimulating innovative basic research into potential drug targets; training, of both Berkeley students and students from developing countries; and translating basic research into drugs for neglected diseases.

Research, training, and translation

Drug discovery is a complex process, starting with basic research that identifies suitable drug targets, followed by validation of these potential targets, and culminating in the development of the medicine to treat a disease. UC Berkeley is a large campus, with many diverse areas of research, and as such is well qualified to carry out all the steps of the drug development process—biological research into the hows and whys of a disease, chemistry research into innovative ways of making drugs, and a pioneering approach to intellectual property, embodied in its humanitarian licensing policy, all on the same campus. CEND facilitates contact between researchers who have similar interests but may not have encountered each other otherwise. To this end, CEND has recently set up an infectious disease supergroup, where campus researchers can get together to discuss their research interests.

Another aspect of CEND's mission is training, both of Berkeley students and of students from developing countries. As Madon says, one of the aims of CEND is "to create biological scientists coming out of UC Berkeley who understand not just basic science but also [have] an understanding of intellectual property and how that affects access to the medicines, vaccines, diagnostics they may one day produce. We also want these Berkeley students to have had some experience working in developing countries so that they understand the unique challenges that you might face in developing a treatment or pursuing a research program that has impact in those settings."

CEND also has programs to promote collaboration between Berkeley researchers and students in other countries, with programs involving the Indian Institute of Technology (IIT) and the South African Center for Excellence in Epidemiology Modeling and Analysis (SACEMA). This summer, 11 students from the IIT spent some time at UC Berkeley in CEND and Energy Biosciences Institute labs researching neglected diseases and biofuels. SACEMA was originally founded by UC Berkeley School of Public Health Professor Wayne Getz independently of CEND, but it is now affiliated with CEND. SACEMA trains African mathematics students in epidemiology, and, as Madon says, "what's nice and unique about it is that it's not the extractive mining approach to research, where you collect data from the country but you take the data out of the country and model it in your lab in the US…you're actually empowering people locally to do the same kind of research that you do in collaboration with you."

> "We're trying to bring new resources to campus to help people engage in the kind of research that they want to, when there isn't a lot of funding."

Finally, an important function of CEND is actually getting potential drug candidates out into the market. While both Welch and Alber have established potential ways to transfer their research to a clinical setting, it is not as easy for many other academic researchers. Madon describes one of her roles as facilitating the interaction between the researchers who come up with the drug targets and the companies that would end up manufacturing them: "We've sort of relied on Pharma or Biotech to come to us and say 'Oh, we liked that patent and we want to license it,' but now CEND, working with [UC Berkeley's intellectual property guru] Carol Mimura, is trying to create that glue between private sector, non-university, non-ivory tower players and campus people who are interested in moving their research into the world where it will have an impact. We are actually shopping our intellectual property around, instead of waiting for companies to come to us."

CEND also enables researchers to get feedback about the relevance of their research. The Drugs for Neglected Diseases Initiative (DNDI) is a non-profit product development organization that promotes not-for-profit partnerships between private industry and academic research that leads to drugs for neglected diseases. Feedback from industry in the early stages of research is useful, and CEND has organized meetings between DNDI and researchers who may have potential drug targets where DNDI members had suggestions to make UC Berkeley research more relevant to treatment of neglected diseases.

Money, money, money

As is often the case, finding funding is a major challenge for individual researchers, which CEND aims to address. "In part, I think CEND is trying to help raise funds so faculty don't have to spend time on the administrative part of global health research," says Madon. She also sees a role for herself in helping campus researchers with research proposals to the NIH and other agencies and simultaneously "making clear to NIH that there is an interest in neglected tropical diseases and that UC Berkeley has a program in it and that we'd like to see enhanced funding [for] it."

For now, CEND is funded by a private donor. The money supports students like

Consumptive Vampires

Consumption, as tuberculosis was called until the 20th century, caused its victims to hack, cough up blood, and waste away until death eventually caught them, sometimes years after their initial symptoms.A century-long epidemic made consumption the leading cause of death in rural 19th century New England. It was a mysterious disease that claimed its victims slowly, creeping through a household and targeting family members one by one, often after the first patient succumbed. The mysteriousness of consumption contributed to many superstitions including vampirism—the belief that the deceased "consumed" the living from the grave.

The New England vampire myth seems to have its roots in the Eastern European vampire tradition (Transylvania, anyone?) but was less spooky—no undead emerging from graves at night to suck the blood of the living, but rather a more mystical "sucking" of the life force. If family members of the deceased fell ill and died of consumption, an occasional practice was to dig up the deceased's remains to look for anything "unnatural." According to this superstition, a body that hadn't decomposed or whose heart still contained liquid blood could still be drawing life from the living. The heart or other organs were then burnt, or if no organs remained, sometimes skeletons were rearranged. Some believed that disruption of bones or organs would prevent the body from continuing to plague the living, while others believed that fumes or ashes from burnt organs could heal consumptives.

One of the skeletons uncovered in a 1990 discovery of an 18th century rural Connecticut burial ground had been rearranged so that the skull and femurs created a skull and crossbones pattern. Anthropologists determined that three skeletons buried at a similar time, including the rearranged one, had lesions on the rib bones that indicated they had suffered prolonged breathing stress and were probably tuberculosis victims. The anthropologists think that a tuberculosis outbreak had led the family members to rearrange the skeleton.

With Robert Koch's discovery of *Mycobacterium tuberculosis* in1882, a germ-based understanding of the disease began to take hold. Eventually the vampire beliefs, like the term "consumption," died out.

—Katie Peek

those from IIT in India who came to UC Berkeley this past summer, and students like Lisa Prach, who has gone to South Africa for her research. Madon describes other fundraising efforts: "We're writing one for minority and health disparities international training to send minorities and underrepresented students here to developing country sites of our collaborators. We're also drafting a proposal that could create an infectious disease modeling center on campus. We're trying to bring new resources to campus to help people engage in the kind of research that they want to, when there isn't a lot of funding [available]."

Is Big Science the future of drug discovery?

Big pharmaceutical companies have traditionally developed new drugs for diseases. They have large research programs, larger budgets and vast resources to throw at problems. However, drugs for neglected diseases, like trypanosomiasis, tuberculosis, malaria, and AIDS, challenge this time-tested model for discovery, simply because the people who suffer from these diseases cannot afford Big Pharma prices for their medicines. It has become increasingly clear that a new approach to the problem is needed, one that addresses the massive cost of discovering a new drug. Directing existing research efforts towards drug discovery may be the answer. This could be an advantageous situation for everyone—researchers have new, exciting, and socially relevant problems to work on, some of the best minds in the business are turned on to the most difficult problems, and drugs could be discovered at a far lower cost. CEND is a venture designed for this new kind of drug discovery and symbolizes so much of what is quintessentially Berkeley—world-class research with a social conscience.

Niranjana Nagarajan *is a postdoctoral fellow in molecular and cell biology.*

Want to know more?
CEND's website:
globalhealth.berkeley.edu/cend/template.php?page=home

Welch lab:
mcb.berkeley.edu/labs/welch

Alber lab:
ucxray.berkeley.edu

World Health Organization site on neglected infectious diseases:
who.int/tdr/diseases

New England Vampire Myths:
ceev.net/biocultural.pdf

A Natural High

Image courtesy of Rachael Knight

The 1960s are remembered for many reasons—the civil rights movement, the Vietnam War, and the sexual revolution to name but a few. But there is a popular saying that if you remember the 1960s, you weren't there. Nowhere is this more pertinent than in the San Francisco Bay Area, where the marijuana-fueled counter-culture of the 1960s began. The movement sent tendrils of change through American academics, politics, and society, and Berkeley in the 1960s will forever be known for weaving the marijuana experience into the tapestry of our culture. Today, Berkeley is making marijuana-related discoveries that will again shape our culture. The latest interest in marijuana at Berkeley comes not from the drug, but rather the natural synthesis of compounds in the human brain and body that work in the same way. At this very moment, your body is producing compounds strikingly similar in action to components of marijuana. These natural "drugs" harbor the ability to control not only our mental and emotional health but also our most basic bodily functions—from the sensation of pain to the regulation of hunger and satiety.

At the leading edge of research into these compounds is a collaborative group with members in the Department of Environmental Science, Policy and Management (ESPM) and the Department of Nutritional Science and Toxicology (NST) at UC Berkeley. In a tale of scientific good fortune and

Harnessing the Brain's Own Drugs

by Paul Hauser

interdisciplinary research, these investigators were able to use their knowledge of pesticide-related compounds to elucidate the action of naturally synthesized compounds that mimic marijuana action. Researchers are now wagering that the inherent power of the marijuana high can be harnessed in novel drug therapies.

The history of the high

Cannabis as a medicinal plant is reported to date back to prehistoric times, but its possession and use remains illegal in most of the world. The term cannabis (or marijuana) most commonly refers to the harvested flowers or buds from the *Cannabis sativa* species of the Cannabaceae, or hemp, family of plants. The diverse and agriculturally useful hemp family has been used throughout history not only to treat ailments, but also to make papers and textiles and to produce seeds and oils for cooking. Since its rise in consumption as a recreational and medical drug in the 20th century, scientists have become interested in understanding the plant's power, particularly amid continuing debates about the benefits and harms of the drug.

Marijuana research started simply enough in 1964 with the discovery that delta-9-tetrahydrocannabinol, or THC as it is better known, is the primary active ingredient in marijuana. Up to this point, it was generally assumed that a cocktail of compounds, categorically called "cannabinoids" because of their presence in cannabis, was collectively responsible for the central nervous effects of marijuana use. But work by Dr. Ralph Mechoulam and colleagues at the Weizmann Institute of Science in Israel demonstrated that THC alone is largely responsible for the changes in mood, perception, behavior, and consciousness known as the psychoactive effects of marijuana. With some 400 cannabinoids found in the marijuana plant (many of which are biologically innocuous or present in such low abundance as to have no effect), the cannabinoid compounds are now classified by their structural similarity to THC instead of their psychoactivity.

As public experimentation with marijuana increased dramatically throughout the 1960s and 70s, so too did scientific experimentation. In these two decades, studies flourished in an effort to understand the drug's cognitive and psychological effects. Early studies described the THC-induced feelings of euphoria, relaxation, fatigue, and noticeably altered perception. Other investigations focused on users' reports of increased appetite (the "munchies"), short-term memory impairment, and depressed motivation. Cannabinoid research was an interdisciplinary field from the start: chemists, biologists, and psychologists all got a piece of the descriptive action as the psychoactive profile of the "gateway" drug was born.

It would, however, be more than twenty years after the initial discovery of THC when the first biological mechanism for the cannabinoid response was proposed. In 1988, a natural brain receptor that seemed to be the target of THC was discovered. Researchers have since learned that the marijuana high is elicited when THC dissolves in the blood and passes into the brain. There it encounters the cannabinoid receptor in the outer membranes of cells that make up the tissue of the brain and nervous system. Its chemical composition and physical shape allow the THC molecule to bind and activate the receptor, thereby inducing its psychoactive effects. The discovery of THC and the cannabinoid receptor suggested a mechanism by which marijuana could produce its potent effects and raised an important question: why would the mammalian brain have evolved a receptor to bind this plant compound?

The answer again camefrom Mechoulam's group in 1992, when they found a naturally occurring compound in the pig brain that also had the ability to bind the cannabinoid receptor. This compound, which they named anandamide, was the first example of a cannabinoid produced by animals. The compound was termed an "endocannabi-

Terms and Acronyms

- **2-AG** (2-arachidonylglycerol) - an endocannbinoid
- **anandamide** - the first identified endocannabinoid
- **cannabinoids** - compounds found in the cannabis plant
- **cannabinoid receptor** - a protein which activates a signaling cascade after binding cannabinoids or endocannbinoids
- **endocannabinoid** - a naturally synthesized cannabinoid
- **FAAH** (fatty acid amide hydrolase) - an enzyme that breaks down anandamide
- **IDFP** (isopropyl dodecylfluorophosphonate) - an organophosphate that elicits the classical cannabinoid intoxication profile
- **MAGL** (monacylglycerol lipase) - an enzyme that breaks down 2-AG
- **THC** (delta-9-tetrahydrocannabinol) - a cannabinoid, marijuana's primary active ingredient

noid" because of its natural, or endogenous, synthesis and its chemical resemblance to the canonical cannabinoid, THC. This discovery was soon followed by the identification of a second endocannabinoid, 2-arachidonyl-glycerol (2-AG). In a surprising twist, this chemical, despite its similarity to other cannabinoids produced in the brain, was initially discovered in the canine intestine.

It was later shown that pure forms of either endocannabinoid elicit the standard response of increased appetite, depressed activity, reduced sensitivity to pain, and mild hypothermia. Knowing that the brain and intestine produce natural compounds capable of inducing these effects by triggering the cannabinoid receptor, researchers needed an explanation for what these compounds do in their natural settings. This was particularly intriguing given their presence in such seemingly disparate tissues as the brain and intestine.

How the brain makes its own bliss

Early work indicated that endocannabinoids are synthesized from common cellular molecules. Specialized fats found in the membranes of nerve cells provide the chemical starting material for the generation of the two naturally synthesized cannabinoids. Researchers became aware that this was a tightly regulated mechanism, able to provide controlled levels of these compounds to activate the cannabinoid receptor and regulate bodily functions.

Further developments came in the mid 1990s, when researchers learned how endocannabinoids are biologically degraded. Two enzymes, monacylglycerol lipase (MAGL) and fatty acid amide hydrolase (FAAH), which break down 2-AG and anandamide, respectively, were purified from rats and characterized. These proteins were later found in nearly all mammalian brains. Together these enzymes break down the endocannabinoids, reducing their biological availability and subsequently preventing them from binding their target receptor. This result explained how the body attenuates this natural chemical signal to prevent us from walking around high on our own cannabinoid tonic, but brought us only slightly closer to understanding the activity of endocannabinoids in the context of normal brain and body function.

In an unlikely twist, it was a UC Berkeley research group working on a class of chemically related compounds known as organophosphates that provided a key breakthrough toward understanding the natural role of endocannabinoid signaling. John Casida, professor in the ESPM and NST departments explains that his lab had "long been focused on the neurological and cytotoxic effects of organophosphate-containing compounds, including common pesticides." It was the lab's investigation into this cellular toxicity, or cytotoxicity, that indirectly led them to the field of endocannabinoid signaling.

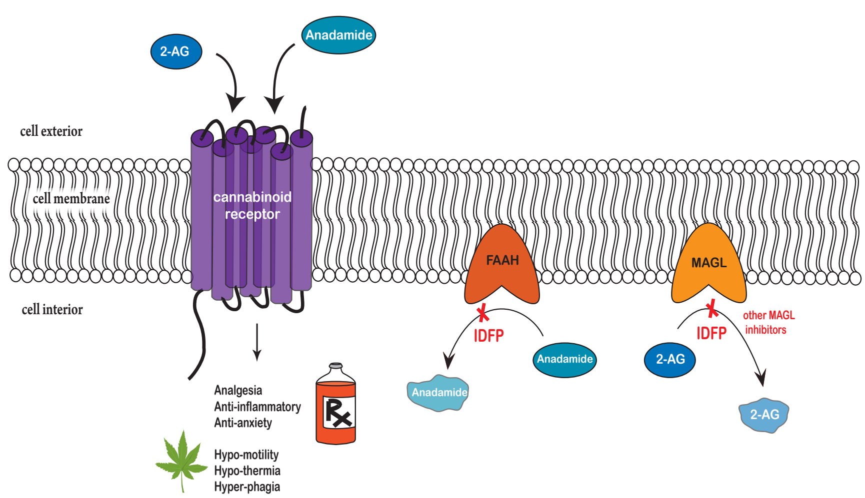
Although the consequences of long-term, low-level pesticide exposure are still being evaluated, it is clear that many organophosphates have the potential to harm animals. The side-effects of some of the compounds he was working with caused Casida to become "particularly suspicious that certain organophosphates were interfering with endocannabinoid signaling." From this hunch, says Casida, "we simply followed the chemical trail" from the poorly characterized side-effects of the suspicious pesticide-like compounds to understanding the relationship between organophosphate activity and cannabinoid signaling.

At the start of this connective trail was the synthesis of a diverse set of organophosphate compounds known as a chemical library. Casida's former graduate student Daniel Nomura assembled and tested the chemical library of compounds one by one for the ability to react with a collection of known brain enzymes. To test Casida's early suspicions, Nomura screened the library for compounds with the ability to act directly on the endocannabinoid system. Casida soon began to see that the endocannabinoid system disruption was "immediately obvious minute by minute and step by step," as he and Nomura observed that certain related compounds were able to inhibit a set of related brain enzymes.

Where it all breaks down for endocannabinoids

One of the compounds that produced a particularly marked cannabinoid-like effect was chosen for further investigation. This chemical, IDFP (or isopropyl dodecylfluorophosphonate as it is more formally known) elicits the classical cannabinoid intoxication profile. Curiously, however, the lab discovered that it was not working by the same mechanism as THC. "I was wondering how IDFP could induce stronger cannabinoid effects than THC without acting directly on the cannabinoid receptor," recalls Nomura. He soon realized that IDFP strongly inhibits both of the major endocannabinoid metabolizing enzymes. Nomura's later experiments showed that IDFP induces ten-fold increases in anandamide and 2-arachidonylglycerol levels, which meant that any IDFP traveling to the brain prevented endocannabinoid degradation. The resulting buildup of endocannabinoids in the nervous system causes the brain to get high on its own stupor-inducing tonic. IDFP produces cannabinoid effects not by directly targeting endocannabinoids or their receptor, but by inhibiting the breakdown enzymes that normally rid the body of these potent compounds.

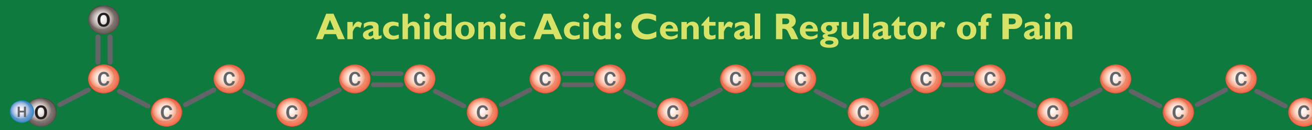
IDFP's unique activity provided a new avenue through which to manipulate endocannabinoid degradation. Ben Cravatt of the



The current model of endocannabinoid signaling and degradation. The body produces two endogenous cannabinoids, anandamide and 2-arachidonoylglycerol (2-AG), which bind to the cannabinoid receptor to induce pharmacologically desirable (Rx) and undesirable effects (marijuana leaf). Degradation of the two endogenous cannabinoids by their respective enzymes, fatty acid amide hydrolase (FAAH) and monoacylglycerol lipase (MAGL), controls the cannabinoid receptor's effects.

Illustration by Orapim Tulyathan

Arachidonic Acid: Central Regulator of Pain



Arachidonic (ara-ki-DON-ik) acid is more than just your average biological molecule with a tricky name. This long carbon-chain fatty acid is required for proper functioning of the human body because of its ability to be chemically converted into a wide range of signaling molecules, controlling functions as diverse as blood coagulation and the central nervous system. It is both taken in through the diet and naturally synthesized on demand so that constant levels are maintained in the body.

Despite this highly regulated system, most people manipulate their arachidonic acid levels on a regular basis. This is because a whole class of common over-the-counter drugs, including aspirin and ibuprofen, targets the arachidonic acid pathway. These drugs, collectively termed non-steroidal anti-inflammatory drugs, or NSAIDs, selectively inhibit enzymes responsible for the conversion of arachidonic acid to natural pain and inflammatory molecules. When you take an aspirin or Advil for your headache or sore muscles, you are selectively blocking two cyclooxygenase (COX1 and COX2) enzymes that modify arachidonic acid. However, as frequently and safely as these drugs are used, there's still a strong interest in making them better.

It is often rumored that if aspirin were to undergo rigorous FDA review under the current standards, it might not pass due to its side-effects. Aspirin can cause the rare but potentially deadly Reye's syndrome in children, and, like its other NSAID cousins, it can eat away at stomach lining and damage the kidneys of chronic users. Both the benefits and risks of NSAIDs come from the reduced arachidonic acid processing: COX2 inhibition dampens pain and reduces inflammation, while COX1 inhibition prevents the production of molecules essential for stomach and kidney health. The logic has always been that selective COX2 inhibition (without COX1 inhibition) could skirt the problems of NSAID use.

Advances during the 1990s brought a flood of selective COX2 inhibitor drugs to market. The efficacy and potency of these drugs equals or rivals other NSAIDs, and they are often prescribed for chronic and hard-to-treat pain associated with arthritis and some cancers. But the now infamous case of Vioxx has brought a new wave of concern about their safety. Vioxx was shown to increase the risk of cardiovascular problems, which prompted Merck, the makers of Vioxx, to voluntarily remove the drug from market shortly after the release of their internal drug trial data in 2004. Concerns about Vioxx and other COX2 inhibitors like Celebrex and Bextra have caused a shift in focus towards finding alternative therapies that manipulate arachidonic acid levels through different pathways.

With recent findings suggesting that endocannabinoids play a role in regulating arachidonic acid levels, heads are beginning to turn in the pharmaceutical world. No one is saying that this development will be easy, much less fruitful, in the long run, but the interest in endocannabinoid signaling and its connection to arachidonic acid has made a big splash. But will it also make waves? Only time will tell.

Scripps Research Institute, a collaborating investigator in the study, showed that removing only one of the degradation enzymes, FAAH, had little noticeable effect. The only difference between Cravatt's and Nomura's experiments was the additional inhibition of MAGL. "We now strongly suspect that endocannabinoid degradation via the action of MAGL is critically important for proper brain and nerve function," says Nomura. As a result of this finding, 2-AG and its enzymatic degradation by MAGL are now front and center in the race to fully understand the endocannabinoid signaling pathway, a race for which the ultimate prize is the development of beneficial therapeutics.

Nomura and Casida have recently discovered that, in addition to increasing circulating endocannabinoid levels, suppression of endocannabinoid degradation in the nervous system has an unexpected secondary effect. When MAGL is inhibited, there is a corresponding reduction in arachidonic acid levels in the brain. Arachidonic acid is an essential fatty acid that is used by nearly all cells to produce signaling molecules as variable as blood clot promoting molecules, natural pain killers, and inflammatory compounds. The observed correlation between changes in arachidonic acid and endocannabinoid levels in this model suggests a strong but as yet not fully understood connection between MAGL activity and hormone signaling.

This discovery also defies conventional wisdom, which has long held that a different enzyme is responsible for maintenance of the brain arachidonic acid pool, and implies that MAGL is controlling not just endocannabinoid levels but a diverse set of brain activities associated with arachidonic acid metabolism. This challenge to the current dogma is ushering in a fresh wave of interest in endocannabinoids. If the evidence stands the test of time, it could have consequences that transcend the endocannabinoid field to enter the consciousness of researchers from fields as diverse as lipid biology, neurology, and pharmacology.

Not least of those interested in endocannabinoid research will be pharmaceutical companies, whose interest arises from the fact that arachidonic acid regulation has a proven track record in the development of therapeutics for pain, inflammation, and hormone signaling. Although Casida cautions that "in order to get [a pharmaceutical] that is highly selective, you have to walk a very thin line," the combined potential of the lab's findings reinforces the essential requirement of endocannabinoids for normal bodily function. This formalized link between endocannabinoids and arachidonic acid provides strong support for the idea that the endocannabinoid system is not just a scientific hallucination, but rather it is a highly integrated network that facilitates vital cross talk between the brain and body.

The endocannabinoid mind-body problem

It's not just Casida and Nomura's findings that are fueling drug companies' interests in endocannabinoids. Mounting evidence suggests that in certain body systems there is potent endocannabinoid activity that is related to, but independent of, its brain effects. Particularly, researchers of the "brain-gut axis" are recognizing the regulatory power of endocannabinoids. The brain-gut axis describes an exchange of chemical messengers between our digestive system and nervous system that communicates messages of hunger and satiety, and subsequently regulates body weight, metabolic rate, and energy management.

The brain-gut axis is thought to have evolved to allow us to maintain unconscious communication between our internal metabolism, the external food supply, and our brain function. By extension, it has been suggested that disruptions in this communication contribute to metabolic diseases such as diabetes and obesity. Small, specialized proteins called neuropeptides, which have hormone-like activities, have been implicated in controlling the brain-gut axis, and it now seems that at least a few of these peptides are further regulated by endocannabinoid levels.

One of these peptides, ghrelin, induces a strong appetite signal when secreted from the gut. Recently, it was shown that this ghrelin-dependent hunger response is suppressed in animals that either lack the cannabinoid receptor or are treated with a compound that blocks cannabinoid receptor activity. This connection strongly suggests that the cannabinoid system is necessary for the proper function of the brain-gut axis.

In a parallel study, changes in a fat tissue secreted hormone, leptin, were implicated in the control of endocannabinoids in the body's fat stores. Interestingly, when leptin levels are increased, there is a parallel decrease in the endocannabinoid levels in fat tissue. This evidence connects other isolated studies showing that elevated leptin levels or lowered endocannabinoid levels can reduce fat stores and promote weight loss. While the connective mechanism remains uncertain, the suppression of appetite and weight gain signals associated with cannabinoids is now linked to the action of leptin, which already is known to have potent activities on insulin action, fatty acid and carbohydrate metabolism, and weight management.

The leptin results, taken together with findings that endocannabinoids are central to neuronal signaling, suggest possibilities for exciting therapeutic development. Casida has begun a collaboration with Ronald Krauss and graduate student Maxwell Ruby from the NST department to explore the peripheral effects (those outside the brain) of endocannabinoid signaling with the hopes of expanding therapeutic understanding of the system. "With all these pathways being impacted by the cannabinoid system, it gives a whole new dimension to exploiting this system therapeutically," says Krauss.

From cannabinoids to cures

Therapeutic exploitation is exactly what pharmaceutical companies are hoping for as they look for ways to harness the endocannabinoid system to develop a new class of commercial drugs. There has been significant interest in using direct cannabinoid receptor activators (such as THC-mimicking pharmaceuticals) to prevent pain and treat disease for some time, but only recently were the first commercial drugs brought to market as pharmacological proof of principle.

Two recently developed endocannabinoid receptor blockers, Rimonabant from Sinofi-Aventis and Tiranabant from Roche Pharmaceuticals, have inspired hope for the future of endocannabinoid-based drugs and established major difficulties in separating the desirable and undesirable effects of cannabinoid-based therapies. According to their fact sheets, Rimonabant and Tiranabant are wonder drugs: the manufacturers claim everything from weight loss and suppressed appetite to improved blood cholesterol and fatty acid levels and increased short-term memory and energy levels. But if you've ever read the fine print on a drug label, you can be certain that life just isn't that simple.

Researchers have made significant strides since the days of giving controlled doses of marijuana to willing volunteers.

While Rimonabant is approved for sale on the European market, neither cannabinoid receptor blocker fared well in recent US Food and Drug Administration trials. The US trials, independent scientific studies, and European consumer surveys all report that these drugs increase depression, anxiety, and even suicidal tendencies among a small but significant proportion of users. It appears that there is a critical psychological function for the natural, low levels of endocannabinoids, such that blocking their activity can create undesirable effects on brain function and mood.

Pharmacologists and drug companies, however, are not willing to concede that all is lost. The psychological side-effects cannot easily be overlooked and require careful investigation, but statistically significant weight loss, increases in beneficial cholesterol, and reduced arterial inflammatory signals among the Rimonabant trial participants are equally difficult to ignore. Pharmaceutical researchers, like their academic counterparts, are discovering that endocannabinoids have both complex central nervous system activities and beneficial whole-body effects.

The endocannabinoid system is so diverse and far-reaching that it is challenging to isolate specific activities that render the system usable for beneficial treatments. Or as Krauss puts it, "there remains a lot of potential within the system for therapeutic intervention, but we don't yet have the best solutions that can take full advantage of that potential." Drug companies believe that selective activation of only the peripheral effects of endocannabinoid signaling could lead to effective treatments for obesity, metabolic disease, and disorders of hunger and satiety. Pharmaceutical companies are now searching for ways to design drugs that would act in the peripheral body but would be prevented from passing into the brain. It is conceivable that targeted therapies could preferentially partition the whole-body benefits of endocannabinoid metabolism from the unwanted central nervous system complications.

With the recent growth in the endocannabinoid field, it's clear that researchers have made significant strides since the days of giving controlled doses of marijuana to willing volunteers. While endocannabinoid pharmacologists are still seeking the full path to their targets, there remains hope that understanding the endocannabinoid system could lead to more effective therapeutic tools for the treatment of diabetes, obesity, and cardiovascular disease. Undoubtedly, endocannabinoid research will remain an interdisciplinary affair, as pharmacologists, lipid biologists, and geneticists all examine the biological benefits and limitations of the natural high. With new discoveries in this emergent field, Berkeley is contributing to research on marijuana-type effects in a way that was never dreamed of in the 1960s. And although this tale is just beginning, it is certain that the latest research has taken the recreation out of cannabinoids. Getting to the bottom of the endocannabinoid story is now a serious business.

Paul Hauser *is a student in molecular and biochemical nutrition.*

Want to know more? Check out:
Dr. John Casida's research profile:
ecnr.berkeley.edu/facPage/dispFP.php?I=466

Dr. Ronald Krauss's research profile:
chori.org/Principal_Investigators/Krauss_Ronald/krauss_overview.html

Richard Karp

Image courtesy of the Inamori Foundation

Forty years ago, Richard Karp joined the faculty at UC Berkeley, and during his tenure helped lay the groundwork for the study of theoretical computer science that underlies much of modern technology, from microchip layout to internet security. He has been honored with such awards as the US National Medal of Science, the Turing Award, and the Fulkerson Prize, among others. In November, he will be awarded the Kyoto Prize, Japan's equivalent of the Nobel Prize (there is no Nobel Prize category for computer science).

I spoke with Professor Karp in his office at the International Computer Science Institute, where he continues to work on algorithm design and computational biology.

With the exception of four years at the University of Washington, you've been at Berkeley since 1968. You must like it here.

Oh yes, I'd rather be here than anywhere else.

What was Berkeley like when you first arrived?

Well, in terms of revolutionary activity, Berkeley was a big hub in the sixties. Soon after I arrived, there were major protests against the Cambodian invasion, and then with the People's Park incident—Reagan brought out the National Guard to "protect" the park from people camping out there—it was all fairly exciting. I remember teaching some classes in my house because students didn't want to hold class on campus and at one point bailing out a colleague who had been arrested for participating in a protest march.

You played a role in founding the computer science department?

The first computer science departments were formed in the mid-sixties. When I arrived at Berkeley, there was a kind of unstable arrangement where the electrical engineering department was home to a number of computer scientists, but a group of those had split off to form a new department to serve the College of Letters and Sciences. As the rivalry that began to emerge between these two departments wasn't healthy academically or socially, the administration decided to create a single computer science division, folded into electrical engineering but with a substantial degree of autonomy. I was not very experienced in academic affairs, having just moved to academia a few years before, but since I had not taken sides in the controversy, I was a logical candidate to lead this new unit. I wasn't a born administrator, so I took the position for only two years, but I played some role in quieting things down, in getting people to accept the arrangement and start building something together.

You're best known for your work on the computational complexity of algorithms. What is an algorithm?

An algorithm is a systematic procedure for performing a computational task. In school we learned algorithms for doing arithmetic—for addition, multiplication, long division. Some of us may have learned the Euclidean algorithm for finding the largest common factor of two numbers. Algorithms are everywhere. At the core of every information processing application, there's an algorithm. Whether it's processing search queries or routing messages through a network or conducting auctions over the web, algorithms are at the heart of it. At the core of all the cryptographic protocols that underlie e-commerce, there's an algorithm for encrypting data which depends in turn on an algorithm for testing whether a number is prime. That algorithm can be written down in a few lines, but it's very subtle and without it we wouldn't be able to conduct business over the internet the way we do.

What about computational complexity?

The first requirement of an algorithm is that it should be correct. It should do what it's supposed to do. Beyond that, it should be efficient. The primary way we measure efficiency or cost—the technical word is "complexity"—of an algorithm is by the time it takes to execute – roughly speaking, the number of basic steps. I've spent a lot of my time devising algorithms that are efficient by that measure.

So computational complexity is about how many steps an algorithm takes from start to finish?

You'd like to have efficient algorithms for practical reasons, but computational complexity is a theoretical field concerned with fundamental laws or limits that say you simply cannot avoid spending a certain amount of time solving some type of problem. Most people are familiar with some basic laws of physics—you can't build a perpetual motion machine, nothing can travel faster than the speed of light, well, there are laws of computation also. In particular, I've been interested in combinatorial search problems, where you are looking for arrangements of finite sets of objects that satisfy some constraints or conditions.

How did you first encounter these kinds of problems?

My father was a school principal and every fall before classes started he tried to solve a complex scheduling problem. He was looking for an arrangement that satisfied a variety of constraints: certain teachers were only available at certain times, certain classes required particular classrooms, certain pairs of classes shouldn't be held at the same time. He got out a bunch of index cards, laid them out on the kitchen table, and starting shuffling them around. I tried to help and that was my first exposure to this type of problem.

So how hard is the scheduling problem?

In general, combinatorial problems like this one, which arise in commerce, in physical sciences, in engineering, even in the humanities and social sciences, can be compared to searching for a needle in a haystack. There are a vast number of ways the objects can be arranged—assigning classes to timeslots, for example—but only a few meet all the requirements. So the question is, are there shortcuts? Some problems have clever, efficient algorithms, but for most of the problems that come up, there seems to be no radical shortcut. You can solve small examples, but as the size grows—the number of classes to schedule gets bigger—the running time of even the best algorithm tends to explode. That is, it roughly doubles every time you increase the size just a little bit.

How is this related to your famous 1972 paper?

Basically, people began to ask whether, for these problems, exponential growth was inherently necessary, whether there was a law of computation that said you couldn't avoid such an explosion in running time. We still don't know the answer to that. What I was able to do, following the lead of a former Berkeley professor named Stephen Cook, was to show that 21 different problems, having no overt similarity in their descriptions, are actually equivalent in the sense that if you could solve any one of them efficiently, you could solve all of them efficiently.

So even though nobody has proved that no efficient algorithm exists for these problems, you started mounting evidence that strongly suggests this is true.

That's right. I used a technique called "reduction" to show that a new problem is as hard as any in the set. You imagine you have an efficient algorithm for solving the new problem and show that you could use the solution to solve some other problem already in the set. By now we have thousands of such problems, with more being discovered every day.

Now you've changed focus—you work in the intersection of computer science and biology?

Yes, I've been working on computational molecular biology since 1992. I work on other things too—problems in networking and other general algorithmic design problems, but a lot of my effort is devoted to problems arising in biology.

This work seems much less theoretical. How did you get into biology?

Well, there were a lot of smart people who were beating me at my own game. The techniques became very sophisticated. I had worked on applications before and I thought I might have an edge because of my knowledge of combinatorial algorithms. Also, biology was increasing in importance, and better yet, it was a subject you could explain to your mother or your cousins. I guess another reason was a sense of competitiveness. Some of my colleagues were going into that area, and I thought if they could do it, I could do it too.

How did the transition work out?

I guess I thought I would come riding in on my white horse with my combinatorial skills and that everything would be easy, but it hasn't been exactly like that. First of all, it's not clear what is meant by a correct algorithm since typically you don't really know the right answers. The biologist is looking for some explanation for a phenomenon and wants to understand how a particular cellular process is regulated, for example. It's not the case that you can recognize the right solution when it's handed to you. It's not like these well-defined theoretical problems where you can verify a solution by inspection. When you come up with a neat algorithm, it's really more a matter of the confidence that biologists have in the results that determine whether it will be accepted by the community rather than some theoretical criterion. And you have to develop good software with good interfaces, and you have to make contacts to get people to use it. So there are a lot of things involved besides the core algorithm itself. I've found you have to really be part of the team and have close connections with biologists. I tend to like to sit alone in my cubby hole, playing with some well-defined problem. Fortunately, I've had postdocs and visitors and other collaborators who help with the liaison with biologists, so I get good feedback.

Dan Gillick *is a graduate student in computer science.*

Want to know more? Check out:

Inamori Foundation (Kyoto Prize):
inamori-f.or.jp/e_kp_lau_thi.html

Professor Karp's Berkeley Page:
cs.berkeley.edu/~karp

LETTER FROM THE FIELD:

A Berkeley Student in Basque Country

FIELD NOTE Spain

We pride ourselves on the research we do at Berkeley, but of course we are only one of many research institutions in the world. International scientific collaborations are growing (the percentage of papers with authors from more than one country almost doubled between 1990 and 2000), and as a result, the National Science Foundation is encouraging graduate students to travel overseas to gain a global perspective on research and career opportunities. That's how I found myself working this summer in the land of *tapas* and *toros*.

I spent two and a half months doing research with Professor of Materials Physics Ángel Rubio at the University of the Basque Country in San Sebastián, Spain. The visit was supported by a fellowship from Berkeley's NSF-funded Integrative Graduate Education and Research Traineeship (IGERT) center in nanoscale science and engineering, which includes an internship in industry, at a national laboratory, or abroad.

My previous work has been on the optical and electronic properties of molecules on metal surfaces (specifically the "switch" azobenzene; see *BSR* Spring 2008) using a computational technique called density-functional theory, which can predict the properties of solids, nanostructures, and molecules. Rubio, who was a postdoc at Berkeley 15 years ago with my advisor, physics professor Steven Louie, is a leader in an extension of this method called time-dependent density-functional theory (TDDFT).

Rubio's group developed a computer program called Octopus, which performs calculations via TDDFT. I went to Spain to learn about this technique and to use it to study the optical properties of molecules and liquids. Together with Rubio's student who wrote part of the Octopus code to work with isolated molecules, I extended it to work for liquids and solids and planned the calculations I'm now doing back in Berkeley with the finished version.

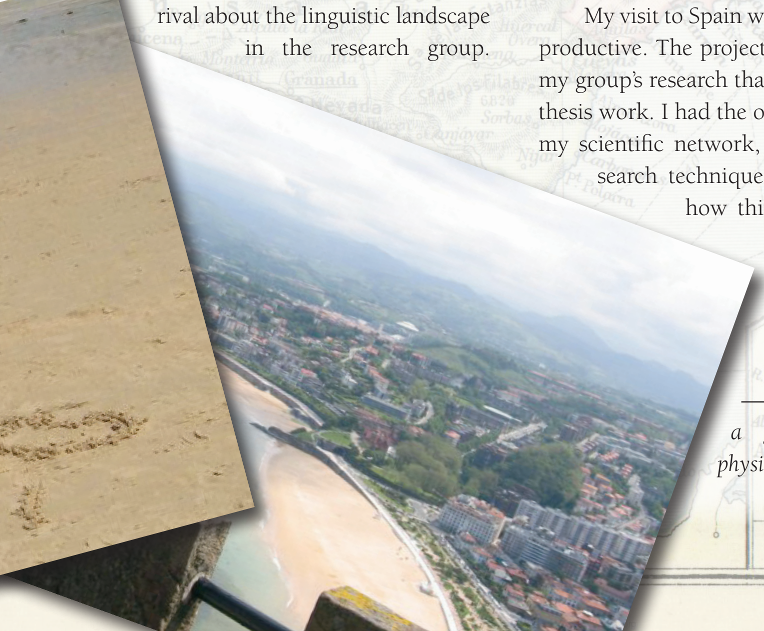
Although the content of science is universal, I certainly found some differences in the research experience in Spain. I was surprised at the frequency with which Rubio's students and postdocs traveled for meetings, workshops, and collaborations. There wasn't a week that the whole group was present, and I even found myself traveling to Berlin with Rubio for a meeting of the developers of Octopus. The Rubio group's jet-setting is partly due to their membership in the European Theoretical Spectroscopy Facility (ETSF), a European Union-sponsored initiative consisting of academic groups in several countries. But all this traveling also indicates a more fundamental point about Europe. Nearly all universities are state-run, and students generally attend the university closest to home. As a result, many of the best students, professors, and resources are not concentrated in one place but are instead dispersed throughout the continent. At Berkeley, we can usually find someone on campus with the expertise we need, but researchers in Europe often have to travel to form collaborations.

I was curious before my arrival about the linguistic landscape in the research group. The official language of Spain is of course Spanish, but many people also speak Basque in San Sebastián (interestingly, "Etcheverry," as in our building on campus, is a Basque name). Moreover, around the world, English is used almost universally for scientific communication. I found that, partly due to the ETSF, Rubio's group is remarkably multi-national. There are postdocs from Germany, Belgium, France, and Italy, an affiliated professor from Russia, and students from Chile, Colombia, and Iran. In fact, the professor and one postdoc are the only Spaniards in the group, and there are no Basques. English is the only common language, and therefore it is the official language of the lab's weekly meeting. Elsewhere in the university, there are fewer foreigners, and most are Latin Americans. Nevertheless, all graduate courses are taught in English to accustom students to communicating about science in English.

My visit to Spain was both enjoyable and productive. The project was close enough to my group's research that it fits nicely into my thesis work. I had the opportunity to expand my scientific network, learn about new research techniques and areas, and see how things work in another group and another country. Hopefully that's what the NSF had in mind.

—**David Strubbe** *is a graduate student in physics.*

Images courtesy of David Strubbe



BOOK REVIEW

When Dinosaurs Stopped Ruling the Earth

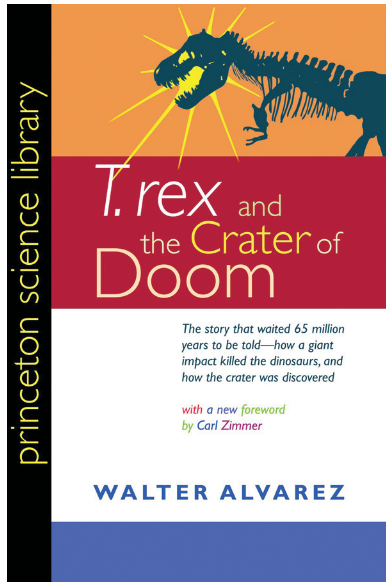
T. rex and the Crater of Doom
by Walter Alvarez
Princeton University Press, Reprint 2008
216 Pages, $16.95

T rex *and the Crater of Doom* tells many stories: the dramatic end of the dinosaur age, the journey to uncover the cause of this world-changing event, and the personal histories behind all the science. Written in 1997 by UC Berkeley Professor of Geology Walter Alvarez, the book details the series of discoveries he made in the late 1970s and early 1980s, culminating in the unearthing of the 65-million-year-old Chicxulub crater on Mexico's Yucatan Peninsula. A second edition of the book is being published this year, a testament to the lasting impact of his discoveries—and to our endless fascination with the giants of the Cretaceous world.

In the book's first chapter, Alvarez describes the catastrophic impact event and the resulting devastation: a cacophony of shock waves and tsunamis before the planet plunged into a months-long night, killing most of the life on Earth. At first it appears he has given away the punch line not yet 20 pages into the book, but it soon becomes clear that his is not a story of suspense. Rather, it is a story of discovery.

Like many scientists, Alvarez's mystery was not the one he set out to solve. While studying the origin of the Apennine Mountains in Italy, he became familiar with the KT boundary, a thin layer of clay found at sites across the world that coincides with the mass extinction at the end of the Cretaceous period. His fascination with this geological phenomenon grew until he put his original research aside and turned to revealing the truth behind the centimeter-thick layer of clay.

As Alvarez investigated the KT boundary, he enlisted the help of his father, UC Berkeley physics professor Luis Alvarez, and Frank Asaro, a nuclear chemist at Lawrence Berkeley Laboratory. Alvarez writes that some paleontologists didn't like the idea of



a geologist, a physicist, and a chemist treading on their ground, but this unorthodox collaboration turned out to be quite fruitful. The trio found that the KT boundary clay contained extremely high levels of iridium, an element that is rarely found in the earth's crust but is present at higher levels in extraterrestrial objects. From here, the search for the source of the anomaly, and the likely cause of the dinosaur extinction, began. The second half of the book details this quest, at turns frustrating, exhilarating, and even apparently doomed before the monumental discovery of the enormous Chicxulub crater.

Alvarez's team used a number of complex scientific techniques to decode the geological clues to the dinosaur extinction, and Alvarez has a knack for describing them in plain language. For example, to explain neutron activation analysis, a technique to detect very small amounts of certain elements, he tells the reader to imagine that among the entire Earth's population, just a few people (representing the small quantity of the element in question) use flashlights as beacons to help them stand out from the crowd. Descriptions like this provide some idea of the science at hand, though readers who want to truly understand the techniques may feel short-changed.

Reading Alvarez's book is a bit like reading a letter from an old friend you haven't seen for 30 years. The casual tone is tempered at times when he writes of Nature with a capital "n" or calls himself a "historian of the Earth," but these serious passages are offset by cheeky commentary and humble asides that keep the book from becoming overly solemn or preachy. Of his early work investigating the KT boundary he writes, "We thought our ideas were new, but unfortunately other people had previously invented them and found out why they wouldn't work." Later, he explains his motivation for continuing an often baffling project by saying, "Scientists cannot resist a good mystery." Furthermore, he makes sure to include the many people, collaborators and detractors alike, whom he encountered along the way.

It is important to note that, although Alvarez presents his theory as fact, there remain some scientists who believe that dinosaurs became extinct gradually. The paucity of dinosaur fossils makes it difficult to come to any certain conclusions about how the extinction occurred, but the striking evidence of the Chicxulub crater makes Alvarez's case for a catastrophic impact event quite compelling. The conflict between catastrophists and gradualists is long-standing, but Alvarez ends the book on a conciliatory note, promoting a world view where gradual change in the form of plate tectonics and erosion is occasionally punctuated by catastrophic events that change the world in an instant.

In the course of his work, Alvarez challenged the geological dogma of gradualism and re-imagined the history of the world. With creative thinking about an old problem, his quest for the truth of the dinosaur extinction took him on a meandering journey filled with startling discoveries and deceptive clues. His story reminds us why people become scientists in the first place. The thrill of discovery makes all the wrong turns and dead ends suddenly worthwhile; ultimately, no one can resist a good mystery.

Rachel Berstein *is a graduate student in chemistry.*

Image courtesy of Princeton University Press

Beyond Bernoulli: The Science of Flight

On a recent flight, I found myself gazing at the wing from my window seat, wondering how exactly this simple-seeming structure manages to keep a few hundred thousand pounds of metal and plastic aloft. I've heard several different popular explanations, though clearly they cannot all be correct. Given the ubiquity of air travel these days, this seems like a small piece of physics we all ought to know.

There are two common ways to justify flight, dubbed the "Bernoulli" and "Newton" explanations, each named after the physicist whose physical laws are invoked. The Newton camp contends that since the wing has a positive attack angle—in other words, the wing is angled upward with respect to the forward motion of the plane—the bottom of the wing bounces air downwards. This downward motion produces an equal and opposite upward force on the plane, allowing it to fly.

The Bernoulli camp, on the other hand, argues that the relative speeds of the airflow above and below the wing generate the lift. As air flows over and above the wing, its speed increases. According to Bernoulli's Laws of fluid dynamics, this results in lower pressure above the wing. The difference in pressure keeps the plane in the air.

Why does air move faster over the wing than under it? This phenomenon is often incorrectly explained by the flawed "equal transit time" theory, which states that if two particles of air reach the wing at the same time, they must reach the other side of the wing at the same time as well. The wings of most planes are curved on top and nearly flat on the bottom, so air traveling along the longer upper surface of the wing must move faster than the air below to satisfy this requirement. Thus, lower pressure above the wing, and presto! Planes fly around the world.

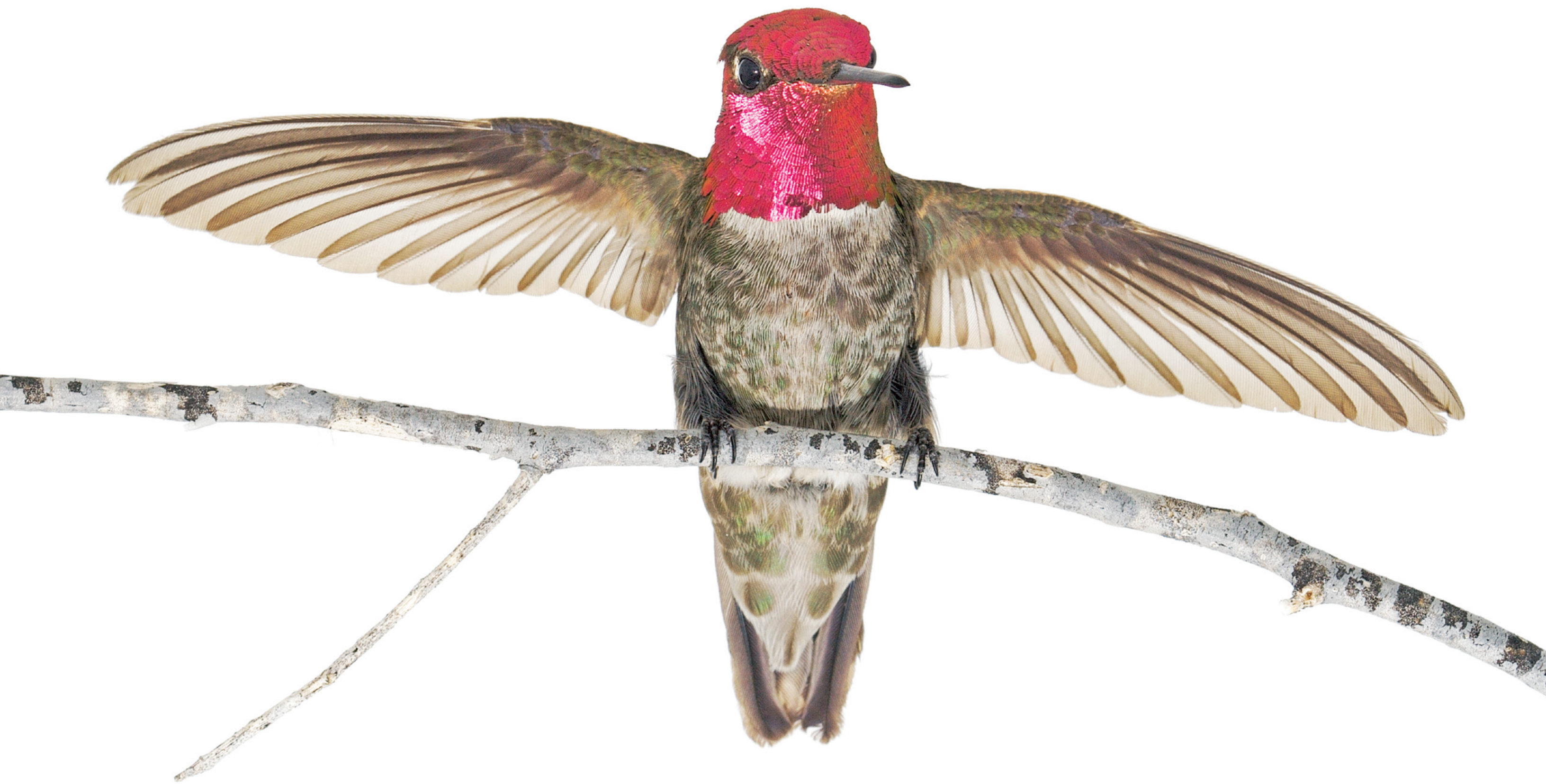
Unfortunately, this is completely incorrect; equal transit times are not actually required by physics. In reality (and in accord with the laws of fluid dynamics), the upper airflow actually tends to reach the edge of the wing first! Furthermore, the plane does no work on the airflow in this scenario, and in physics, where there is no work, there is no force. Finally, a plane can technically fly with a straight, flat wing at a moderate angle of attack; stunt planes can even fly upside down.

Now that we've debunked that rumor, let's return to the original question: Newton, Bernoulli, or neither? Both explanations contain elements of truth, but neither provides a complete answer. In particular, the Bernoulli explanation ignores what the bottom half of the wing is doing, while the Newton explanation ignores the top half. The entire wing produces lift. So how do planes really fly? Ömer Savas, a professor of mechanical engineering working on vortex dynamics created by aircraft, explains airplane lift as a "turning" of the airflow. The wing ultimately directs air downward, creating an upward force on the wing through a combination of angle of attack and wing shape. The flow of air above the wing is indeed faster than the flow below, resulting in a lower pressure. But the flow also follows the shape of the wing. At positive attack angles this will lead the flow downward. This is true for both the lower and upper airflows, and it is a general property of fluids interacting with solid surfaces. The combination of all these effects generates lift—and, ultimately, flight.

The general problem here is that boiling a complex fluid dynamics problem down to a simple explanation often leads to some important facts getting lost in the translation (a difficulty that is not lost on yours truly!), and there are plenty of details and intricacies that cannot be covered in this short article. Engineering schematics of wings are manufacturing secrets, after all, and not all planes look alike. But the next time you find yourself in a plane with a neighbor who wonders how exactly they are staying afloat at 30,000 feet, you will at least be armed with a sensible answer.

Image public domain

Louis-Benoit Desroches *is a graduate student in astronomy.*



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