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DEAR READERS,

When our former editor-in-chief, Kaspar Mossman, first approached me about taking over the reins of the Berkeley Science Review, I was a little scared. How was I, the guy with no formal journalism education and only one issue’s worth of editorial experience, going to run the magazine? My only qualification seemed to be the note “you should be an English major” scrawled pejoratively by a professor who graded one of my windy undergraduate lab reports. Admittedly, I had some big shoes to fill. Kaspar, like many BSR alums, was about to push off on an AAAS Mass Media fellowship. Another editor, Michelangelo D’Agostino, was leaving for London for a summer stint at the Economist.

So I steeled myself, took a deep breath, and called in all the help I could get. From our crack team of editors, to our remarkable art director, Ainsley Seago, this issue really shines with all the optimism, wit, and patience that defines Berkeley grad students.

Issue 9 is so chock full of the breaking science stories that have made this issue arguably the best student-produced science magazine in the nation, that we had to add four pages just to hold it all.

More fascinating stories than I can list await you in this issue. Check out our interview with newly-tenured professor, Ignacio Chapela (p. 51), and stories on Berkeley’s place in a critically-acclaimed opera (p. 20), the harmonious coexistence of viruses (p. 16), and why wolves are good for Yellowstone (p. 18).

Anyone that’s had a friend or family member diagnosed with cancer knows that the treatment can often be as bad as the disease. On page 16, Mark Abel writes about a team developing viruses to deliver drugs precisely to cancers, hopefully paving the way for less debilitating chemotherapies.

Will Grover offers a chilling look into Berkeley’s nuclear heritage on page 41 with a story on Joseph Hamilton, a professor who injected plutonium into human patients.

Looking to the past for hints into the future, the story on page 30 examines what the extinction of big mammals like sabertooth tigers can tell us about the fate of their modern day counterparts, California bighorn sheep.

This issue also marks the start of a new column, Who Knew?, that aims to debunk common misconceptions about science. Check the back page to learn why the Coriolis effect doesn’t have anything to do with which way your toilet flushes.

More than anything, I’d like to thank everyone that made this issue possible. As always, the BSR is assembled by an all-volunteer staff of graduate students. If you like what you see, and especially if you don’t, sign up to work on the next issue.

Check out our website, sciencereview.berkeley.edu for past issues, current positions, and upcoming Science Writing Seminars. Or drop us a line at sciencereview@gmail.com. If you can’t help directly, consider making a tax-deductible donation. We can always use the money!

Enjoy the issue,

Charlie Emrich

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The Sharpest Image

The onward march of computer speed is driven by the ever-shrinking size of a computer chip’s basic building block—the transistor. Smaller transistors mean more can fit on a chip, increasing their performance. Gordon Moore, co-founder of Intel, in 1965 famously predicted the number of transistors in computer processors would double every 18 months. And they have, to today’s nearly 200 million transistors per processor due largely to improvements in manufacturing technology. Today, transistors are made using a technique called photolithography. Much like making a photographic print with an enlarger, photolithography uses light to “print” transistors on a computer chip. The minimum size a transistor can be made is limited by the wavelength of light used, a barrier known as the diffraction limit. Beating the diffraction limit has been a holy grail of engineers ever since Moore’s prediction, and now it seems that researchers in Berkeley’s mechanical engineering department have done just that. Xiang Zhang and his colleagues used a thin layer of silver as a lens to make lines six times smaller than the wavelength of the light source they used. This was possible because light striking the silver surface creates a ghost image just tens to hundreds of nanometers beyond the silver. Unlike conventional optics, the ghost image produced by the silver “superlens” contains all of the precision of the original object. Taking advantage of this phenomenon means getting the superlens really close to, or even touching the computer chip. While this might not be too big of a challenge for chip manufacturers, don’t expect to find silver superlenses in LensCrafters anytime soon. —Charlie Emrich

Want to know more?

Mixed Signals

Seventy years ago, Hans Spemann earned a Nobel Prize for his discovery that a cluster of cells—now termed “Spemann’s organizer”—signals an embryo to form backbone structures. Since then, researchers at UC Berkeley, including postdoctoral fellow Bill Smith and Professor Richard Harland, discovered a protein, called noggin, which is responsible for organizing these cells into a backbone. The team injected noggin into the belly of a vertebrate embryo and, as anticipated, saw backbone structures where the belly was normally formed, confirming the role of noggin in signaling backbone development. Does this mean that backbones won’t form without noggin? Surprisingly, the experiment of blocking the protein noggin showed little effect on embryonic development—the frog embryos still developed backbones. They tried the same experiment with other proteins also known to spur backbone development: xnr3, chordin, follistatin, and cerberus. Each time they got the same result: blocking one protein had no effect on backbone formation. Undeterred, the Harland group recently made a breakthrough by considering several proteins collectively and discovered a striking result. Published in the 2005 March issue of Developmental Cell, Mustafa Khokha, postdoctoral fellow at UC Berkeley, showed that simultaneous blockage of three proteins, chordin, noggin, and follistatin in *Xenopus tropicalis* not only inhibits backbone formation, but greatly expands belly formation. Khokha explains, “defining your back-belly axis is such an important step that you actually have multiple proteins with the same activity there. Just in case one of them fails, the others can compensate.” Redundant signaling bestows the vertebrate embryo with a resilience that increases the chance of survival, revealing that, indeed, you really gotta have spine to make it in the world. —Prayrana Khadye

Want to know more?
Walk This Way

If you have eight legs, why stroll around on just two? Cephalopod enthusiasts are asking this question because, as it turns out, octopuses can walk. According to Christine Huffard, a graduate student in integrative biology who first recorded octopus bipedal locomotion along with Berkeley professor Bob Full and Farnis Boneka at Indonesia’s Universitas Sam Ratulangi, potential predators may be fooled by such uncustomary behavior. Huffard and dive crews captured walking footage of two wild species: *Octopus marginatus* in Indonesia and *Octopus (Abdopus) aculeatus* in Australia. They analyzed video recordings for speed and gait patterns, and found that octopus locomotion in these rare instances would be described by any good biomechanic as walking. In one clip, *O. aculeatus* points six of its curvy legs upward and, bearing a remarkable resemblance to an unassuming algae, walks stealthily backwards on its other two legs. In another video, *O. marginatus* makes a bipedal getaway with its six remaining legs wrapped tightly beneath its head in a round, brown mass reminiscent of the coconuts that decorate its close-to-shore underwater habitat. Apparently, the sneaky octopus has a wider array of cryptic capabilities than previously thought. —Elizabeth Read

Want to know more?
Check out videos of octopuses walking: ist-socrates.berkeley.edu/~chuffard

Jurassic Punk

Baggy pants and pierced tongues just weren’t in during the Jurassic. Outlandish anatomy was more the style—large bones sticking out your back might have been the hip way to identify members of your scene. A group of palaeontologists led by UC Berkeley professor Kevin Padian has published a study suggesting that extreme styles were used long before high school cafeterias, and may have been why stegosaurus had a double row of plates down the back and a spike-laden tail. In fact, species recognition may be the only function of those distinctive boney outgrowths. The researchers sliced through plates of several stegosaurus species and found that the plates lacked specialization necessary for thermoregulation. For heat transfer, large networks of blood vessels would be needed to move blood through the plates. Additionally, other dinosaurs of similar size seemed to survive without elaborate appendages for temperature control. They also rejected defensive and sexual display functions as the plates and spikes are not solid enough to protect the creatures, and are not different enough between male and females to be used in sexual display. Instead, the researchers chose form over function, suggesting that, like present-day teens, stegosaurs went to great pains just to look good.

—Delphine Farmer

Want to know more?
Visit the Padian lab at:
www.ucmp.berkeley.edu/people/padian/webintro.html
Superbugs!
New bacteria on the block

You are crawling with bacteria. Most, happily, are minding their own business. Your gut is home to oodles of *E. coli* that help digest food, while your skin and nose are likely to host *Staphylococcus aureus*—staph. If you’re unfortunate enough to get these normally harmless “bugs” in a cut, scrape, or just some place they shouldn’t be, you’ll end up with an infection and a doctor’s prescription for antibiotics.

Normally, that’s all it takes to get rid of a staph infection, but soon after antibiotics became widely prescribed, in the 1940s, bacteria started evolving ways around them. By the 1960s, strains of *S. aureus* resistant to methicillin (a common antibiotic of the day) began appearing in hospitals. Over the past few decades, these methicillin-resistant *S. aureus* (MRSA) strains grew more common and lethal in hospitals, gaining the ability to inflict deadly pneumonias and even the dreaded “flesh-eating” disease in normally healthy people. To make matters worse, today’s MRSA is increasingly resistant to even the newer weapons in our antibiotic arsenal. And it spreads fast.

At first, MRSA was found mainly in hospitals, where sick patients’ weakened immune systems and abundant antibiotic use combined to create a perfect ecosystem for the bugs to spread. In fact, MRSA is now the leading cause of infection in U.S. hospitals, so prevention methods have been developed assuming hospitals are the source.

But George Sensabaugh, a professor in the UC Berkeley School of Public Health, and his graduate student Binh Diep, have revealed exactly the opposite trend in MRSA dynamics.

Recent reports of MRSA infections in low-risk groups—such as healthy young people—suggested to Sensabaugh that MRSA is alive and thriving in the general community and that it is growing fast as a public threat. To study the population dynamics of community-acquired and nosocomial (hospital)-acquired MRSA strains, referred to as CA-MRSA and NA-MRSA, Sensabaugh and his team focused on samples collected from MRSA-infected San Francisco residents.

Determining whether patients contracted MRSA inside or outside a hospital is hard to do. The method developed by the Centers for Disease Control and Prevention (CDC) and used by most MRSA investigators relies mainly on how recently an infected patient was hospitalized. Sensabaugh believed that epidemiologic characteristics—such as the length of a patient’s hospital stay—do not correctly distinguish between the two groups of bugs. For example, although most patients determined to have community-acquired MRSA were recently hospitalized, it doesn’t necessarily follow that they were infected while in the hospital. Patients who are HIV positive, injection drug users, or have other conditions that lead to frequent hospital visits might actually have CA-MRSA infections. By overlooking these possibilities, Sensabaugh asserted that we underestimate the prevalence of CA-MRSA infection and undermine public health efforts to control infectious spread.

This is where genetic testing came in. In collaboration with a team from UCSF, Sensabaugh and Diep went to work on staph isolated from patients in San Francisco. Instead of defining a MRSA infection according to the patient’s hospitalization record, they studied the DNA of each of the bugs that had infected 490 individuals. They used the standard techniques of pulsed-
field gel electrophoresis and multilocus sequence typing to characterize the isolates at very coarse and fine scales, respectively. They also used a low-cost technique developed in Sensabaugh’s lab—multilocus restriction-fragment typing, a hybrid of the two standard techniques—to further refine the genetic of some of the isolates.

Their investigation revealed that CA-MRSA is not a descendent of a hospital-based strain of MRSA, but evolved on its own. In fact, the two types are genetically distinct, differing in both their resistance to the antibiotics that we use against them and the toxins they use against us.

Alarmingly, the seven-year study period witnessed a nearly five-fold increase in cases of MRSA. This coincided with a five-fold increase in community-acquired MRSA infections, but no change in hospital-acquired cases. In other words, more and more healthy people were getting sick from MRSA. It seems that Sensabaugh was correct when he predicted that prevention efforts have underestimated community-acquired staph. The team also found that the CA-MRSA infections were overwhelmingly caused by only four strains, and that each carried the “type IV SCCmec” set of genes, which gives the staph methicillin resistance.

One of the strains, ST8:8, is emerging as a true superbug. It was first observed in 2000, infecting only a single patient. Just two years later, ST8:8 had caused 300–400 cases, and by late 2004, was responsible for 1200 cases. ST8:8 is now estimated to cause 90% of all the CA-MRSA infections in San Francisco. And contrary to the traditional picture of MRSA dynamics, ST8:8 appeared in hospitals only after its astonishing spread through the community.

How did this superbug spread so far and so fast? Like the other CA-MRSA strains, it carries genes that make it resistant to methicillin. But as Diep notes, ST8:8 packs even more weapons, including the vicious pvl toxin, which can cause deadly pneumonias. And it’s increasingly found to carry multi-drug resistance, which can make it nearly impossible to treat.

Humans have managed to stay alive in this world by using our smarts to outwit our attackers. By investigating the genes that make MRSA so nasty and studying how they evolve and spread, Sensabaugh and his team hope to learn enough about these superbugs so we can stop them before they stop us.

Karen Marcus is a physician-in-training and musician.

Want to know more?
Surfers, fishermen, and divers know that the ocean is a noisy place. It’s crowded with the yelps, pops, and bangs of species calling to each other, the sounds resonating through their swim bladders or blowhole—and that’s just the fauna. Another whole host of mysterious sounds are created simply by the waves. It turns out that waves on the ocean surface, created by the vagaries of the weather, may propagate down through thousands of feet of oceanic abyss and into the Earth’s crust to create a background seismic vibration, measurable across the planet, that persists in the otherwise quiet intervals between earthquakes.

The presence of this background vibration, which seismologists call ‘Earth hum’, was first noticed during the 1980s, when superconducting gravimeters— instruments that measure gravitational acceleration changes caused by the ground shaking—were finally sophisticated enough to record subtle long-term vibrations. The first clue to their source came when Professor Toshiro Tanimoto of UC Santa Barbara looked at data from these seismometers that had been amassed over several years, and noticed that the intensity of the hum shifted with the seasons. He found that the hum was about 10% stronger during the winter: December to February in the Northern Hemisphere, and June to August in the Southern Hemisphere.

But seismologists have discovered that Earth hum is different. Its quiet, barely detectable vibrations can only be heard when the din of earthquakes has ceased, indicating that its source is somehow different from traditional seismic sources. Since the Earth hum was first detected, seismologists have been trying to understand where the vibrations are coming from and how they are generated.

UC Berkeley Professor Barbara Romanowicz and her student Junkee Rhie have definitively answered the first of these questions. Using seismometer arrays in California, Japan, and Europe, they showed, in a September 2004 paper in the journal Nature, that the source of the vibrations is in two major regions of the Earth’s oceans. Specifically, the majority of vibrations emanate from the Pacific Ocean south of Alaska during the northern hemisphere winter, and the Southern Ocean—the continuous band of water that circles Antarctica—during the southern hemisphere winter.

Because these regions are among the roughest on the planet—especially when fierce winter storms blow through—locating the Earth hum at these spots points to a complex interaction between the atmosphere, ocean, and seafloor as the mechanism responsible for the vibrations. Spahr Webb, an earth scientist and oceanographer with the Lamont Doherty Earth Observatory, explains that the hum is driven by ‘infragravity waves’, which are a lower-frequency version of the oscillations in the ocean surface that surfers make use of when they ride towards shore. According to Webb, “The simplest way to think of the creation of these waves is to know that...wind waves come into a beach in ‘wave groups’. After the short waves break, you are left with a low-frequency (20 - 1000 sec) oscillation in sea level: the sea level is lower after the big waves break, and higher after the smaller waves in the group break. This low-frequency oscillation ‘leaks’ back off the beach as ‘free waves’ which are seen all over the deep ocean as infragravity waves.”

While Romanowicz’s finding of the geographic source of the waves supports the idea that it is indeed ocean waves driving the background hum, more detailed information is needed to confirm the exact mechanisms of the process. “I have this model in my head of how the ocean storm generates waves and they...
interact with the ocean floor to create multiple forces of seismic waves. Now
we need to prove it,” says Romanowicz. “I would like to see instrumentation
that would cover the whole water column,” Romanowicz said, envisioning data collection “from the sea floor with seismometers, through the ocean with pressure sensors and chemistry, and through the buoys at the top that can measure wave height and atmospheric parameters.”

Romanowicz believes the larger Earth Science community can also benefit from her findings. Because the Earth is impermeable to light or x-rays, it turns out that the best way to ‘see’ the deep convective structures—such as rising magma plumes or sinking plates—is to use seismic waves, and observing these structures are key to understanding plate tectonics. Romanowicz proposes to use the Earth hum to explore these in a new way, by “getting us away from using standard seismic sources—earthquakes—to using noise to look at the structure. Earthquakes happen at specific times and locations in space and they don’t illuminate structures as uniformly as we want, but we may do better if we can use the noise,” she says. “Continuous sources of seismic waves such as the ‘hum’ may allow [us] to obtain better sampling of the Earth and therefore lead to better quality three dimensional images of the Earth’s interior.”

Jennie Rose is a freelance writer in San Francisco.

Want to know more (and listen to the Earth hum)?
seismo.berkeley.edu/~barbara/hum.html
From the standpoint of biodiversity, our planet is in crisis. Species are disappearing before we learn about them, and existing efforts to expand our knowledge of biological diversity proceed slowly and deliberately. Today, to explore even a small nook of the tree of life is the work of a lifetime.

So what is to be done? One enthusiastic answer comes in the form of “DNA barcoding,” a new technique promoted by some biologists as a solution to the biodiversity logjam.

Here’s the idea: all organisms have a unique blueprint composed of vast sequences of DNA that are subdivided into genes. Genes are passed from parent to offspring, generation to generation. But as lineages of organisms reproduce through time, the genes that are passed along undergo change, and different genes change at different rates. Because all organisms are related and DNA is the mechanism of inheritance, comparing different genes can yield clues about different levels of relatedness. For example, a slowly evolving gene would be informative for organisms that shared a common ancestor deep in time (like a ladybug and a grasshopper), but a faster changing gene would be needed for more closely related individuals (like members of two ladybug species).

Advocates of barcoding zero in on a segment of one particular standard gene, present in all species that they believe varies enough to use it for identification, just as a product barcode uniquely identifies a product. They have attracted tens of millions of dollars and considerable media attention to sequence, or decode, this gene for vast swaths of life. The barcode gene is most often the Cytochrome C Oxidase subunit I (COI) in the mitochondria, a cellular organelle. According to the barcoding vision, a field biologist or amateur naturalist curious about a specimen’s identity would need only obtain the sequence of its barcode gene—a quick and inexpensive process that could soon be accomplished by a handheld device. The investigator would then compare the sequence to a database of existing sequences to yield an instant identification accompanied by life history, ecological, or other relevant information.

At the center of DNA barcoding’s rising stock lies the promise of many practical applications. Customs officials could easily identify trafficked, endangered, invasive, or other important species. Animal and plant ingredients in food products could be pinpointed. Biodiversity could be catalogued over large areas to readily identify diversity hotspots for conservation.

Not everyone shares the vision. A growing opposition to DNA barcoding has emerged from within the ranks of evolutionary biology. And many of the sharp volleys in the debate are sounding from labs here at UC Berkeley.

Asked whether species can be said to have barcodes, Berkeley integrative biology professor, Brent Mishler was unequivocal. “No.” Mishler, an evolutionary biologist who studies mosses and serves as director of the University and Jepson Herbaria on campus, argues that DNA barcoding borrows from a dangerously false view of biological diversity. Barcoding “makes some sense for some systems, like screws in a warehouse,” he says, “but not for an evolving system.”

Products in a warehouse maintain a uniform level of difference from one another that can accurately be tracked by a barcode. But species are not discrete and unchanging units. They are aggregations of individual organisms that collectively constitute the present-day representatives of an evolving lineage. The conditions that drive the evolution of these lineages act on organisms, not on singular characteristics like fur color or particular genes. A single trait, like a gene, might distinguish species within a group of organisms with a common evolutionary history. But any single characteristic is insufficient a priori and on its own to diagnose and classify the whole of biotic diversity. “Contrary to their posturing as cutting-edge,” Mishler argues, “DNA barcoders are returning to an ancient, typological, single-character approach, and are maintaining a pre-Darwinian view of species.”

In fact, studies have shown that the family trees of particular genes do not always correspond to the family trees of the organisms that harbor those genes. And empirical studies of barcoding projects have used the same data as barcode...
proponents to reveal the absence of a one-to-one relationship between mitochondrial barcode variation and species variation. For Daniel Rubinoff, associate professor of Entomology at the University of Hawaii and former UC Berkeley PhD student and postdoc, the reasons for these shortcomings come down to a simple fact. “A dynamic process like speciation can’t be modeled by a procedure as rigid as barcoding.”

Biologists who caution against barcoding do not object to using genes to identify species. But they argue that because evolution is not uniform across the tree of life, biologists must first understand groups of organisms. Only then can they determine the best characteristics for species identification. Kipling Will, assistant Professor of Insect Biology and associate director of Berkeley’s Essig Museum of Entomology, emphasizes the need for integrative taxonomy, an approach that employs more traditional means, in addition to DNA, to categorize organisms. According to Will, it is after “systematic and taxonomic study, [that] the best tools to identify important biological units can be used. This might be DNA. It might even be [the mitochondrial gene] COI.”

As technologies arise, Mishler, Will and others want to see them employed within the framework of integrative technology, not outside of it. “There’s a huge desire to describe biodiversity,” says Will. He warns that taxonomy is not a rote task that can simply be automated. “It requires human brains to figure it out. And what they want is a shortcut…[that] seems to be losing a lot of important information on the way.”

Others worry less about the scientific shortcomings of DNA barcoding, focusing instead on the attention and funding the idea brings to collecting and cataloging world biodiversity. “Can we wait? Do we have something more realistic, better right now?” asks David Vieites, a postdoctoral researcher in the Wake lab in Integrative Biology. Vieites says he agrees fully with the criticisms of DNA barcoding. But he’s willing to accept and improve an imperfect system. “We have to try to make it better. In whatever database that’s built just put a lot of ‘be carefuls.’”

Pro or con, the Berkeley evolutionary biology community has been at the center of the barcoding debate. As Mishler points out, this is in part because “Berkeley is strong across the board in systematics,” a fact that has a lot to do with the university’s collection of strong natural history museums—the Museum of Vertebrate Zoology, the University and Jepson Herbaria, and the Essig Museum. It is in collections like these that the fruits of collecting expeditions across the globe are deposited, and where biologists can begin to discern the nature of evolutionary history. Regardless of their stance on barcoding, biologists can agree that any solution to the biological diversity crisis must begin in collections like those housed here.

Aman Singh Gill is a Berkeley graduate and lab manager of the Kipling Will lab, in the Department of Environmental Science, Policy, and Management.

Want to know more? Visit Berkeley’s Natural History Museums on the web: bnhm.berkeley.edu
Two bacteria-infecting viruses, known to a small circle of microbiologists as f1 and IKe, each consist of a short loop of single-stranded DNA enclosed in a flexible protein capsule. With little else to their daily lives apart from replicating their genetic packets, these bacteriophages lie on the murky boundary of what can be considered a living organism. Yet, over the course of some ingenious artificial selection experiments, postdoctoral researcher Joel Sachs of the Department of Integrative Biology and his collaborator James Bull at the University of Texas have induced these feisty bacteriophages not merely to coexist but to cooperate within the same bacterial cell.

Although Darwin taught us that organisms are inherently selfish, cooperation among organisms is the foundation of biological diversity. That lichen you see encrusting a chunk of salt-and-pepper granite on the John Muir trail is actually a symbiotic pairing between algae, which converts sunlight to sustenance, and a fungus, which guards the algae from desiccation in the mountain air. And, of course, millions of years ago an ancestral eukaryote (a group in which humans and all animals are members) swallowed up another single-celled organism—which has become our mitochondria, responsible for energy conversion at the cellular level. Trillions of these mitochondria reside inside every human—along with the billions of one-celled organisms which peacefully inhabit our gut and assist in digestion. In such a selfish world, how have these types of mutualisms maintained stability over evolutionary time? This is precisely the question Dr. Sachs set forth to address in his study of the humble bacteriophages f1 and IKe.

Sachs spent the early part of his graduate research career studying cooperation in nesting birds and photosynthesizing jellyfish, but he was drawn to the simplicity of using bacteriophages to delve deeper into the mysteries of cooperation. Bacteriophages make their living by infecting bacterial cells and hijacking the cell’s resources in order to replicate their own genetic matter. Normally, the two phages Sachs studies have difficulty surviving if they infect the same bacterial cell because the two compete for the same cellular machinery and must endure a reduced rate of replication than if they were each the sole inhabitant.

In his most recent study, Sachs designed a method to select for bacteriophages that, instead of competing for cellular machinery, could actually cooperate with one another. The first step in his elegant plan was to engineer these competing phages to each carry a different antibiotic resistance gene. He then raised the bacterial hosts on plates that were coated with both types of antibiotics so that only coinfected bacterial cells could survive. The coinfected bacterial cells were evidence of bacteriophage cooperation. At the start of the experiment, as expected, the two phages performed rather poorly, but after fifty cycles of reinfection—during which time the phages were slowly evolving—not only were they able to improve their own reproductive rate, but they exceeded the reproductive output of their solitary ancestors.
In order to parse out the evolutionary changes that led to such successes, Sachs sequenced the entire genome of f1 and IKe before and after his selection experiment. Unfortunately, he ran into a bit of a stumbling block. Sequencing the f1 genome was no problem, but when he tried to sequence the evolved IKe genome, he got nothing. “I was so down,” he says. “Nothing was working. I didn’t know what the problem was with my sequence data. We were just getting hints and little chunks that were working.” Finally, as a last ditch effort, Sachs used gel electrophoresis, a process by which an electric field separates out biological particles of different sizes on a gel medium. “I guess my Eureka moment was when I finally ran that gel.”

The DNA from the modified IKe travelled further than the ancestral DNA, which meant that IKe had discarded nearly 60% of its genetic material. The “little chunks” Sachs had sequenced before weren’t chunks at all but IKe’s entire scaled-down genome! This new streamlined IKe consisted of only three genes: the crucial antibiotic resistance gene, a gene which allows the phage to replicate, and a kind of regulator gene. What was missing, Sachs realized, was IKe’s protein capsule. Sachs ran a quick experiment to prove that IKe was unable to produce a capsule on its own, which meant that it was somehow able to use f1’s protein capsule—rather remarkable since the two phages are quite different. At the beginning of the experiment phages were cross-packaging less than 3% of the time, but by the end, IKe was able to slip inside f1’s protein coat 100% of the time.

Thus, these two phages were able to cooperate in the long-term because their reproductive success was inextricably linked: f1 depended on IKe’s antibiotic resistance and IKe depended on f1’s protein coat. “Enhancement of partner fidelity,” Sachs says, “is a widespread mechanism by which individual interests are aligned.” But Sachs’ results don’t just hold for tiny phages, they can be used to explain the existence of those crusty lichens to the origins of our mitochondria and even to the interactions among biologists themselves. When asked if all this work on the vagaries of cooperation had made him better at working with his colleagues, Sachs replied, “Maybe not, but at least I know when it’s beneficial for me to cooperate.”

Brendan Borrell is a graduate student in integrative biology

Want to know more? Check out:
Better Living Through Viruses
Chicken Soup for the Cell

Drug-induced side effects are taking over. Pay attention to the prime-time commercials for even half an hour and you’ll hear about more side effects than solutions. The problem is not necessarily the drug molecules, but the way they are introduced to the body—inoculation. Matt Francis, assistant professor of chemistry at Berkeley, has big plans about how to make inoculation go more smoothly and is applying this idea to powerful anti-cancer drugs.

Most drugs are either taken orally or injected. Either way, the drug molecules enter the bloodstream, flooding the patient’s body and visiting every tissue. The drugs can potentially interact with every type of tissue, helping one portion of the body while hurting another. This lack of specificity (e.g. for cancer) is the origin of the depressed red blood cell count, irritability, nausea, and hair loss that chemotherapy patients endure.

If drugs could be concentrated in the sick portion of the body—in the tumor—these side effects would virtually disappear. Doses could decline because instead of throwing drugs at every organ in the body the treatment would be tactical, constrained to one area. This is the goal of the Francis lab, and they draw inspiration from an unlikely source: viruses.

The idea is to use viruses as a scaffold, attaching drugs and other molecules to their surfaces. There are three problems to overcome with this approach, explains graduate student Ernest Kovacs. The first is actually attaching a drug or any other molecule to the virus. The second is that for the drug to be useful the virus particle has to find a tumor, and the third problem is that the virus has to survive the patient’s immune response long enough to deliver its payload.

The Francis lab has been working to attach foreign molecules to the surface of a virus called bacteriophage MS2. Why this one in particular? “There are several reasons,” says Kovacs. Among these, “its known crystal structure provides excellent guidance for our selective chemical modifications.”

A virus is a combination of a capsid (a shell made mostly of protein) and a genome (DNA or RNA coiled inside). Capsids are typically made of hundreds of protein molecules, each of which is a combination of amino acids, like colored beads arranged on a string. Coil the amino acid strands to make proteins, stack the proteins to make a capsid. It would be difficult to get anywhere on a chemical problem like this without a crystal structure, a map of where the different amino acids lie.

Each amino acid can react chemically, bonding to a foreign molecule. Francis, Kovacs, and their coworkers have been perfecting the chemistry that enables them to remove the viral genome, then attach any molecule they desire to either the inner or outer surface of the capsid. This flexibility enables the placement of drugs on the inside, and camouflage against the immune system on the outside.

Kovacs is now teaching the viruses to target tumors. He points to a messy workbench enclosed under a glass safety hood. Today, he is working on synthesizing viruses that have folic acid bound to their exteriors because most types of cancer cells have a gigantic number of folic acid receptors on their surfaces—many more than healthy, normal cells. Bacteriophage MS2 has 180 proteins in its capsid (“180 times the chemistry,” he grins), which should lead to a huge concentration of drug-carrying viruses in tumors.

Francis and his students can bind whatever drug they wish to a viral capsid, they understand how to make the virus target cancer cells, and they think they also have a way to get a patient’s immune system to ignore the virus.

Even though bacteriophage MS2 is harmless to humans—it won’t infect our cells—the immune system will destroy it. Poly-(ethylene glycol), PEG,
is a polymer that acts like camouflage. It dissolves in water, making it easily deliverable throughout the body and, most importantly, your immune system can’t make antibodies for PEG. This means that, unlike the viruses that cause diseases, your body will never gain immunity to a PEG-coated virus.

So the game plan is: bind drugs, folic acid, and PEG to the outside of bacteriophage MS2, try it out on real tumors, and if all goes well, go to the FDA for approval. This scheme could save the lives of millions of cancer patients, and reduce the miserable side effects that come with chemotherapy.

Mark Abel is a graduate student in chemistry.

Want to know more?
Check out the Francis lab on the web: www.chem.berkeley.edu/francisgrp

This virus is the “syringe” that, after modification, will stealthily deliver drugs to targeted tissues.
Crouching Scientist, Hidden Salamander
The Korean salamander that shouldn’t be there … or should it?

Lying in an icy grave of frigid industrial water in a black ice bucket, a salamander waits to have its liver taken out—a small but important step in making herpetological history. The salamander is *Karsenia koreana*, and its recent discovery is a story of surprises, paradoxes, and new insights into the history of salamanders.

This story began in April two years ago in a rocky, forested habitat in the vicinity of Jangtae-san, Daejeon-si, Chungcheongnam-do, Korea, where Stephen Karsen, a high school biology teacher from Illinois who teaches at the Taejon Christian International School in Korea, came across an unusual salamander. “I knew the moment I picked it up that it had to be at least a new record for South Korea— or possibly completely new,” he recounts.

Karsen, unable to identify the salamander, approached amphibian specialists M. S. Min of Seoul National University, S. Y. Yang of Inha University in Incheon, and a former professor, Ronald A. Brandon of Southern Illinois University in Carbondale, who in turn drew it to the attention of David B. Wake, professor emeritus of integrative biology and Curator of Amphibians at UC Berkeley’s Museum of Vertebrate Zoology.

The salamander was clearly different from all known Asian salamanders and was identified as a plethodontid, or lungless salamander. Based on the morphological and molecular data, it was placed in a new genus—*Karsenia*, named for its original discoverer, Karsen. The common name is Korean crevice salamander, or Ikkee dorongyong in Korean.

Wake, known to some as “Commander Salamander,” and his colleagues published the discovery in *Nature* last May. They explain that this Asian discovery was initially astonishing because 99% of lungless salamanders are found in the Americas. Prior to the discovery of *K. koreana*, the only place outside of the Americas that lungless salamanders were found was the western Mediterranean.

But as surprise at this discovery wanes, hindsight is leading researchers to revise their initial assumptions.

“We should have expected to find plethodontid salamanders in Asia. It is actually quite logical,” acknowledges Wake. The fact that the species is found in both the Americas and the Mediterranean strongly suggests that there was a continuous population at some point in the past. This realization has necessitated modifications to the hypotheses of plethodontid historical biogeography.

Another reason the discovery was unexpected was because the amphibian population of Korea was thought to be fully catalogued. Researchers did not expect to discover a new species of any animal in such a seemingly well-understood ecosystem.

How did *K. koreana* escape notice for so long in such a familiar environment? David Vieites, a post-doctoral fellow in the Wake lab and a co-author of the *Nature* study, attributes this to the fact that these plethodontids are terrestrial. In Asia and in Europe, there is an understandable bias for exploring aquatic habitats because most salamanders live in water, even as adults. “These are not aquatic at all. So these Korean researchers searched only in aquatic habitats, [which is] one of the reasons why these salamanders are overlooked,” explains Vieites.

Now that researchers know where to look, they are finding that *K. koreana* is actually very common. Following his group’s initial publication, Vieites traveled to South Korea with two goals in mind: to collect more specimens and tissue samples and to figure out whether there are more plethodontid salamanders in surrounding regions. He spent 10 days in the field hunting for the salamander throughout Taejon, the Korean crevice salamander’s only known relatives are in Italy and the Americas, raising the question: how did it get to Korea?
a city near the site of Karsen’s initial discovery, and neighboring areas; in the end, his work paid off, and he reported that *K. koreana* is relatively prolific.

According to Vieites, this salamander can easily be found in at least three national parks—a fortunate circumstance for researchers interested in studying the new species.

Vieites found around 40 specimens and collected around 80 tissue samples from tail tips. Based on this data he was able to estimate that the salamander has a well-distributed range of 50 by 150 km. Because all of the specimens were morphologically similar, Vieites suspects there is just one species rather than a huge radiation of plethodontid salamanders in Korea, as is the case in the Americas.

Looking forward to future findings of plethodontid salamanders in Asia, Vieites states, “We have plethodontid salamanders in the Americas, the Mediterranean, and now in Korea. Why not in other parts of Asia? China is enormous, huge. If we are lucky, maybe we’ll find more. Why not? We don’t know, but I think it’s worth it to give it a shot in China. It will be fun.”

Last May alone Wake’s group discovered five species of salamanders. Those five species fall into three genera, including *Karsenia*. In 1985, there were approximately 4,000 species of amphibians and, at last count, there are 5,951 species of amphibians, according to AmphibiaWeb (amphibiaweb.org).

This is especially good news considering that worldwide amphibian populations are in decline. So along with the paradox of being a predictable surprise, the first Asian representative of the plethodontid family presents another welcome paradox: according to Wake, at a time when “amphibians are declining, we are finding new species.”

Janet Fang received a BA in Integrative Biology and English from Berkeley.

Doctor Atomic
... or how we learned to stop worrying and love our nuclear heritage

One hundred years after Einstein’s “miraculous year” of 1905, and 60 years after the atomic bombings of Hiroshima and Nagasaki, the San Francisco Opera will host the world premiere of Doctor Atomic.

Set in the New Mexico desert, this latest collaboration between composer John Adams and director Peter Sellars explores the hours leading up to the first atomic bomb explosion at the Alamogordo “Trinity” test site in July of 1945. Witnessing the blast, J. Robert Oppenheimer, leader of the Manhattan Project quoted from the Bhagavad Gita: “now I am become death, the destroyer of worlds.” Envisioned as an American Faust—a tale of science’s seductive power—Doctor Atomic highlights the scientific and moral crises surrounding the world’s first nuclear bomb.

The dawn of the atomic age was not just for physicists and historians. Wolfgang Willashek, dramaturge for Doctor Atomic, comments that “both communities: the Berkeley and the opera community can learn a lot from this wonderful experience.” Mark Pedretti, a graduate student instructor recently awarded a grant from the Consortium for the Arts & Arts Research Center to develop the course “Nuclear Time: History and Representation”, notes that “Most students—indeed, probably most Americans don’t really have a good understanding of what was at stake in the [Hiroshima and Nagasaki] bombings. They have distanced themselves from the unspeakable horror of what a nuclear attack actually does.”

Do Americans have a responsibility to fully understand the horror of the nuclear attacks on Hiroshima and Nagasaki? This anniversary provides a solemn opportunity to reflect on such questions and also to consider the continued development and maintenance of our own nuclear arsenal.

The sets for Doctor Atomic draw inspiration from blueprints of nuclear labs. Featured characters include Oppenheimer and his wife, Kitty; Edward Teller, father of the hydrogen bomb; and General Leslie Groves, the US Army commander of the Manhattan project. Pedretti adds that “the opera affords the campus an opportunity to engage in a broader exploration of the atomic age, nuclear weapons, and the legacy of the bomb for American culture and thought.”

Adams and Sellars mine the rich scientific and cultural histories left after the Manhattan Project for the meat of Doctor Atomic. The libretto and arias sprung from sources ranging from cold war era poetry and biographies, to technical manuals of nuclear physics, declassified military files, and Oppenheimer’s personal letters—some which are currently archived in the Bancroft Library. Known primarily as the director of Los Alamos National Laboratories and leader of the Manhattan project, Oppenheimer was a UC Berkeley physics professor early in his career. He

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Gerald Finley (as J. Robert Oppenheimer) paces beneath Doctor Atomic’s ominous centerpiece, an enormous, suspended atomic bomb.

The universe is made of stories, not of atoms.
—Muriel Rukeyser
Hungry Like the Wolf

Predator reintroduction in Yellowstone may soften the impact of climate change.

As the sun rises over the cold, grassy plains of Lamar Valley in Yellowstone National Park, Dr. Chris Wilmers stands atop a small hill just beyond reach of the white fog blanket below. High above his head he holds a radio antenna, straining to get a fix on his target—the Druid wolf pack, the largest group in the park with over 20 animals. When he finds them, he tracks them with powerful spotting scopes, hoping to catch a view of a kill. Perhaps he’ll witness an elk hunt, with the pack working strategically to isolate an animal from the herd before striking together as a unit. One wolf attacks a rear leg, two more move in to grip another rear leg and a front, while a fourth lunges for the neck.

It’s just another day in the “lab” for Wilmers. But it’s a scene that could not have taken place before 1995, when gray wolves were reintroduced to Yellowstone for the first time since the last wolf in the park was shot in the 1920s. According to recent findings of Wilmers and colleagues in Berkeley’s College of Natural Resources, the returned predators may affect Yellowstone differently than anyone had foreseen. Their new study, published in *PLoS Biology*, shows that wolves can almost single-handedly propelled the Berkeley physics department into becoming a powerhouse in theoretical physics. Indeed, the early theory for creating an atomic weapon was developed, not at Los Alamos, but in UC Berkeley’s LeConte Hall. The consequences of these discoveries are important to contemplate as citizens of the US and perhaps even more so for those of us at Berkeley who have inherited this scientific legacy.

Given Oppenheimer’s tenure at UC Berkeley, the campus will be hosting events in conjunction with the Doctor Atomic premiere and in commemoration the 60th anniversary of the bombing of Hiroshima and Nagasaki. The Pacific Film Archive is presenting a series titled “Doctor Atomic Goes Nuclear,” featuring films addressing topics of nuclear war and culture, including Berkeley journalism professor Jon Else’s film *The Day After Trinity*: J. Robert Oppenheimer and the Atomic Bomb. Else is also documenting the development and production of Doctor Atomic on film.

In addition, UC Berkeley’s Consortium for the Arts & Arts Research Center is sponsoring poetry readings, panels, lectures, addressing the atom bomb’s creation and its fraught legacy. The Consortium has also offered curriculum development grants to instructors and faculty to develop courses for the Fall 2005 and Spring 2006 semesters that explore issues related to the atomic age through the visual, performing, and literary arts.

The stage is set for the reawakening of public understanding of our atomic heritage. Doctor Atomic and the events and projects sponsored by the Consortium for the Arts hold the promise to introduce a new generation to the significance of our nuclear past, present, and future.

Melissa Fabros is a graduate student in English.

Want to know more?
Check out: doctor-atomic.com
Consortium for the Arts at UC Berkeley: bampfa.berkeley.edu/bca
The Exploratorium’s website: www.exploratorium.edu/doctoratomic
soften the impacts of climate change on the park’s ecosystem because of the unique way they distribute food to the region’s scavengers.

For ecologists, the reintroduction serves as a rare opportunity to examine a region with and without the presence of a top predator. Biologists know that predators impact their prey populations, which in turn affect populations lower down the food chain. Wilmers’s work casts a wider scope. He focuses on wolves’ influence on other carnivores that rely on the scavenged remains of wolf kills to survive through winter, including bears, eagles, ravens, foxes, coyotes, vultures, and several smaller birds.

“Scavengers are the great recyclers of nutrients,” says Wilmers. Professor Wayne Getz, Wilmers’s coauthor and dissertation advisor in the Department of Environmental Science, Policy, and Management, agrees “They are absolutely critical to the health of the ecosystem.”

Without wolves, scavenger food availability depends almost entirely on environmental conditions. According to previous work by Wilmers and Getz, snow depth and the population density of elk—the most common grazing animal in the Yellowstone area—were the biggest factors affecting carrion abundance. “Deep snow on the ground makes it harder for elk to move around on the landscape and harder to reach resources hidden in the snow,” explains Wilmers. When elk die, scavengers feast.

Prior to wolf reintroduction, elk death peaked strongly around late winter, when energy levels are low and food is scarce. Wolves change that equation by hunting year-round and smoothing out the peak of food availability. “Wolves serve to stabilize the availability of scavenger resources throughout the year,” says Getz.

Without wolves, scavengers are significantly more sensitive to climate change because their food sources are so dependent on winter conditions. Wilmers is one of the first to examine some of the effects of climate change on Yellowstone. He found that snow depths have been steadily declining over the last 55 years (since data has been recorded daily at ranger stations). Winters are getting shorter, as measured by the number of days with snow on the ground, resulting in carrion reduction.

Wolves reduce the severity of these climatic effects on their fellow carnivores. Wilmers established a formula from field data describing how carrion availability depends on pack size, kill rates, and biomass of elk.
consumed at each carcass. Another formula describes carrion resources in the absence of wolves, based on snow depth. From these, he determined Yellowstone carrion changes with and without wolves between 1950 and 2000, due to measured climate changes. Without wolves, carrion availability in April—a key time when large scavengers like bears emerge from hibernation—would have decreased by 66 percent. With wolves, the figure is only 11 percent. Wilmers verified these results with a separate model that simulates the dependence of wolf and elk population dynamics on parameters such as fertility rates, lifespan, hunter kills, and more.

“Scavengers adjust to the bottlenecks” in food availability, says Getz. “Bottlenecks are much worse without wolves. They are likely to be even more severe under the effects of climate change.”

These results build on Wilmers’s earlier work showing that wolves voluntarily surrender partially-eaten kills to scavengers. With the effort it takes to bring down an elk, one might expect a pack to guard the precious meat from challengers. But for wolves, it can be more efficient from a caloric standpoint to leave the kill and bring down another later. Other predators behave differently, Wilmers explains: “Mountain lions, for example, are solitary animals. When they make a kill, it’s usually in dense forest,” making it easy to hide away future meals. Wolves, on the other hand, hunt prey in wide, open valleys, visible to competitors. “The ravens are already flying overhead … they don’t really have the option of trying to hide it.” Leftovers must be protected or surrendered.

Protection, says Wilmers, “is a dangerous prospect,” when competitors include grizzlies, coyotes, or a rival wolf pack. Instead, the pack gorges itself and moves on. “There’s a feeding frenzy. They circle around the elk and eat as much as they can. Once they’ve filled their bellies, they move off a couple hundred yards away to sleep it off. That’s when the scavengers move in.”

Wilmers has done the math to show this is a smart idea for wolves. Measuring the energy intake of wolves from a kill is no small feat. To accomplish it, Wilmers timed wolves and scavengers consuming different parts of the elk body—first the organs and entrails, followed by muscles and brain, hide, skeleton, etc. He also butchered hunter-killed elk to measure the calories contained in these different body parts. Finally, he took bone marrow and incisor samples from wolf kills in the field to determine the sex, age, and condition of the elk that died. All of this data allows Wilmers to estimate how much energy a wolf generally receives from a kill—and how much is left to scavengers. He discovered that wolves’ propensity to gorge and move on is the most energy efficient choice under their circumstances. ‘Wolfing’ down the meal turns out to be beneficial for both the wolves and the scavengers.

Taken as a whole, the research shows the broad effect wolves have on their surroundings, and it’s an important lesson for areas facing environmental stresses. As Wilmers puts it, “ecosystems with intact predators are more resilient to change.”

LORNA LUNDQUIST is a graduate student in astrophysics.

Want to know more?

“If you don’t sleep in seminars, you’re not working hard enough.”
—Dudley Herschbach of Harvard University citing Pimentel’s Theory during a seminar, September 27, 2005.

“I think one of the great projects of the next decade will be understanding the molecular biology of free will.”
—Gerry Rubin of UCB speaking at “Science of the 21st Century: Symposium to Honor Charles V. Shank” May 24, 2005, after showing a video of two flies fighting over a feeding spot.

“Who knows, after the last reality show dies a horrible, painful death, who knows … maybe the next vogue in television will be science.”
—Dan Mogulof, former TV producer and current Executive Director of Public Affairs for UCB, during IB304, October 11, 2005

“If you studied all of the people in this room as a group, you would find that the average person has one testicle and one ovary.”
—Steven Chu, Director of LBL, speaking on October 4, 2005: “Bio-molecular Machinery as Seen Through Single Molecule Methods.”
GRAVITY IS A RELENTLESS FORCE. Twenty-four hours a day, seven days a week, it keeps our feet firmly planted on the ground, sending back down to Earth everything that goes up. Or almost everything. But even in those rare moments when man manages to escape the clutches of Earth’s gravity with a rocket, it doesn’t relinquish its hold easily—it pulls and tries to slow the craft all the while.
And so it is with the universe, physicists used to think. Since the Big Bang, galaxies have been hurtling away from one another. But just as with a rocket or a ball, gravity should act to slow the expansion down. Maybe gravity is strong enough to pull all the galaxies back together in a Big Crunch, like a ball that eventually returns to the ground from which it was thrown. Or maybe, like the rocket, the galaxies would continue to go forever, all the while slowing but moving just fast enough to keep going. Certainly, though, gravity would slow the expansion down.

In 1998, however, Berkeley physicist Saul Perlmutter made an astonishing discovery: our universe is actually expanding at an accelerating rate. This discovery, named ‘scientific breakthrough of the year’ by the journal *Science*, contradicted conventional cosmological theory and gave birth to the mysterious concept of “dark energy.” Faced with the reality of an accelerating universe, physicists have been forced to reevaluate their assumptions about matter and energy. Einstein’s theory of general relativity suggests that the universe must contain far more energy than science has thus far been able to measure. This energy is called “dark” because we can’t detect it directly, just as “dark matter” was termed dark (though dark matter and energy are unrelated in every respect but name). The nature of this energy remains one of the key open questions in modern physics. Perlmutter and his colleagues at LBL, along with cosmologists around the world, are now in a race to provide a convincing answer to these open questions.

**Einstein’s greatest blunder?**

By 1917, Einstein had cooked up a stunningly beautiful theory that explains how gravity works: both energy and massive bodies like the Sun warp the fabric of space and time itself. In turn, other objects, like an orbiting planet, travel along the curved contours of this distorted space. While Einstein’s theory of general relativity succeeded where Newton’s theory of gravity failed, it made an unexpected prediction: the universe is either expanding or contracting. Convinced that the size of the universe must actually be static, Einstein corrected his equations by giving space-time itself an intrinsic repulsion that he called the “cosmological constant.”

Experimental refutation of Einstein’s static universe soon came from astronomer Edwin Hubble. High in the mountains above Los Angeles, Hubble first discovered that there are many galaxies beyond our own Milky Way. He also noticed an odd phenomenon: the light from these distant galaxies was shifted in wavelength toward the red end of the electromagnetic spectrum. He attributed this to the Doppler effect—the same process that causes the pitch of a siren to drop as it passes an observer. This implied that the galaxies were all moving away from us. Furthermore, if he made a graph of the speed of a star versus its distance from the Earth, the data points fell on a straight line. Such a plot has become known as a Hubble plot, and the slope of the Hubble constant, which quantifies the actual speed at which the universe is expanding. While these discoveries catapulted Hubble to the status of a legend among scientists and socialites*, Einstein was left feeling that the cosmological constant, resulting from his insistence on a static universe, was the “greatest blunder” of his life.

At first glance, Hubble’s result poses a pretty serious problem: if everything is flying away from us, the Earth must...

*Hubble counted Charlie Chaplin, Aldous Huxley, and William Randolph Hearst as his friends, and the Hooker telescope where he made his observations became a tourist attraction.
occupy some unique and central position in the universe—a conclusion many theologians might embrace. Hubble realized that this issue is moot if the entire universe is expanding. “The picture isn’t that stuff is exploding away from us,” explains Berkeley physics professor Lawrence Hall, but that “everything is moving away from everything.” Hall, who has studied the interface between cosmology and particle physics for years, points out that “nothing’s really moving. More space is just being created between neighboring galaxies. It’s more like space is being stretched.” “As a photon travels through the universe that’s stretching” explains Perlmutter “its wavelength gets stretched in exact proportion to the stretch of the universe’. This accounts for the shifts in wavelength measured by Hubble. “Redshift on a Hubble plot is telling us very directly the total expansion of the universe since the light left a star.” In this way, Hubble’s plot was the first history of the universe’s expansion over time.

**Standard candles**

While Hubble’s discovery was a fundamental insight into the nature of the universe, his techniques were crude by modern standards. By comparing a celestial object’s intrinsic brightness to its brightness as measured here on Earth, astronomers can tell how far away the object is. Since Hubble had only rough estimates of the actual intensities of the galaxies he was measuring, he did not know their exact distances. The problem, Perlmutter jokes, “is that there are no light bulbs in the sky conveniently stamped, ‘60 watts’.”

Astrophysicists have recently discovered that a certain kind of supernova does have a known absolute brightness—the astronomical equivalent of a 60-watt standard. “When stars with masses similar to the sun use up their fuel,” explains Perlmutter, “they ordinarily spend the rest of eternity as a white dwarf, gradually cooling away. But if a white dwarf orbits a neighboring star close enough that the star’s solar wind falls on the dwarf, it will build up mass little by little until it reaches just enough mass for a runaway nuclear explosion.” Such explosions are known as type Ia supernovae and always have a similar intensity because they always occur when the star reaches a very specific threshold mass. T ermed “standard candles” by cosmologists, type Ia’s have allowed the measurement of the Hubble constant in recent years with unprecedented precision.

**The universe quickens its pace**

The Hubble constant is actually a bit of a misnomer. “It should never have been called the Hubble constant,” laments Hall. “I would call it the Hubble function, and
the Hubble function is a function of time.” Conventional reasoning suggests that as the universe expands, gravity should pull it back inward, thus slowing its expansion. This means that the Hubble constant—the speed of the universe’s expansion—should be smaller today than it was in the past. Perlmutter’s team set out to measure this deceleration over a decade ago using these type Ia “standard candles” to survey very distant, and hence ancient galaxies.

Perlmutter recalls that “we thought we would see the supernovae brighter than predicted by Hubble’s Law. By seeing how much brighter would tell us how much the universe was slowing down.” Surprisingly, his group at LBL as well as a competing group from Harvard, saw exactly the opposite. “They were even fainter than what you would expect for a universe slowing at all, and in fact were so faint that they could only come from a universe that is speeding up.”

The most popular way to account for this newfound acceleration has been to revive Einstein’s cosmological constant. Instead of casting it as a fudge-factor to make the equations spit out a static universe, the cosmological constant has been reborn as a new, unseen form of energy. This dark energy exerts a strong negative pressure that counters the inward pull of gravity. In order to match the rate of expansion that the LBL and Harvard teams independently measured, the unexplained dark energy must account for two-thirds of the total energy content of the universe.

The circumstantial evidence

Perlmutter’s supernova data are not the only measurements to suggest that dark energy exists. Several forms of corroborating evidence, including recent measurements of the Cosmic Microwave Background (CMB) and of the large scale structure of the universe, have since emerged. The CMB is a lingering remnant of the birth of atomic matter about 400,000 years after the Big Bang. These freshly cooled atoms gave off light whose wavelength has since stretched into the microwave region of the spectrum as the universe has expanded. These microwaves comprise our most ancient picture of the 14 billion year old universe. Put another way: if the universe were an eighty year old man, the CMB would be a photograph of him taken just eighteen hours after birth.

Berkeley physicist Paul Richards used the MAXIMA telescope, floating on a balloon high above much of Earth’s atmosphere, to measure the CMB and get a glimpse of the universe’s baby pictures. Richards describes observing the CMB as “looking at a fog across the bay. As you look further and further away, further and further back in time...you only see its surface and nothing within.” The light coming from this surface is remarkably uniform, marred only by very slight fluctuations—ripples caused by the Big Bang itself. The nature of the fluctuations can tell physicists about the geometry of the space they travel through.

According to Einstein, gravitational forces arise because matter and energy alter the geometry of the space in which they reside. An empty, non-expanding space will be “flat”, meaning it follows all the rules taught in high school geometry, such as parallel lines never crossing. However, when space is filled with massive objects or energy, it becomes “curved” and many of these familiar rules of geometry break down. Even if an expanding universe contains mass and energy, it can still be flat, provided that it has a very specific density. This “critical density” describes a universe just barely light enough to avoid an eventual collapse.

Examining the CMB closely reveals that the universe is flat. Richards explains, “you can judge the distance to a car down the street because it looks smaller than it really is and how much smaller tells you how far away it is. But if you put
a lens in front of your eye, it will distort the image, making it look smaller or larger. But that’s exactly what a curved space does to light, it lenses it.” Curved space will also distort the polka-dot pattern in the CMB. Because scientists know the size of these spots in the CMB and the distance to them, they can calculate how large the fluctuations should appear when seen from Earth: for a flat universe, they should be the size of a full moon. But the size they actually appear depends on how curved the universe is, because a highly curved universe would magnify or de-magnify these dots from their size in a flat universe. The MAXIMA telescope was one of the first to successfully measure that the size of these fluctuations is indeed the correct size for a flat universe, and this has since been confirmed by satellite measurements.

Richards’ measurements of the CMB and of these fluctuations imply that our universe has a flat geometry. Einstein’s theory of general relativity says that a universe with mass and energy (like our own) can only be flat if the density of that mass and energy is equal to one critical value, known as the ‘critical density’. But all the known energy and mass density of the universe was found to be too small to account for this critical density. The remaining slice of the pie is now thought to be comprised of dark energy.

A third line of evidence, the mapping of the large-scale structure of the universe, independently suggests the presence of dark energy. By focusing their telescopes on large, distant areas of the sky, cosmologists are able to measure the number of galaxies and their clustering and distribution across the largest scales of the universe.

Their experimental observations can only accommodate a universe with massive particles that account for 30% of the critical density. In close agreement with Perlmutter’s supernova data, most cosmologists believe that the missing 70% of the universe’s density can be accounted for by dark energy. Evidence from all three types of measurements—supernovae, CMB, and the structure of galaxy clusters—all converge on the same conclusion: the cosmos must be 70% dark energy.

What is dark energy?

If so many measurements suggest that the universe is permeated with dark energy, then what exactly is it? Hall admits, “we don’t have a clue.” Physicists do, however, have a few guesses. Two such guesses, vacuum energy and quintessence, are based on so-called “vacuum fluctuations.” Even the best vacuum isn’t really empty. Particles are continually popping in and out of existence. These are vacuum fluctuations—the short-lived creation and destruction of matter-antimatter particle pairs in a vacuum. While this might sound like science fiction, such fluctuations create measurable effects in laboratory experiments on Earth. At first, vacuum energy appears to be a good candidate for the source of dark energy. The only hitch is that estimates of vacuum energies from known matter-antimatter pairs are way too big: $10^{120}$ times too big. That much ‘extra’ energy would have long since torn apart our universe. Daunted, but not beaten, particle theorists are hard at work looking for new exotic particles with vacuum energies small enough to drive the more gentle acceleration we observe in the sky.

Quintessence, or the ‘fifth essence’, was originally proposed by ancient Greek philosophers to explain how the heavens were held together. Today particle physicists use the word to describe a hypothetical energy field that varies over time and space, holding the heavens together. This hypothetical “quintessence field” is made up of many small energy fields generated by vacuum fluctuations. Theorists predict that the small fields should oscillate over time like a ball rolling up and down the sides of a bowl; the pace at which the field oscillates determines the rate of the vacuum fluctuations. The universe-spanning quintessence field is oscillating so slowly that it has yet to complete one full cycle during the 14 billion years since the Big Bang. A quintessence field would still oscillate like the ball in a bowl, except this bowl would look more like a giant plate with a very gentle slope that allows for what Hall describes as a “slow roll down to the bottom of the well.”

The quintessence field theory, like the vacuum energy theory, uses the existence of vacuum fluctuations to balance the universal energy sheet. The two theories do, however, make very different predictions: while vacuum energy-driven acceleration would be constant, quintessence-driven
The next step

In Perlmutter’s eyes, “the theorists are still in brainstorming mode.” That hasn’t discouraged his group from pushing ahead with the next round of supernova measurements. “We can compute what the recent history of the expansion of the universe would look like, and it does indeed differ for a cosmological constant, or a quintessence field, or other theories.” Today the density of dark energy is far greater than that of matter because while matter has been spreading out as the universe expands, the density of dark energy has remained constant. Peering back in time—when the universe was much smaller—there must have been a point when the density of matter and dark energy were equal. The time of this balance point would differ depending on whether dark energy is caused by vacuum energy, quintessence, or some other, more exotic source. The current goal of Perlmutter’s group is to precisely characterize the expansion rate near this time of equal densities. This will be crucial in determining the true origin of dark energy.

Perlmutter and his team are engaged in a constant battle to find a signal—light from supernovae—after it has passed through interstellar dust. “The challenge behind this next round of measurements,” according to Perlmutter, is to understand how “the dust in the supernovae host galaxies… attenuates the brightness of the explosions.” Their latest trick has been to sidestep the problem entirely by looking for dust-free galaxies. “We’ve chosen to focus on clusters of galaxies, because in clusters, you mostly have older elliptical galaxies, and in older galaxies you have more Type Ia supernova and almost no dust.”

To search for these supernovae, Perlmutter’s team has cornered nearly a quarter of the remaining lifetime of the Hubble Space Telescope. Launched in 1990 and orbiting 375 miles above Earth, the Hubble telescope will likely continue functioning only until 2011 without a service mission from the recently re-grounded Space Shuttle fleet. This powerful telescope should be able to find tens to hundreds of type Ia supernovae in the next few years. Looking even further down the road, Perlmutter’s team hopes to launch a dedicated satellite called SNAP (SuperNova Acceleration Probe) that will find hundreds to thousands of supernovae each year and will perhaps allow cosmologists to precisely characterize the properties of dark energy.

One hundred years ago, Albert Einstein published his first papers on relativity, radically altering our conceptions of space and time. Today, the struggle to understand cosmic acceleration and the recent development of the theory of dark energy are not only fundamentally challenging our understanding of the laws and origin of the universe, but are also hinting at its ultimate fate. As the Hubble Space Telescope spends its final days squinting at some of the universe’s most ancient galaxies, it’s becoming increasingly clear that the fate of the universe ultimately hinges upon the shadowy physics of the vacuous expanse between the stars.

Roger O’Brient is a graduate student in physics.

Want to know more?
Check out the Supernova Cosmology Project at LBL: Supernova.lbl.gov
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Mystery of the Missing Megafauna

Mastodons, saber-toothed cats, wooly mammoths and enormous ground sloths—these creatures and other giants roamed the earth for hundreds of thousands of years. Then, during the most recent ice age, they abruptly disappeared. Between ten and fifty thousand years ago, two thirds of the genera of large mammals alive on earth died. Now we may be in the midst of another great extinction, and biologists fear that our most charismatic creatures, species like the giant panda, the giraffe, and the African elephant, are about to meet the same fate. At Berkeley, researchers are working to unravel the root causes of large mammal extinctions, in hopes of learning how to protect currently threatened megafauna. One group is digging into the fossil record, investigating the origins of the late Pleistocene extinctions, while another is trying to understand the causes of present-day extinctions by looking in detail at a single species that roams the southwestern deserts, the California bighorn sheep. What these researchers find may help us mitigate the strains on today’s “charismatic megafauna”.

by Ruth Murray-Clay
Anthony Barnosky, a paleobiologist in Berkeley’s Integrative Biology department, studies the Pleistocene, which lasted from 10,000 to 1.8 million years ago, in an effort to understand the mystery of the large mammal extinctions. This epoch of geologic history was characterized by hugely unstable climate, as the planet oscillated between frigid “ice ages” and warmer “interglacial” climates more than twenty times. Many of the plants and animals living in the Pleistocene were similar to those inhabiting the planet today, but the epoch’s large mammal diversity was notably greater: mammoths and mastodons, saber-toothed cats and dire wolves, giant beavers and armadillos, and many others roamed the globe.

Most of these behemoths persisted through the climate swings from one ice age to the next. But during the most recent ice age, between 10,000 and 50,000 years ago, the large mammals went extinct in record numbers. At least 97 of the world’s approximately 150 genera containing animals weighing more than 44 kilograms disappeared, with the most striking losses concentrated in the Americas and Australia. What killed them? The unusual severity of these extinctions is the subject of a heated debate between those who believe that climate change caused the losses and those who think that humans were primarily responsible.

The late Pleistocene extinctions began with the onset of the latest ice age and lasted until the transition to the current interglacial period. In northern high and mid-latitudes (in Europe, Siberia, and Alaska), two pulses of extinctions occurred. As the planet cooled between 20,000 and 45,000 years ago, warm-adapted species were lost, and as the planet warmed between 9,000 and 12,000 years ago, cold-adapted species disappeared. These correlations suggest a causal role for climate change in the extinctions.

However, climate change alone cannot account for their severity. During at least some of the major heating and cooling events of the earlier Pleistocene, the number of small, medium, and large animals found in North America remained roughly constant, and none of the earlier ice ages caused the widespread extinctions characterizing the most recent ice age. Global oxygen isotope records show that the rapid deglaciation at the end of the late Pleistocene was neither faster nor more extreme than other similar events over the past 700,000 years.

Another major change was occurring on Earth during the last glacial period that differentiated it from prior ice ages: humans were dispersing far from Africa. In North America, the first humans to reach the continent, the Clovis-style hunters, arrived within 1500 years of the majority of the extinctions in the area. In Africa, where humans evolved with large animals rather than invading as fully developed hunters, extinction rates were lowest, affecting 18 percent of mammalian megafauna genera. Europe lost 36 percent, and North and South America, where the first human inhabitants were already skilled hunters, lost 72 and 83 percent respectively. In the Americas, Eurasia, Australia, and Madagascar, most large, slow-breeding animals that did survive occupied territories inconvenient for humans—they were nocturnal or they lived in the deep forest, in trees, or on tall mountains. Finally, the extinction affected large, slow-breeding species preferentially, rather than hitting small animals first and indirectly affecting large animals through their food supply, as would be expected if climate change were the primary culprit. For many scientists, these data suggests that humans were a significant factor in the late Pleistocene extinctions.

Barnosky and his collaborators
Robert Feranec and Alan Shabel from Berkeley, Paul Koch from UC Santa Cruz, and Scott Wing from the Smithsonian Museum of Natural History, summarize these arguments in an October 2004 review in Science. They suggest, however, that the conclusion pegging humans as the cause of the late Pleistocene is too simplistic. They argue that a closer look at extinction events worldwide suggests that while human impacts generated the extinctions, climate change played a vital role in determining their regional differences, timing, and perhaps extent.

In their paper, the authors review the evidence for causal factors producing extinction on a region-by-region basis. For instance, they note that in Australia, extinctions of animals like the marsupial lion occurred after humans arrived during a period of little climate change, while in Alaska, mammoths died out during periods of climate change when very few humans were present. In Eurasia, the evidence increasingly suggests that Pleistocene climate change caused large mammals to shift their ranges, contributing to their extinction. Eurasian extinctions also coincide with the spread and then an increase in population sizes of modern humans. These populations may have impacted megafauna as early as 30,000 years ago.

In North America, where dating is most robust, the case for an interaction between both climate and human impacts is clear. Within 1500 years of the arrival of the Clovis hunters, who traveled from Asia across the Bering land bridge to North America roughly 14,000 years ago, at least 15 species of megafauna went extinct in the region, including mammoths, mastodons, rhinos, saber-toothed tigers, and giant ground sloths. The arrival of humans and their practice of overkill coincided with a major climate change event, and Barnosky argues that if first contact had been significantly earlier or later, the extinction event would have been much less dramatic. “What made the big extinction event was putting together the two causes,” Barnosky says.

Barnosky and the members of his lab have been contributing to the extinction debate by studying the effect of climate change on ecosystems and evolution. In a paper published in the Proceedings of the National Academy of Science in June of 2004, Barnosky, Shabel, and collaborators including former graduate student Christopher Bell use fossil evidence gathered at Porcupine Cave in Colorado to study the effect on mammal populations of glacial-interglacial transitions from 600,000 to 1,000,000 years ago in the mid-Pleistocene, long before humans arrived. Mid-Pleistocene sites are less common than those representing the late Pleistocene, and the differences between them can help separate the effects of climate from the effects of humans. The group used the sediments in a sequence of mid-Pleistocene fossils to identify glacial and interglacial conditions, and followed the area’s species composition and richness over transitions in the Pleistocene, comparing their results with species composition in historical and modern times. The group found that the mammal community near Porcupine Cave was structurally and functionally stable over the long periods of time preceding the historical period. The species present in the region changed, but the species richness and functional relationships in the ecosystem remained the same, with only minor adjustments during periods of climate change. In addition, they found that the “fine-tuning” of the ecosystem generated by these minor adjustments occurred by affecting species of smaller size and at lower trophic levels. These findings differ markedly from the changes seen in the area during the 19th and 20th centuries. Human hunting has targeted large animals and carnivores, changing the ecosystem from the top down, causing the preferential loss of large mammals, as was also observed in the late Pleistocene.

What caused the double punch of humans and climate change to be so effective? Barnosky’s research suggests that humans directly affect large animals through hunting or some other mechanism, while climate change affects small animals first through their plant food supplies. To better understand how these mechanisms work in our current world, Clint Epps, a recent graduate of the department of Environmental Science, Policy and Management, has focused on megafauna currently living in California: the desert bighorn sheep.

Desert bighorn sheep (Ovis canadensis nelsoni) live in small populations, usually fewer than 100 individuals, in the arid mountain ranges of the Mojave, Sonoran, and Great Basin deserts of the southwestern United States. Brown with
white highlights on the nose and rump, the sheep range in length from 150 to 180 cm (5 to 6 feet), and are armed with spectacular thick, curved horns. Though they weigh up to 127 kg (280 lbs), the sheep jump and climb with enviable dexterity up steep mountain slopes, protecting themselves from predators such as the mountain lion. The estimated 56 populations of desert bighorn sheep in California occupy many small, isolated mountain ranges, separated by uninhabitable desert. While each population on its own has a low chance of long-term survival in this harsh environment, the metapopulation, or system of small populations, is more stable if there is good connectivity between the individual groups. If one population dies out, individuals from neighboring populations can recolonize the emptied habitat, ensuring the continuity of the species in the region.

Epps, a lifelong outdoorsman and self-described “hillbilly,” spends his summers camping in the sheep-occupied mountain ranges of the Mojave Desert. Despite daytime temperatures that can reach 125° F (52° C), frequent vehicular breakdowns, and extreme isolation, the desert can be rewarding during the hot months. As Epps explains: “Summer is the best time to find sheep in the Mojave. The hotter the better—when they cluster near water, it’s much easier to collect data on the sheep.”

In a paper published in the journal Conservation Biology in February 2004, Epps and his colleagues, including his advisor, professor Dale McCullough, examined current and historic sheep populations. Using data from the last 60 years, they found that thirty of the eighty populations of sheep known to live in southern Californian mountain ranges over that period are now extinct. To determine the primary causes of these extinctions, the researchers looked at each mountain range hosting a current or historic sheep population, and considered factors such as annual precipitation, temperature, and human-related characteristics such as proximity to towns and cities, poaching, mining, and contact with livestock that may have carried disease.

The researchers were surprised to find that sheep extinctions were most closely correlated with local climate conditions. According to climate records for the southwestern desert region, the mean annual temperature rose 1 degree Celsius (1.8 degrees Fahrenheit) from 1901 to 1987, while, over the past century, annual precipitation dropped by about 20%. Those places where the climate was warmest and driest suffered the greatest number of sheep extinctions. Future changes are predicted to be more severe.

Desert bighorn sheep numbers decline in response to decreased rainfall because desert ecosystem productivity is limited by available water. In general, the more it rains, the more desert plants will grow. Temperature increase, however, can help or hurt sheep survival, depending on timing. Warmer springs and summers lead to lowered diet quality as plants wither in the heat, while warmer winters lead to earlier plant growth and higher diet quality in the spring, a critical time for the survival of bighorn lambs.

The sensitivity of sheep populations to climate change may result from their geographical distribution. While other large mammal species may gradually shift their territories north in response to global warming, bighorn sheep have a limited ability to move to new environments. Often, potential new ranges are uninhabited for good reasons (like higher temperatures and lower rainfall). Complicating the situation, Epps and his colleagues found another significant obstacle for sheep survival. In their quest to find new mountain range habitat, sheep must cross the broad and bleak desert flatlands, which offer a suite of other threats.

In addition to increased exposure to predators, dispersing bighorn sheep may encounter human-made barriers such as interstate highways that are difficult or impossible to cross. In addition to analyzing population extinction and the effects of climate on diet quality, Epps collected pellets for analysis of fecal DNA. After an analysis of the genetic diversity of 27 populations of desert bighorn sheep, the group concluded that new highways and other human-made barriers effectively isolated sheep populations, halting gene flow across the barriers and significantly reducing the genetic diversity of the groups in only 40 years.

The California bighorn sheep case illustrates what may happen to other large mammal species. As global temperatures change, a species’ habitat may shift from one place to another. To survive, the animal must move with its habitat. But human settlements and barriers can be as difficult to cross as the forbidding desert, and many animals will be deprived of a way to follow their preferred environments. As a result, many animals face extinction.
from climate change. This situation is particularly acute for desert species, which often live in naturally fragmented habitats: in addition to the desert sheep, the huge desert tortoises are also having difficulty.

Barnosky emphasizes this point. “Animals respond to ‘normal’ climate change,” he explains, “by tracking their climate across the landscape. In order for that to work, their life history has to be such that they can move with their climate. There has to be habitat to pass through.” But habitat destruction and fragmentation challenge nearly all of today’s large animals as human development spreads into remote corners of the globe. Large animals are particularly sensitive to habitat fragmentation because individuals often require broad territories of continuous land. Their habitat is often the same land that people prefer, and for similar reasons: like us, they need access to water and food.

Today, both climate change and direct human impacts such as habitat fragmentation are occurring at rates unprecedented in recorded history, leading Barnosky and his collaborators to warn that climate change should be considered a serious threat to large animal populations. If the late Pleistocene may be taken as a guide, the combination of direct human impacts and climate change is particularly dangerous and could catalyze extinctions massive enough to destabilize global ecosystems.

In his studies of bighorn sheep, Barnosky says, Epps could easily be observing today processes similar to those that led to the late Pleistocene extinction. So how are California’s bighorn sheep doing? They still have a chance—“for the moment,” says Epps, “they’re holding their own. Some populations are going up, and some populations are going down. There’s lots of variation in the system.” Over the years covered by the Berkeley group’s study, a couple of the areas hosting extinction events were recolonized, but these areas were not isolated by roads or human settlements. Whether or not the bighorn sheep in California ultimately survive, both studies clearly warn that the dual pressures of climate change and direct human impact may be too much for today’s megafauna to bear.

Ruth Murray-Clay is a graduate student in astronomy.

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An Inter-Continental Ballistic Missile launches from North Korea, arcing through the atmosphere towards the United States. Thirty seconds later, the US missile defense has detected the launch, setting off a pre-determined set of responses. At 45 seconds, they track the enemy missile, determine its path, and calculate a firing solution. At 75 seconds, the US launches an interceptor missile from a boat stationed in international waters off the Korean coast. At 165 seconds the two missiles collide, destroying the enemy missile. This timeline for a successful interception leaves no room for uncertainty or error. Is it a realistic defense strategy, or just a fantasy on the part of the US Department of Defense?
In the fall of 2000, this problem attracted the attention of the American Physical Society, the nation’s premiere organization of physicists. In response to the large amount of money and resources being dedicated to boost-phase missile defense systems and the lack of technical information available to the public, the APS launched a project of its own, a two-year study of the technical feasibility of destroying an enemy missile early in its flight path. Destroying a missile during its boost phase—its first stage of flight, while it is actively launching into space—is an extremely attractive idea to the US Defense Department because once an ICBM has reached space—the so-called midphase—it could separate into multiple warheads and decoys, swamping any defenses.

One of the scientists involved in the APS study was UC Berkeley professor Roger Falcone. Falcone studies ultra-short pulses of light as well as the interaction of very high power lasers with matter. It is the latter research area that attracted the interest of the APS study organizers. This area of research fits in well with one of the tactics examined in the study, the Airborne Laser (ABL). Other group members chosen by the APS to participate in the study were experts in rockets, radar, and guidance systems.

In order for the study to be accessible to the public, all information used by the group had to be public knowledge. This brought the challenge of coming up with reliable unclassified estimates of the classified technology held by the Defense Department. So the group avoided classified information by extrapolating from technology developed by the scientific community. With regard to imaging technology, Falcone explained, the group looked at “what the astronomy community had developed for things like Hubble and other space telescopes...we looked at what the most advanced scientific technologies were, extrapolated a little bit on that and said well they can’t really do better than this unless they know something that astronomers don’t know.” The group was also briefed by outside experts on aspects such as detector technology and missile technology. According to Falcone, “we listened to anybody who we thought was knowledgeable...most experts participated quite enthusiastically.”

One crucial group did not participate in this study: the Missile Defense Agency (MDA), the Department of Defense agency running the missile defense program. According to Falcone, the MDA repeatedly turned down APS group requests for briefings or meetings. He added, “they decided early on not to participate in our study.”

Once, however, these two parties were brought together in the same room. This feat was the accomplishment of Dean Wilkening, the scientific director of the Center for International Security and Cooperation (CISAC), and an expert in missile defense who briefed the APS group during their study. Wilkening organized a boost-phase defense meeting, which included missile defense contractors as well as academics. Wilkening confirmed that the MDA was reluctant to participate in the conference. “In general they are skeptical of academic scientists,” he added. This is presumably due to a long history of criticism of missile defense, by academic scientists, physicists in particular. The people trying to develop these systems, he continued, don’t find it rewarding to meet with academics because they believe academic scientists are all skeptics or critics.

The Boost Phase

1) The boost phase, while the missile is launched on a rocket through the atmosphere;
2) The mid phase, as the missile arcs through space towards its target;
3) the terminal phase, as the missile re-enters the atmosphere.

The Department of Defense’s Missile Defense Agency pursues a layered defense system, intended to defend against all three phases.
According to Wilkening, many of them are. Perhaps one of the most polarizing debates between missile defense critics and true believers is the debate over the Patriot missile. At the center of this debate, on the critic side, is an MIT physicist named Ted Postol. During the first Gulf War, the Patriot came to symbolize American military might and technical superiority. It was touted by the first President Bush as “proof positive that missile defense works.” Official estimates put the Patriot effectiveness at 96%.

Postol did his own studies on the Patriot’s performance, estimating the success rate of the missiles by examining US Army data on Patriot-Scud engagements as well as news media video recordings. By analyzing, for example, the speed of falling objects emerging from an engagement and the explosions of these objects on the ground, Postol tallied the number of warheads destroyed. His own estimate of the Patriot’s success rate was vastly different. In a 1991 hearing before the House Armed Services Committee, Postol testified that, in comparison to the damage caused

Timeline for an interception

The one-word answer to why boost-phase defense is so challenging, says Falcone, is **timeline**. The time available to shoot down a missile in the boost phase is given by the “burn time” of the missiles. For comparatively slow liquid-propellant missiles, the answer is 240 seconds. For faster-burning solid-propellant missiles, it is only 170 seconds.

To successfully intercept a missile in its boost phase, a defense system must:

**Detect a launch.** The current US tracking system, the Defense Support Program (DSP), cannot detect exhaust plumes of rockets until they have reached an altitude of 10km, and sample once every 10 seconds.

**Identify the launch as a hostile missile.** This means distinguishing the bright spots of the rockets from bright spots due to aircraft or fires on the ground.

**Track the rocket and determine its heading.** The group points out that the path of a peaceful space launch would likely be indistinguishable from an attacking missile.

**Fire interceptor(s).** The group found that the earliest launch times possible were 65 seconds (liquid propellant) and 45 seconds (solid propellant).

**Accelerate the kill vehicle.** The rockets of the interceptors must accelerate their payload, a “kill vehicle,” which is then hurled to the position where it is expected to intercept the missile. The kill vehicle must then home in on and hit the missile. The booster rocket must accelerate rapidly enough to reach a missile launched at least 45 seconds earlier.

**Home in and hit the missile.** The kill vehicle must track its target and maneuver to hit it. The vehicle must switch from the easy task of tracking the exhaust plume to homing in on the smaller and cooler body of the missile.
by Scuds before the introduction of the Patriot, the post-Patriot damage was the same or, in some cases, worse. The Patriot success rate dropped from 96% to almost 0%. Most likely, there were no Scud missiles intercepted by Patriots during the Gulf War at all. In this case, at least, the effectiveness of our defense was entirely psychological.

So, is the APS study the axe-grinding of a group of anti-missile defense academics? Probably not. For one, they weren’t all academics. As Falcone explained, “we had a group of scientists and engineers, some like myself, who were outside the military complex and some who made their careers at Lockheed or at RAND designing missiles or radar, people who had actually designed weapons systems that are currently operating.” Further, the group excluded anyone who might be prejudiced by previous studies done on boost-phase defense. None of the members had come to any conclusions about the feasibility of boost-phase defense before the study began. Finally, according to Falcone, the political viewpoints of the members of the group never came into play. Falcone continued, “I think everybody going into the study knew that the answer [to whether boost-phase defense would work] wouldn’t be yes or no, that the answer would be: the system would be subject to the following limitations.” As it turns out, those limitations are severe.

The general conclusions of the study were as follows. Against liquid propellant ICBMs, the slower of the two types, the United States has some limited defense capability. Against faster solid propellant ICBMs we have none. The group stressed that all findings reflect “upper bounds” on performance, reflecting “optimistic assumptions” and the “theoretical possibility” of an intercept.

As Falcone put it, “for a large amount of money in missile defense you could get an extremely limited defense system.” This would involve surrounding North Korea with interceptors, waiting for a launch. Falcone explained that during APS study group meetings when the members began realizing how close the interceptors would have to be stationed waiting for a missile launch, it seemed an almost ridiculous situation. “It was suggested that, if you are going to be looking right at the missiles, you might as well just go in and shoot [them] up with machine guns.”

But the bigger problem, according to the study, is that what limited defense capability we have completely disappears once attacking countries acquire solid propellant missiles. The study states “countries of concern might acquire or develop solid-propellant ICBMs within the next 10-15 years and that it would be imprudent not to consider them in evaluating the feasibility of boost-phase defense systems.” The study further notes that, “A boost-phase defense would create incentives to develop or acquire solid-propellant ICBMs.”

In other words, armed with this knowledge, North Korea would seek solid-propellant missile technology and eliminate our defense capability.

These considerations are strictly technological. There are also many political issues to consider. One is the destabilizing effect our missile defense development has on our relationship with Russia and China. Another is the problem of shortfall. After a successful interception, the attacking missile falls to the ground short of its intended target, but outside the country that launched it. Falcone sums up this problem as: is it acceptable for us to shoot down a missile to defend ourselves and have it fall on Western Canada? It is possible that a nuclear weapon would not be triggered if it were to crash to the ground short of its target; even so it would scatter radioactivity. What would be the political ramifications of sending such
a weapon crashing into China?

Given that the Department of Defense is pursuing this strategy, the question arises: does the Department of Defense's analysis of boost-phase missile defense lead to more optimistic conclusions? Thanks to the CISAC meeting, the only instance where the MDA was brought together with the APS study group, Falcone has some basis on which to answer this question. While the MDA made no formal response to the results presented at the meeting, they did make oral comments on areas where they thought the group had made some wrong assumptions or had not taken certain technologies into account. Did the APS group and the MDA arrive at the same conclusions? According to Falcone, “there was nothing we heard from the MDA that said we were wrong about our assumptions on rocket sizes, acceleration rates, mass, sensor technology… I think we came to the same conclusions on system design challenges. That was the result of our meeting.” Falcone believes that the conclusions of the MDA match up reasonably well with those of the APS. Wilkening agrees. He does not believe there were any serious technical disagreements between the APS study, the analysis by the MDA, or his own work.

Then why does the Defense Department pursue a program with such limited chance of success? According to Falcone, the difference is attitude. “I think there’s a sense in the military… that technological surprises can happen, and advanced research and development, and testing, will pay off… There’s a ‘can-do’ attitude [which says] ‘if you give us enough money we will solve what seem to be insurmountable problems of science and technology.’” Wilkening sees the difference not as an issue of optimistic outlook, but a question of, as he puts it, “preferences.” “MDA is obviously in favor of building missile defense. They’re committed to it.”

Whether it is their “can-do” attitude or just a matter of “preference,” it is clear that the MDA is in favor of the program. And, as Falcone points out, politicians would like to believe them. Falcone understands that the idea of a missile shield is extremely politically satisfying: a seemingly clear-cut solution to the threat of offensive missiles aimed at us. He adds “and if you’re a politician with the responsibility for national defense who doesn’t really have a fundamental understanding of physics… you could buy into it because you want it to work.”

In fact, missile defense has a long history of appealing to politicians. It was over 20 years ago that President Reagan committed the United States to a missile defense shield known by its detractors as “Star Wars.” As Falcone explains, Reagan was told that a nuclear exchange with the Soviet Union would leave a hundred million Americans dead, since the only defense we had against the Soviet threat was mutually assured destruction. “And Ronald Reagan said when he was told that, he considered this to be irresponsible, he couldn’t be the president of this country [and be] responsible for defense and believe that the defense is letting a hundred million Americans die. So some scientists offered him the idea of a shield, and he said, we gotta do it, it doesn’t matter how much it costs.”

As it turns out, the APS studied the feasibility of that project as well. The 1987 Star Wars study, Falcone said, was important in explaining to people how the vast majority of the parts of that program “were just not feasible from a basic physics perspective… it was a vision by the President which ultimately had little basis in reality.” Maybe so, but the president’s mandate lives on in the missile defense community.

According to Wilkening, the missile shield idea has persisted ever since. He explains that members of the administration have “done battle for 20-odd years with the arms control community. Now they’re in the driver’s seat and having a heyday.”

Wilkening sees a major difference in perceived threat level between some analysts and the Bush Administration. According to him, “The Bush Administration genuinely believes it’s important for our security.” As a source for this belief, Wilkening points to the Rumsfeld Commission report. In 1998 Congress ordered a study of the missile threat to the United States. The commission was headed by
Donald Rumsfeld, then Chairman of the Board of Directors of Gilead Sciences, Inc. The report states, “A nation that wants to develop ballistic missiles and weapons of mass destruction can now obtain extensive technical assistance from outside sources. Foreign assistance is not a wild card. It is a fact.” The report further asserts “nations about which the U.S has reason to be concerned are exploiting a dramatically transformed international security environment... an ever-widening access to technology, information and expertise that can be and is used to speed both the development and deployment of ballistic missiles and weapons of mass destruction.” The Rumsfeld Commission concluded that the missile threat is huge and growing.

“the impact of all of these studies is probably pretty minor.”

With this kind of commitment from the Bush Administration, what impact does a study by the APS have? As a case in point, take the issue of space-based missile defense, putting hit-to-kill interceptors on satellites in low earth orbit. This strategy was examined in detail by the APS study, and determined to be infeasible. Launching the thousands of massive satellites necessary to defend against a single solid-propellant ICBM from North Korea or Iran would require a five to tenfold increase in the current United States space-launch capability. Wilkening, who believes that boost-phase defense could work, says that emphasizing space-basing is “not the way to go.” But, according to Wilkening, the MDA doesn’t like options other than space-based defense. “It’s an article of faith amongst pro-missile defense people.” Apparently, such articles of faith are not subject to technical scrutiny. According to Wilkening, the study will have little effect on the Bush administration or the MDA. He continued, “the impact of all of these studies is probably pretty minor.”

If the study will have no effect on the mindset of the missile defense community, what about on politicians who make funding decisions? Wilkening thinks that, for a number of congressmen, the study “reinforced the belief” that missile defense, especially space-based missile defense, was not feasible. Unfortunately the study was poorly timed to the Congressional calendar. According to a Congressional staffer, by the time the study came out, in July 2003, Congress had already set the budget for fiscal year 2004 missile defense funding. And by the time fiscal year 2005 budget hearings were going, the study was old news.

According to Wilkening, the threat of missile launch against the United States is less of a concern than conventional terrorism, bioterrorism, or global warming. He adds that missile defense spending is “not a worthwhile allocation of scarce resources.” Falcone agrees with Wilkening’s assessment. His theory on why the budget is so large is simple: momentum. Falcone explains that once contract money starts flowing out of Congress, it’s nearly impossible to shut it off. Missile defense budgets fuel the livelihoods of too many, and the lobby is too strong to shrink them. Today’s inflated budget is a reflection of the political climate of an earlier time. Missile defense got its big start under Reagan, and it is his words that open the MDA’s Ballistic Missile Defense System overview. The then-president asks, “What if free people could live secure in the knowledge that their security did not rest upon the threat of instant U.S. retaliation to deter a Soviet attack?” For one thing, the threat of Soviet attack disappeared along with the Soviet Union. But more importantly, the United States probably faces far less risk from a complicated, expensive, and risky ICBM launch than from an anonymous untraceable and inexpensive weapon delivered, for example, by container ship. Our exorbitant spending on missile defense, to the tune of several billion dollars per year, is an attempt to solve the problems of a new political climate with the same cold-war era solutions. The world has moved on, but our defense programs and our budgeting are frozen in time.

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Want to know more?
APS study report: www.aps.org/public_affairs/popa/reports/nmd03.cfm
Discussion of the report: www.physicstoday.org/vol-57/iss-7/p13.html
Sixty years ago Berkeley was a campus at war. Plutonium, which had been discovered by Cal chemist Glenn Seaborg and his colleagues in 1940, had been identified by Manhattan Project scientists as a potential bomb-making material; by 1945 it was the subject of intense research at Berkeley, Los Alamos, and the University of Chicago. The frantic pace of wartime research led to numerous accidents: Los Alamos chemist Don Mastick swallowed much of the world’s plutonium when a test tube he was holding exploded in his face. Mishaps like this made Manhattan Project leaders anxious to better understand the health effects of plutonium. For answers, they turned to Joseph Hamilton, a young Berkeley professor who was already an expert on the toxicology of radioactive materials.

In the late 1930s, Hamilton made a name for himself by measuring the uptake of various radioisotopes into plants and animals (including himself). His status as a professor at both UC Berkeley and the University of California School of Medicine (now UCSF) provided him with radioactive materials from Berkeley’s cyclotron and clinical patients from the hospital. In 1944, Hamilton and his colleagues received eleven milligrams of plutonium earmarked for toxicology studies in rats. His initial rat results were disturbing: plutonium concentrated itself in the bones and seemed to stay there for a long time. Manhattan Project leaders like J. Robert Oppenheimer wanted more detailed information about the effects of plutonium on the human body.

On April 10, 1945 in Oak Ridge, Tennessee, a construction worker named Ebb Cade became the first human to be intentionally dosed with plutonium. Through a solution containing the radioactive element injected into his arm, Cade received almost five times the minimum amount of plutonium believed at the time to cause adverse effects. He was in the hospital following a car wreck but had no life-threatening ailments and was characterized by a doctor at Oak Ridge as “a well developed, well nourished colored male.” Sixteen days later, at the University of Chicago’s Billings Hospital, a cancer patient named Arthur Hubbard received what was described to his daughter as “some new treatment”—the second plutonium injection. At about the same time, Joseph Hamilton and his colleagues were walking the halls at the UC Hospital in San Francisco looking for their own test subject.
Man and the Rat

Albert Stevens arrived at the UC Hospital in May of 1945 complaining of stomach pains. The 58-year-old house painter was diagnosed with inoperable stomach cancer and given six months to live. Shortly after hearing this diagnosis, Stevens received Hamilton’s first plutonium injection. “CAL-1,” as Hamilton’s team designated Stevens, became the subject of intense analysis. His urine and feces were collected and sent to Hamilton’s lab at Berkeley for analysis. A few days after the injection, doctors removed parts of his stomach, liver, spleen, lymph nodes, pancreas, and ribs, and sent these to Berkeley as well.

A UC Hospital pathologist who studied CAL-1’s stomach samples concluded that Stevens actually did not have cancer after all—the terminal diagnosis was a mistake, and an otherwise-healthy man had received what was later characterized as a “so-called lethal textbook dose of plutonium.” Hamilton and his colleagues wrote a paper about CAL-1 entitled “A Comparison of the Metabolism of Plutonium in Man and the Rat.” The report noted that, like rats, humans collect plutonium in their bones, particularly in the sensitive bone marrow responsible for making blood cells. But humans, Hamilton and his coauthors found, rid themselves of plutonium even more slowly than rats, and plutonium poisoning was “a matter of serious concern for those who must come in contact with this material.” Hamilton’s superiors in the Atomic Energy Commission (the successor to the Manhattan Project) claimed that the Man and the Rat paper “might adversely affect the national interest” and refused to allow its publication.

Less than three months after Albert Stevens became CAL-1, atomic bombs were dropped on Hiroshima and Nagasaki and World War II was over. Although the wartime race to understand the toxicology of plutonium had also ended, Joseph Hamilton’s plutonium injections continued. Simeon Shaw, also known as CAL-2, was a four-year-old Australian boy suffering from bone cancer. An injection containing a variety of radioisotopes from the Berkeley cyclotron was administered to Shaw on April 26, 1946, nearly eight months after the end of WWII. Within a year of the injection, the recipient of Hamilton’s second injection succumbed to bone cancer.

Hamilton’s other war

When he wasn’t studying the effects of radioactive materials on CAL-1 and CAL-2, Joseph Hamilton was advocating their use as weapons. Radiological warfare—the use of radioactive material not as a bomb but as a radiological poison for military use—had been tossed around in the days before the Manhattan Project (and was apparently an objective of the Nazi bomb project) but was largely forgotten after the Manhattan Project was initiated.

By 1946, Hamilton was one of the few remaining supporters of radiological warfare. Years before, he had written the first of what became a series of letters to his superiors advocating the consideration of radioisotopes from Berkeley’s cyclotron as possible radiological weapons. In a letter to Manhattan Project Health Division head and former Berkeley colleague Robert Stone, Hamilton wrote that radioisotopes sprayed from aircraft “offer the possibility of infecting to dangerous levels, large areas such as cities... The poisoning of water supplies such as reservoirs, wells, etc. and food must be kept in mind.” Whether this early letter inspired any reaction from the Manhattan Project leadership is unclear, but Hamilton’s enthusiasm about radiological warfare seemed to heighten during his plutonium injection studies. Following the CAL-1 and CAL-2 injections, Hamilton outlined the utility of radioactive materials as military poisons in a 1946 letter to his Manhattan Project boss, Colonel Kenneth Nichols. Hamilton detailed strategies for poisoning municipal water supplies with radioisotopes and described the terrorizing psychological aspects of radiological warfare.
(“It can be well imagined the degree of consternation, as well as fear and apprehension, that such an agent would produce upon a large urban population after its initial use”). He described “radioactive smoke” that could be designed to maximize the absorption of radioactive material in the lungs and the subsequent deposition of the material in the bones. Such a preparation, said Hamilton, would be “well adapted for producing fission product aerosols to subject urban populations to fission product poisoning.” The effects of radiological poisons on the human body are described in detail:

Following absorption into the body the majority of longer-lived fission products whose half-lives extend from the order of two weeks to many years, are accumulated and tenaciously retained in the skeleton. There, they produce internal irradiation of the very sensitive bone marrow and even rather trivial amounts can produce lethal effects. [emphasis added]

Hamilton’s assessment of the accumulation and “lethal effects” of fission products in bone marrow echoes the conclusions of his “Plutonium in Man and the Rat” paper, written earlier that year and supported with data from the analysis of CAL-1’s urine, feces, and internal organs.

**Informed consent**

In December of 1946, a trial began in Nuremburg, Germany for twenty-three Nazi doctors accused of performing medical “experiments” on concentration camp prisoners without their informed consent. That same month, Joseph Hamilton sent a letter to Colonel Nichols outlining Hamilton’s plans for continued human injections. Nichols replied by shutting down Hamilton’s research:

...this report indicates that certain radioactive substances are being prepared for intravenous administration to human subjects... It is felt that such work does not come under the scope of the Manhattan District Program and should not be made a part of its research plan. It is therefore deemed advisable by this office not only to recommend against work on human subjects but also to deny authority for such work under the terms of the Manhattan contract.

You will take immediate action to stop this work under this contract, and report to this office upon compliance.

In January of 1947, Nichols and Hamilton’s other Manhattan Project superiors stepped down and the Atomic Energy Commission (AEC) took charge of Hamilton’s research. Undoubtedly conscious of ongoing events in Nuremburg, AEC leaders immediately issued strict rules limiting the use of human subjects. A patient had to be informed about the nature of a proposed experiment and grant their consent before the experiment was initiated, and researchers had to believe that the experiment would benefit the patient. But at the same time, the AEC continued to censor papers about the plutonium injections. In refusing to release a paper describing the results of the injections, an AEC official observed:

Unless, of course, the legal aspects were covered by the necessary documents [informed consent], the experimenters and the employing agencies, including the US, have been laid open to a devastating lawsuit which would, through its attendant publicity, have far reaching results.

Hamilton and his colleagues clearly had not obtained the “necessary documents” from CAL-1 or CAL-2. Fearing legal reprisals, the AEC hid evidence that its own scientists, like those on trial in Nuremburg, had performed medical experiments on patients without their informed consent.
Two months after the AEC human subjects rules were issued, and with the Nuremburg trial still under way in Germany, sixteen-year-old bone cancer patient Hanford Jang became CAL-A following an injection administered by Hamilton’s scientists. The injection was probably administered without Jang’s understanding or consent (he couldn’t speak English) and Hamilton and his scientists offered no possible therapeutic justification for the injection; Jang was dead within a year. Bay Area resident Elmer Allen, also a bone cancer victim, became CAL-3 after receiving Hamilton’s fourth radioisotope injection a month after CAL-A. No documents indicating that CAL-A or CAL-3 granted their informed consent have been found.

By November of 1947, the AEC rules on human subjects had grown even stronger:

We believe that no substances known to be, or suspected of being, poisonous or harmful should be given to human beings unless all of the following conditions are fully met: (a) that a reasonable hope exists that the administration of such a substance will improve the condition of the patient, (b) that the patient gives his complete and informed consent in writing, and (c) that the responsible nearest of kin give in writing a similarly complete and informed consent, revocable at any time during the course of such treatment. [emphasis added]

The revised AEC rules marked the first known use of the now-ubiquitous phrase “informed consent.” No further plutonium injections were planned at Berkeley, perhaps because another interest was consuming more and more of Joseph Hamilton’s time.

From Berkeley to Dugway

While the AEC was anxiously hiding Joseph Hamilton’s human experiments on the toxicity of plutonium, the US Army was building a weapons program around the results of his research. In May of 1948, Hamilton’s advocacy of radiological warfare convinced Army brass to form a committee of scientists to study the feasibility of radiological weapons, with Hamilton as a member. The committee recommended that biological research into the deleterious health effects of radioisotopes be conducted by the Army Chemical Corps at the University of Chicago, that production of possible radiological weapons be conducted by the AEC, and that military testing of possible radiological weapons be performed by the Army Chemical Corps at a suitable location. That location was the Dugway Proving Grounds in Utah, and the tests, which involved releasing material akin to Hamilton’s “radioactive smoke” over the Utah salt flats and monitoring its distribution, began in October of 1949 and continued until 1953.

So why was Joseph Hamilton—a man charged with protecting the health of Manhattan Project workers exposed to plutonium—so enthusiastic about radiological warfare? Some have suggested that he perceived radiological weapons as more humanitarian and less destructive than conventional nuclear explosives. A long-lived but less-potent radioisotope could be used to contaminate factories and farms, rendering them useless without inflicting direct casualties. Others have noted that the opposite could also be true: a short-lived but potent radioisotope could be used to incapacitate or kill the inhabitants of a city while leaving valuable infrastructure intact. Regardless, Hamilton was clearly motivated by the fear that a hostile power could use radiological weapons against the United States:

I strongly feel that the best protection that this nation can secure against the possibilities of radioactive agents being employed as a military tool by some foreign power is a thorough evaluation and understanding of the full potentiality of such an agent.

The purpose of the plutonium injections was, in Hamilton’s own words, “to evaluate the possible hazards… to humans who might be exposed to [plutonium], either in the course of the operation of the pile [nuclear reactor], or in the event of possible enemy action against the military and civilian population.” Hamilton wrote this four months before Albert Stevens became CAL-1. Clearly, he recognized the material
he was injecting into his patients was a potential weapon—maybe a weapon that could be used against the US, but a weapon nonetheless. And although much of Hamilton’s earlier research was in therapeutic uses for radioisotopes (including his pioneering use of radioactive iodine to diagnose and treat thyroid disorders), attempts to justify the plutonium injections as “experimental therapies” fall short. In 1946, after the injections of CAL-1 and CAL-2 but before CAL-A and CAL-3, Hamilton conceded that “to date no fission products, aside from radioactive iodine, have been employed for any therapeutic purposes.” His superiors recognized this, too: AEC officials refused requests for the declassification of Hamilton’s research because, in addition to the legal risks arising from the lack of informed consent, his work involved “experimentation on human subjects where the material [plutonium] was not given for therapeutic purposes.”

Hamilton’s injections may have been one of the first human radiation experiments, but they were by no means the last: nearly 4000 human radiation experiments were conducted under government contracts from 1944 to 1974. To investigate “reports of possibly unethical experiments funded by the government,” President Clinton formed the Advisory Committee on Human Radiation Experiments in 1994. The various experiments described in the Committee’s 620-page report include the injection of radioactive iodine into 60 students at a Massachusetts school for mentally retarded children in 1962, and the irradiation of 130 healthy Washington and Oregon prison inmates’ testicles from 1963 to 1973 as part of a joint AEC/NASA study. Troubling as they are, Hamilton’s experiments in the 1940s were born of the wartime race for the atomic bomb and conducted at a time when the toxicity of materials like plutonium was poorly understood and the importance of informed consent was still being established. The same cannot be said for the scores of human radiation experiments performed decades later.

**What is Easy?**

Near death with leukemia undoubtedly caused by reckless exposures to radiation throughout his career at Berkeley, Joseph Hamilton lamented to his colleague Patricia Durbin in 1957, “you know, the sad part is that all the easy experiments have been done.” As long as I’ve been a graduate student at Berkeley and, as such, a scientific descendant of Hamilton, I’ve wondered what he meant by that. Were these really “easy experiments” to him? Maybe Hamilton and his students fell into the trap described by AEC doctor and Hamilton contemporary Leonard Sagan in an interview conducted by the Advisory Committee on Human Radiation Experiments:

> Doctors who were doing research wanted to be professors, and in order to be a professor, you have to have lots of publications, so your highest priority is to conduct research and publish it... What can happen is the patient says, “No, I don’t want to do that.” That’s not in your interest. Your interest is to have that patient participate, so do you tell him or her? No. Does anybody care? No. So you don’t tell them. That’s why [the ethical rules] were ignored, because there’s a conflict between informed consent and the ability to conduct research and the physician is interested not in the patient’s welfare, he’s interested in his or her welfare. So he doesn’t inform him.

Performed in an atmosphere of wartime secrecy, Hamilton’s “easy experiments” never fell under the scrutiny of an independent review panel. Disturbing conflicts of interest like Hamilton’s involvement in the Army radiological warfare program went unrecognized. It was easy, as a researcher, to put one’s own interests ahead of a patient’s interests, and Hamilton was one of a number of researchers who did just that.

Things aren’t so easy today. Berkeley researchers wishing to study human subjects must first obtain approval from the Committee for the Protection of Human Subjects—a rigorous process. Additional rules protect vulnerable subjects like CAL-2 (a minor) and CAL-A (a non-English speaker). And all subjects must grant their informed consent—a term coined partially in response to Joseph Hamilton’s “easy experiments.”

Will Grover is a graduate student in chemistry.
Scientists can be a strange tribe. They've been known to cloister themselves in the lab for days on end, and outsiders often accuse them of having a fashion sense all their own. Furthermore, it only takes a brief glimpse at a specialist journal to notice that scientists have developed unique languages and customs as well.

It's not such a conceptual leap then to understand the narrative structure of A Machine to Make a Future: Biotech Chronicles by Paul Rabinow and Talia Dan-Cohen. Rabinow, Professor of Social and Cultural Anthropology at UC Berkeley, and Dan-Cohen, a former Berkeley undergraduate anthropology student, have very self-consciously chosen to play the part of the post-modern anthropologists observing an isolated, undiscovered tribe of biotech researchers and managers. Slightly tongue-in-cheek, they conclude that their "job as anthropological chroniclers of the contemporary is to tell the tale of these days in an appropriate fashion—find a form for the natives' points of view, leave things in an appropriate state of irresolution." Fortunately, there was "no problem of access to informants"—no jungles to cross—and "no language barrier"—no ancient, undocumented tongues to learn (though the glossary of genetic terms at the end of the book might beg to differ).

The book centers on a series of lengthy interviews conducted by Rabinow and Dan-Cohen in 2003 at Celera Diagnostics, a biotech company based in nearby Alameda. Celera Diagnostics was founded in 2001 to capitalize on the success of its sister company, Celera Genomics, the well-known private competitor to the public Human Genome Project. Since its inception, Celera Diagnostics has been scanning the genome on an unprecedented scale, looking for mutations in single base pairs of DNA that lead to functional differences in proteins and that are correlated with disease. Its goal is to discover, standardize, and produce genetic tests for these various diseases.

Celera Diagnostics, the authors contend, is thus constructing a "machine to make a future." If it succeeds, life in the future will be drastically different than it is today: common tests will scan people's genomes for telltale signatures of diseases and for the markers that will reveal how responsive they will be to various treatments. The task of the book then is to pry this machine apart and to examine its constituent pieces—the scientists, technicians, managers, lawyers, and even execute assistants that make the company hum.

Rabinow and Dan-Cohen let the interviews speak for themselves, with very little authorial synthesis. What results is a snapshot of an engaged company-in-motion that isn't shoehorned into a linear narrative. The interviews explore a number of themes: the emergence of Celera's business and scientific strategy, the design and implementation of the colossal robotic machinery that runs the genetic tests, and some of the ethical and social issues surrounding such research (though these interesting issues tend to be underemphasized).

The most interesting parts of the book explore the relationship between commercial, corporate science and science as it's practiced within the academic community. The conventional view is that the rise of corporate science has eroded both the disinterested nature of research and the sense of trust and openness between researchers. Closed, secretive, corporate science, on the one hand, is out to make a profit, while open, academic scientists, on the other, are out for the good of humanity.

Of course, as anyone involved in science could have guessed, the picture that emerges from the interviews is quite different and more complicated. Researchers at Celera often work side by side and openly with other companies and with outside academic researchers. And academic researchers often serve as paid consultants, receiving considerable amounts of cash and lab equipment. University scientists just as often act in their own self-interest—that choice Science or Nature publication—as much as they try to advance knowledge. The views of those at Celera run the gamut—from the patent attorney who admits that "if it was entirely up to me, I'd say, 'Never publish anything! Never talk to anybody'..." anybody outside until we get the work done!" to the technician who genuinely feels that his research should be open to the community "in order to better mankind" to the consultant who worries about the fact that "across the globe hundreds of millions and maybe billions of people would have no access" to any of Celera's findings.

As informative as these parts are, the good bits of the book come like a needle in a haystack of biological and strategic jargon. One has to ask whether the post-modern concerns about form and narrative structure take away from the book as a whole. The lack of a strong authorial voice means that it's sometimes hard to keep track of the shifting alliances of companies and senior managers. The discussions of patenting genetic discoveries and of the relationship between corporate science and the academy do warrant giving the book a glance though, especially since it's a quick read. But while it might serve as useful source material for future anthropologists seeking to reconstruct the machine that made their future, for those non-anthropologists in the present its obsession with form and its insistence on the authors reeding into the background leave the reader looking for something more.

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In the late 1990s a political storm raged across America over the use of federal funds to support scientific research on cells derived from human embryos. On August 9, 2001, in his first live address to the nation, President Bush set forth a proclamation: federal funds would be eligible to support research on pre-existing human embryonic stem cell lines but would not be allowed to fund research using any newly derived cell lines. Scientists around the country cried foul, claiming that what looked like a compromise would actually stifle scientific endeavors for years to come and limit the possibilities for curing some of the most devastating diseases afflicting the nation.

In 2004, California entered the fray with Proposition 71. Supported by 59% of voters, the measure set aside $3 billion in general obligation bonds to fund stem cell research in the state of California. Proposition 71 established the California Institute for Regenerative Medicine (CIRM) to make grants and provide loans for stem cell research, facilities, and other vital opportunities. In the short term, CIRM will be funded through “bond anticipation notes” designed to be purchased by philanthropic organizations. CIRM, modeled after the National Institutes of Health (NIH), will be headquartered in San Francisco. Proposition 71 also established an independent oversight committee to govern the institute and ensure ethical and responsible implementation of funding. In November of 2004, UC Berkeley’s Chancellor Birgeneau was appointed to the 29-member committee.
To actively compete for this funding, UC Berkeley established the Berkeley Human Stem Cell Center, through which 30 faculty are now associated. If the group succeeds in receiving funding through the CIRM, an effort that Randy Schekman, Professor of Molecular and Cell Biology is actively spearheading, a formal center would be created. The research center would likely be housed in a separate facility on campus, in large part because stem cell research supported by state funding must be physically separated from any research supported by federal funding. Even seemingly trivial items like petri dishes bought with NIH money have to be kept separate.

Until recently, the grant allocation process through CIRM was stalled by litigation put forth by a variety of interest groups. The primary lawsuit argued that members of the independent oversight committee have conflicts of interest in deciding who should get grants and loans. Some interest groups have claimed that Proposition 71 will only serve to line the pockets of big business. But many Berkeley researchers disagree. “They’re being sued by people who opposed it in the first place and are trying to keep it from happening,” says Schekman. Kevin Healy, a professor in the Department of Bioengineering, thinks it is “a knee jerk reaction that big institutions are bad, [that] they always have this nefarious wizard of Oz behind the scenes… I don’t see it that way. I will say that development of technology that is then transferred to industry, is a mission statement of the University.”

Finally, on August 3, 2005 CIRM announced recommendations for a first set of training grants that provide funding for the training of pre-doctoral students, post-doctoral students, and fellows. Given the go-ahead, Berkeley researchers can now draft grant proposals tailored to these recommendations.

The Berkeley Center is well poised to receive funding because many of the faculty on campus, including members of the Departments of Bioengineering and Chemical Engineering, already conduct research on stem cells. Such labs work on federally approved embryonic stem cell lines as well as the less controversial adult stem cells. Adult stem cells are not restricted by the federal ban because they are not derived from human embryos.

To understand the role that stem cells may play in medicine, it is important to distinguish between embryonic and somatic (or adult) stem cells. Embryonic stem cells are isolated from the inner cell mass of a developing embryo. These cells are all unspecified and are considered pluripotent, meaning they can differentiate into any cell type in the body.

The progeny of a dividing stem cell can either remain a stem cell, a property called self-renewal, or can go on to become more specialized cell types in a process termed differentiation. These cells are harvested less than a week after a human egg is fertilized, when the developing embryo contains about 100 to 150 cells. The outer cell mass of the embryo would eventually become the placenta and the inner cell mass would become the fetus. The embryos that scientists use are typically left over after in vitro fertilization attempts.

Adult stem cells can be found in pockets throughout the body in organs such as bone marrow, the brain, the umbilical cord, and muscles. These cells possess a somewhat restricted lineage for the particular tissue within which they reside. The properties of adult stem cells have been recognized for years and are the basis for lifesaving treatments like bone marrow transplants for leukemia patients. In this case, adult stem cells found in bone marrow give rise to new hematopoetic (i.e. blood) cells in the transplant patient. Adult stem cells are less controversial than their embryonic counterparts but are considered to be limited in the types of cells they can become, and thus, their clinical value is unclear.

David Schaffer, an assistant professor in the Department of Chemical Engineering wants to learn how to maintain adult stem cells derived from the nervous system in their undifferentiated state and how to control their differentiation into new neurons. For many years, scientists believed that new neurons were not produced in the adult brain. However, in the early 1980s, scientists observed neurogenesis, the creation of new neurons, in the brains of adult canaries. In the early nineties similar experiments were conducted in rodents, and in 1998, neurogenesis was demonstrated in humans.

This finding has sparked the hope that continued research will enable diseased tissue to be regenerated by activating healthy stem cells. According to Schaffer, “It is believed that in the adult organism there are a couple of regions [where] stem cells reside and are very active and are continually generating new neurons, but there are many other regions in which there appear to be quiescent stem cells. The hope is that we can learn enough about the molecules that regulate these cells,
that maybe we can wake them up if they’re dormant and mobilize them to regenerate tissue when they may not normally be able to do so.” A lofty goal, indeed, but some initial experiments are showing glimmers of hope.

For example, Schaffer has targeted a signaling molecule, Sonic hedgehog (Shh, named after the SEGA video game character), as a potential candidate molecule that may be useful in turning on quiescent stem cells. When Schaffer tested to see whether Shh caused adult neural stem cells to differentiate into actual neurons he observed a surprising result. Rather than stimulating differentiation, it caused them to divide more rapidly. Importantly, in rats, his group was “able to triple the number of newborn [stem] cells within the brain, [and] if you waited long enough, a large number of them actually turned into neurons,” says Schaffer. The ability to increase the rate that stem cells, and ultimately neurons, are produced in the hippocampus has enormous therapeutic implications for the regeneration of neural tissue in patients with neurodegenerative diseases such as Alzheimer’s. Schaffer is currently taking his work a step further and is examining whether the introduction of Shh in the brain of a rat can result in the repopulation of hippocampus cells in an animal model of Alzheimer’s disease. Ultimately, Schaffer thinks that the real promise lies in using molecules like Sonic hedgehog to control the fate of embryonic stem cells, as opposed to the adult stem cells he works with currently. He thinks that because embryonic stem cells are completely undifferentiated they will be easier to control using these types of external signals. Additional sanctioned funding, state or otherwise, is critical for him to proceed with further experiments.

Another venue of experimentation that has made progress while funding battles ensue is Healy’s lab. Healy is tackling another step on the road to regenerative therapy using stem cells by improving methods for accurately simulating the environment in which a stem cell resides in the body. Stem cells are very sensitive to cell culture conditions and will readily differentiate when conditions are inadequate. Understanding how to maintain stem cells in their undifferentiated state outside of the body is a major hurdle to establishing long-term viable embryonic stem cell lines. Healy states that “in many ways, culturing stem cells is a lot like taking care of a pet, in the sense that you have to feed it, you have to change the media that bathes the cells, and you have to put them in the right environmental conditions”.

To achieve this goal, Healy is developing three-dimensional polymer scaffolds that mimic the natural support structures found in tissues, called extracellular matrices (ECMs). A variety of biomolecules can be attached to ECMs so that different types of tissues can be grown on it. For example, sonic hedgehog could be readily attached so that embryonic stem cells could divide and spread along the matrix. Using an embryonic stem cell line currently supported by federal funding, Healy’s group has identified the combination of chemicals and materials that promote embryonic stem cell self-renewal in the short term. They are currently testing whether they can maintain the undifferentiated state of the cell line for six to eight months, the standard for self-renewal.

Just as importantly, moving to a synthetic matrix
would relieve researchers of the necessity to grow embryonic stem cells on a “feeder cell” layer of irradiated fibroblasts (skin cells) that do not continue to grow. Through unknown mechanisms, this procedure maintains the human stem cells in their undifferentiated state in cell culture. One of the roadblocks to using the current federally funded cell lines is the fact that these feeder cells may harbor diseases that could contaminate the stem cells and ultimately be transmitted to a patient. Using a synthetic matrix like the one Healy is developing would allow researchers to establish cell lines that are contamination-free. For this research to continue, however, Healy will need new cell lines to test the synthetic matrices.

In addition to the role that stem cells may play in regenerative medicine, several faculty members would like to explore normal cell processes using embryonic stem cells. This is the case for Randy Schekman, who heads the Berkeley Human Stem Cell Center. The broad scope of his work has focused on membrane assembly and trafficking of proteins in, out, and around the cell. While the core of his research uses yeast as a model organism, his group has recently started working with mammalian cells to examine defects in trafficking processes that may play a role in early onset, familial forms of Alzheimer’s disease. The Alzheimer’s defect surrounds a protein called presenilin 1 (PS1). Mutant forms of this protein can, through undetermined means, cause incorrect processing of amyloid precursor protein, resulting in the production of plaque forming peptides in the brain—a hallmark of Alzheimer’s disease. Defects in PS1 may clog up the garbage disposal mechanisms of the cell by impairing protein traffic and disrupting the removal of processed amyloid precursor protein.

To further understand protein trafficking and the role it may play in Alzheimer’s disease, Schekman would like to expose human embryonic stem cells to the mutant presenilin gene and see if they can detect the production of the plaque forming peptide. Schekman investigates the following question: “Is there a developmental switch that unleashes this pathway, or is it just a pathway [always switched on] in the embryo and so [the peptide] is just accumulating…in the nerve cells over many years or decades?”

Questions like this will remain unanswered until the CIRM begins distributing funds to Berkeley researchers and to scientists in the rest of California. While several departments on campus advertised to last year’s graduate student applicant pool that California was the place to be for stem cell research, Schekman says they didn’t observe a noticeable difference in the number of students who applied for this purpose. However, Schekman explains, “Students and postdocs are market-driven in what they choose to do. They go into areas where they think there are going to be jobs in those areas. This is an area where I’m sure there are going to be jobs in the future and I’m sure students will follow the prospect… But other states are not going to sit around and wait for California to take this lead.”

Recent fractures within the Republican party over the federal policy on stem cell research make it difficult to predict the direction that the national debate will take. A variety of propositions are on the floor of the US Congress, some of which have been linked to other controversial issues such as therapeutic cloning, and it is likely that the current federal policy will see significant changes in the near future. However, for now, Berkeley researchers would be satisfied to see the funding earmarked by Proposition 71 make its way to the benchtops of their laboratories. It remains to be seen whether the hopes planted in stem cell research will blossom, but Berkeley scientists anticipate that their research will play a major role not only in the development of their field but also, ultimately in the future of medicine.

Rachel Shreter received her master’s in molecular and cell biology.

Want to know more?

California Institute for Regenerative Medicine: cirm.ca.gov
Healy lab: biomaterials.berkeley.edu
Schaffer lab: www.cchem.berkeley.edu/schaffer
Schekman lab: mcb.berkeley.edu/labs/schekman
Born the youngest of 11 children to parents from the Michuacan countryside and raised on a dairy farm on the outskirts of Mexico City, microbial ecologist Ignacio Chapela’s upbringing is not one you would call typical of a UC Berkeley professor. But then, not much about Chapela is typical. From his upbringing, to his self described “19th century biology education,” to his 3-year stint with Swiss agrochemical giant Sandoz (now Novartis) followed by his vocal opposition to biotech company-university ties, Chapela defies the norm time and time again.

During his term at UC Berkeley, Chapela has gained campus-wide attention and drawn national headlines on many occasions. He led the charge in protesting industry-university relations when the College of Natural Resources signed a multi year contract with Novartis. His research group then published a hotly contested study in the journal Nature, presenting evidence of transgenic genes in wild Mexican corn. More recently, he has been in the news during his drawn-out battle for tenure and the surprise announcement that it had been granted in May of this year. Now, with his newly awarded tenure to the Department of Environmental Science, Policy, and Management, Chapela talks to the Berkeley Science Review about his past, his research program, and his plans for the future.

When did you choose to study biology?

By the time I was 14 or so I was really into both insects and minerals. I would just take off and go into the mountains and collect, collect, collect, and lie down and observe—a lot of this by myself…

I have a story that I like to tell [about] how I really became locked into biology. It was before college, late in the afternoon, and I was lying down in a field of tall grass and the fireflies were coming out. Some were crawling up to the tips of the grass and when they got to the top, they would start lighting up, while the others flew around them. And then I started seeing that they were actually talking to each other, the ones in the grass were communicating with the flying fireflies. I ran into the house and got a coffee can and put a candle in it and poked a hole with a nail so I could mimic the firefly light, like morse code. And I managed to get one of the fireflies to land on my hand on command. I had no idea what the biology was behind it, I just had this feeling that I understood it, and could participate. It was an emotion that was really hard to get rid of. It hooked me and I think I’m still riding on that high.

Where did you go to college? (and how did you choose mycology?)

My college degree was in Mexico. There, at least at the time, it was really a 19th century education in biology—so in terms of courses we’d have like 4 zoology, 4 botany, 2 mycologies, microbiology. We had ecology and biochemistry and math and all that but the meat of it involved seeing the diversity of life. That was wonderful. When I first saw the fungi I said, “wow, this really is it”—just so much here of interest, so much not known, and so much is just weird.

It’s interesting, somebody asked me in a radio interview once: “What is your favorite science fiction writer?” I was really worried because I didn’t have a good answer. I thought about it and eventually I found myself saying...
“You know, that’s very interesting because I don’t read science fiction. And I think the reason is that I don’t need it.” Because what you see in the microscope, what you learn from even the simplest experiments, or just simply walking out through the field is such that I become flabbergasted. It’s just so amazing.

Do you notice the trend to focus more on molecular biology in the United States?

Definitely. I think it’s a huge loss. The most limiting part of it is not what we don’t show you, but what we lead the students to believe they know. We lead the students to believe that because somewhere there’s a database that contains the human genome that we have humans figured out. And because we’re just piling up that database with more and more genomes of more and more organisms that no one knows anything about—even what they look like. We have no idea what they look like, let alone what they do, where they live, are they still living or not. And we lead students to believe that we know everything, give them this false assumption. And to me, that is the most problematic thing. We take all the satisfaction out of the students by doing that. They say, “my god, how come I’m not understanding that?” I see a forest out there and I have no idea what it’s doing. I’m so ignorant. People don’t feel ignorant out here, and that’s terrible.

After you completed your undergraduate and masters degree in Mexico, you went to Wales to do your PhD in mycology. Where did you go after that?

I went to Cornell as a postdoc, where I was looking into endophytic (internally-living) fungi. I was interested in going to the tropics to work, but one day someone called and there was this voice on the phone at 8 in the morning saying, “This is so-and-so calling from Switzerland. We have been looking at your publications and we’ve been talking to people who know you and we’re wondering if you want to do whatever it is you’re doing, just come and do it here.”

Chapela’s caller was a representative from Sandoz, then the world’s second largest agrochemical and pharmaceutical company. Later renamed Novartis, Sandoz offered Chapela a job and he took it.

How was the job with Sandoz?

It was wonderful, especially the first year—totally open, lots of money, no bounds, no limitations. I was doing whatever I wanted. What they were interested in were the byproducts of my work—all these strains of fungi that nobody had checked for new compounds, like pharmaceuticals and biochemicals. They were just basically using me to bioprospect. And I made the point of saying, “You’re not going to get anything out of me anywhere else in the world outside of Switzerland. I’ll just work in Switzerland,” because at that point I was becoming aware of the problems of bioprospecting.

Why did you leave Sandoz?

I can’t give you any one reason. I didn’t leave because I was angry, they didn’t do anything wrong, I wasn’t disgusted with them. I left because of family reasons, but [there’s more]: the first year was absolutely a blank check. The second year, I think they liked me, they were very complimentary, always asking for my advice. At some point they asked me to develop a microherbicide, a biocontrol agent to kill weeds. And I really liked this idea. I was very naively thinking we could transform this huge transnational company into producing green products. Biocontrol agents instead of chemicals—wouldn’t that be wonderful!

Now I think that’s crazy, to be spraying pathogens around the world where people don’t know what they do, but at the time, I thought it was a really good idea. And I developed a product that was really good. We were optimizing a pathogen to be more pathogenic, which was fun. But through that, I started interacting more and more with the herbicide group. I remember the boss of the bosses there, he kept saying “you just need to know you will have to give up fungi, maybe for a while. Just think about it—make this investment now, then when you retire, you can do as much mycology as you want. Just work with us right now.” I don’t feel that they were trying to brainwash me. They were really trying to help me and make me part of the family.

I [went around the company and] looked at people in the eye to try to find someone who was 50, and who was still shining in the eyes. At the end of my survey after a year, I was coming up with a blank. Lots of people looking forward to retirement, really good skiers, great houses in the Pyrranese, in the Alps, but their eyes… That was a really important reason. So I left because of that and I’m glad I did now.

After Sandoz?

I went back to Cornell to work on fungi, and to work with Tom Eisner, who had started this initiative with the Costa Rican government and Merck [to pair Merck’s bioprospecting with a conservation program for Costa Rica]. It was fantastic. I had access to a lab doing lab-based work, but at the same time, I had access to all of Tom’s connections and Tom knows everybody: in Capitol Hill, all over the world governments, and NGOs. I had an open telephone to all of these people.

It was an incredibly fast learning curve on politics and the media and he was very media savvy. At that time, he had the record for the most covers of Science and Nature. And he just knew how to talk to reporters and how to deal with them. And that opened my eyes so much to the realities of politics, media in biology.
How did you end up here at UC Berkeley?
I was not going to go to Berkeley. They called me and they said we’re thinking of opening a position and we’re wondering if you’d want to apply. It took two years of going back and forth with interviews, with 2 or 3 deans and 3 or 4 chairs of the department, and my case just kept going and going. Then eventually they said yes and I came with all my prejudices against California that everybody had, but I discovered a wonderful place. It’s a place that has really changed me. I feel like I belong. In California itself and this place. I have things to figure out here. All those other places I had been before, I was a foreigner, kind of surfing on the surface. This is a place where I feel like I want to go deeper.

How was your research program affected by your attenuated tenure case?
My physical, lab-based research has suffered badly. I managed to wave my students out just in time for my contract to end. I was supposed to be out of here by the end of June. My last student left just this last August for his job and that’s it! Lab closed! So the lab has been mothballed for two to three years, and it’s an incredible handicap in research. So it’s a huge challenge. I’m still trying to get the campus to recognize the damage to my research because of their illegitimate handling of my case. They claim that it was perfectly fine, that the process worked, and I say no way. But it’s not hopeless. I thought I was going to be out of Berkeley, so I have a little team of people outside the university and we’re already developing some ideas. One idea has to do with producing maps of the biogeography of transgenics—kind of like microbes at a geographical scale. What we’d be doing is best analyzed using the conceptual tools from microbial biology. Because what we’re doing [with transgenics] is introducing pieces of DNA with very specific properties; I am interested in figuring out their population dynamics, how much and how they move, where they go, how they change, where they change, how they interact with the environment. It would involve driving a transect from Iowa to Guatemala, producing data, and coming up with a map of the scale of abundances and distribution of transgenic corn. Corn, because, if I can do it with corn pollen- which you have to admit is a great crowd pleaser, one way or the other people get all riled up about it- then I can do it with anything.

So my private wish is to come back to this idea and do biogeography, and with anything that is flying through the air. Could be spores, could be pollen, it’s the same type of thing. So yeah, I feel like I can come back to mycology and it’s not that I’m not thinking about it, I want it to happen, but right now it seems more important in terms of public service to look at the transgenics and also there is much more interest, which I think is appropriate. The reason why people give money to this is because they are interested, so why should I not do it?

How do you feel about teaching?
This was my first job teaching and I really discovered that I like it a lot. I’ve done more teaching then I’m required. But my feeling about this place is that my position is something like 75% research 25% teaching, whereas this type of job actually warrants 75% teaching, 75% research and 75% service.

Do you have any tips for anyone pursuing a tenure-track position at a public university?
I don’t have any dos and don’ts. All I can say is that I wouldn’t change anything. I have absolutely no regrets. I feel that I’ve been doing my job all along. I’m paid to do research, and I’m paid to teach, but I’m also paid to keep a position where a certain way of looking at problems can be expressed, where certain people can come and be heard in the market of ideas, where a certain view of the world is represented at this university. It’s a tough job, but that’s why we have such prestige. That’s why being a professor at Berkeley is something that people respect.

Where do you expect yourself and the world to be 20 years from now?
I don’t have any doubt that I will be asking questions about the microbial world, the invisible world. It’s fun and it’s just fascinating. I have developed a bias for the microbial world. I look at a landscape and I see a landscape of microbes where people see trees. So I like providing that bias to the world and to myself.

I also think that my research will be more and more engaged with questions of social repercussions. I think that in 20 years we are going to be in an even worse place than we are right now. Pretending we are not in a crisis is like trying to cover the sun up with a finger. Unbiased and scientific opinion making will be so necessary that I think I will not really have the choice of just studying an obscure group of fungi. I would love to be able to just study them and just dedicate myself to them, but I don’t think that’s OK, especially now that I’m in the position of public representation. As long as I’m here, I have to be representing what’s important to the public. And it’s fun, too. There’s lots of fun to be had.

Cheryl Hackworth is a graduate student in molecular and cell biology.
Berkeley Groks

Spreading science news by any means necessary

Getting a dose of science used to be such a chore. You’d have to pore through a mountain of journals and wade through the swamp of jargon every month. Fortunately for all of us, Frank Ling and Charles Lee take the pain out of staying in the know with their weekly KALX radio show, Berkeley Groks. The half-hour program is equal parts news cast and freewheeling conversation between the two hosts, Ling and Lee, who cover the week’s developments in the scientific world with an approachable, funny, and at times downright irreverent style. Berkeley Groks has been broadcast at noon every Wednesday—“it’s the fulcrum of the week,” quips Lee—since early 2001, generating over 200 episodes in all.

The show typically begins with a round-up of the week’s discoveries in science, followed by the interview of a guest, who is later quizzed on five questions generated by the “Grokatron 5000” supercomputer. Recent guests include George Larson, editor of Air & Space magazine and Michelle Feynman, daughter of the late, great physicist Richard Feynman. The show’s roster also boasts a number of Nobel prize winners, George Foreman, journalist Bill Moyers, and Ling’s favorite, Sylvia Nasar, author of A Beautiful Mind.

Ling and Lee met while undergraduates at Cal Tech and both went on to pursue PhDs at Berkeley. They cooked up the idea for a science show after working in the news department at KALX. The pilot episodes they pitched were panned for being too dry so they shifted to a conversational style that Ling describes as being “like Click and Clack,” the two brothers that host the NPR show Car Talk. Both Lee and Ling have since finished their PhDs and are now postdocs—Ling at Cal and Lee at the University of Chicago—still going strong with their radio show.

As for the future, Lee says they “had the idea to expand to other stations,” but Ling stresses that they’re “not supposed to use the ‘s’ word.” Syndication. That hasn’t stopped them from branching out to the internet. Most of their past episodes are available through their website, as well as the new format du jour, the podcast. For those not in the know, podcasting does for radio what TiVo does for television, allowing you record a program for later consumption. Podcasting enables listeners to download a radio program to their computer or iPod, so they can listen to it whenever they like. Kick-started by former MTV VJ Adam Curry, podcasting has grown from a grass roots effort to a new media outlet. Beyond Groks, you can catch podcasts from Rush Limbaugh, the Philadelphia Eagles, CNN, and even Fox’s “The OC” (yes, that “OC”).

So will podcasting be the medium of the future for Berkeley Groks? Lee is skeptical, pointing out that radio is “a medium where anyone can tune in. It’s very cheap to transmit, very cheap for people to get” and by comparison, computers are still quite pricey. “People have been talking about the death of radio for years, and it’s not going to happen.” Whatever does happen, Berkeley Groks will be there, making sense of science for the rest of us.

Charlie Emrich is a graduate student in biophysics.

Want to hear more?
Check out Berkeley Groks every Wednesday at noon on KALX 90.7 FM. Podcasts can be found at groks.net or through the iTunes music store.
The No-Spin Zone

Do you remember that episode of “The Simpsons”—the one where Bart calls collect to Australia to determine if the toilet drains clockwise or counterclockwise? Lisa explains that water drains in the opposite direction in the southern hemisphere because of the Coriolis force. Later, the Simpsons discover a toilet in the US Embassy, which drains in the “American” way thanks to hardworking technology. It is a funny episode and one of my personal favorites. Unfortunately, it makes no scientific sense. The Simpsons, great icons of popular culture, are propagating a terrible misconception about the role of the Coriolis force that is so prevalent, we all seem to share it. If you’ve ever stared at your toilet while repeatedly flushing it (not that exciting, I must warn you), you probably noticed that it only drains in one direction, reinforcing the notion. The Coriolis force is not the culprit, however.

The Coriolis force is a pseudo-force, much like a centrifugal force, resulting from a rotating coordinate system (i.e. the Earth as it spins). Inez Fung, professor in the Department of Earth and Planetary Science and director of the Berkeley Atmospheric Sciences Center, explains that as the Earth rotates, a person standing at the equator moves in a larger circle than someone at higher latitudes, and thus moves faster. A pocket of air moving northward from the equator would therefore “gain” on the Earth below, resulting in an arced path that drifts eastward. Similarly, a pocket of air moving southward from the Arctic would “trail” the Earth below. This east-west pseudo-force is what we call the Coriolis force.

It is responsible for many atmospheric effects including the spiral patterns of hurricanes, as surrounding air is funneled into a central low-pressure zone. “What is relevant,” says Fung, “is the time and distance traveled.” Storm systems develop over several days and travel hundreds of kilometers. Your toilet draining lasts ten seconds and is (hopefully) confined to a foot-wide bowl. Fung points out that a sky diver doesn’t need to account for the rotation of the Earth below because the Coriolis force is simply too weak on such quick, small-scale events.

So why does your toilet always drain in the same direction? There are other factors that far outweigh the Coriolis force: the symmetry of the bowl’s shape, the direction that the water jet flows when you flush, and the location of the drain. Any of these mundane details can determine which way the water drains. Despite what you’ve heard on “The Simpsons”, you won’t need to travel to Australia to find an oppositely draining toilet. A quick peek in your neighbor’s bathroom might be enough (though you should probably ask first).

Louis-Benoit Desroches is a graduate student in physics.

Editor’s Note: This is the first run of a new column designed to debunk popular misconceptions about scientific ideas—the kinds that even scientists by and large believe. Here, we examine common notions of physical phenomena and set the record straight. If you can help shine a light on a commonly-held scientific misconception, drop us a line at submissions@berkeley.edu.
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