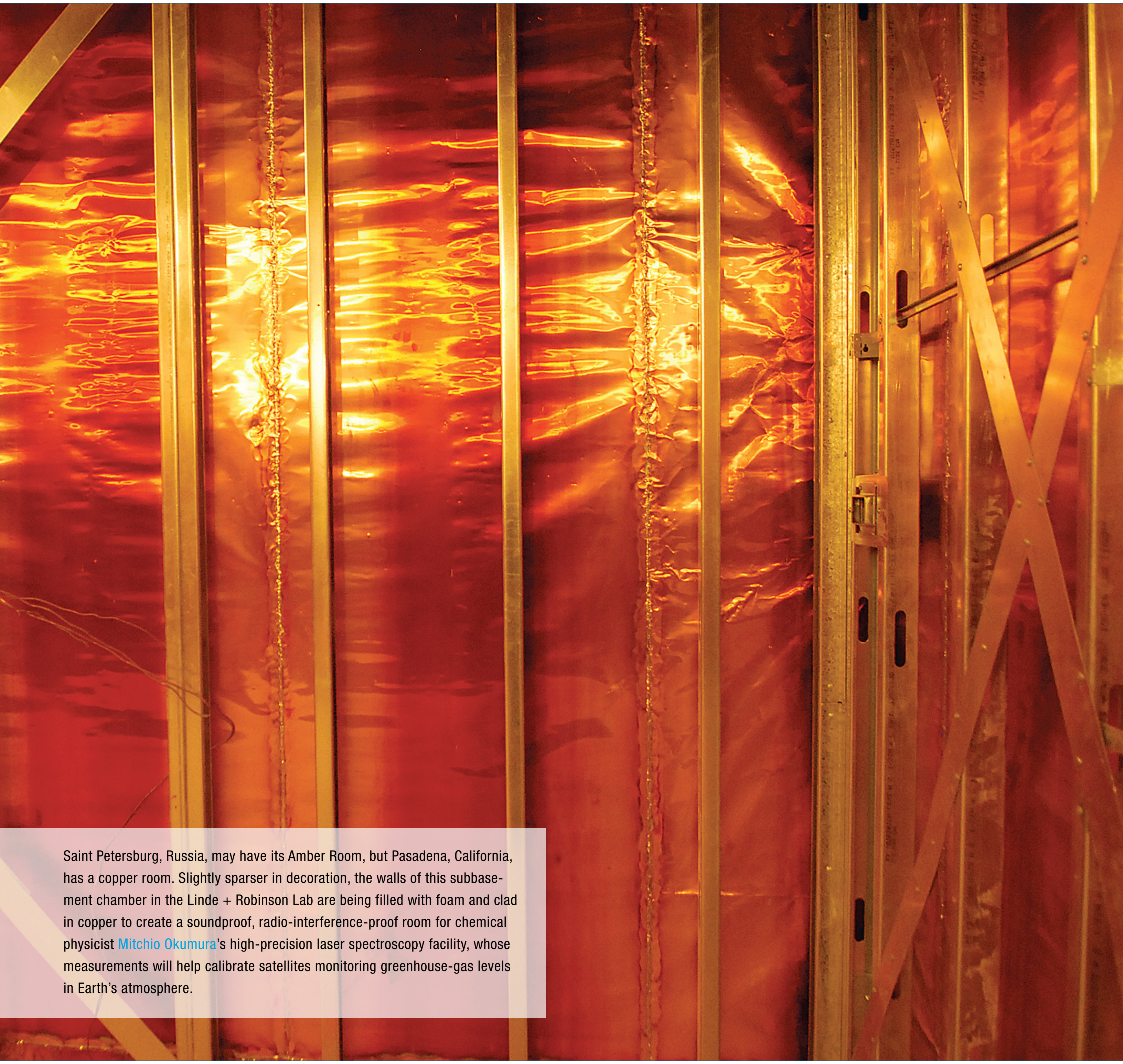
Random Walk



Saint Petersburg, Russia, may have its Amber Room, but Pasadena, California, has a copper room. Slightly sparser in decoration, the walls of this subbasement chamber in the Linde + Robinson Lab are being filled with foam and clad in copper to create a soundproof, radio-interference-proof room for chemical physicist Mitchio Okumura's high-precision laser spectroscopy facility, whose measurements will help calibrate satellites monitoring greenhouse-gas levels in Earth's atmosphere.

DAWN OVER VESTA

At around 10 p.m. Pasadena time on July 15, JPL's Dawn spacecraft slipped into orbit around the giant asteroid Vesta. The spacecraft that was the first to use ion drive—a system that accelerates ions to generate thrust instead of relying on chemical fuels—to boldly go beyond Earth orbit is now the first spacecraft ever to orbit a main-belt asteroid; in a year, Dawn is slated to beome the first spacecraft to leave orbit around a main-belt asteroid and go orbit a second one.

Vesta is 530 kilometers in diameter, and the second most massive object in the asteroid belt. Discovered in 1807, it is thought to be a protoplanet that never quite formed, offering us a look at how a rocky hunk like Earth might have appeared during its infancy.

Dawn will continue to tighten its orbit around Vesta for about three weeks, during which time the navigation team will measure Vesta's gravitational pull in order to make a highly accurate calculation of the asteroid's mass. This will reveal whether Vesta, like Earth, has a nickel-iron core and an olivine mantle—a so-called differentiated interior, which would be a consequence of that interior having once been molten. Meanwhile, the science team will continue its search for possible moons orbiting the asteroid while calibrating the spacecraft's camera and spectrometers. Detailed mapping of Vesta's surface commences in August.

In July 2012, Dawn will restart its ion engine (another first!) and head off to the dwarf planet Ceres, the biggest object in the asteroid belt, arriving in February 2015. *—DS* E&S

This shot of Vesta was taken on July 17 from a distance of about 15,000 kilometers. The resolution is about 1.4 kilometers per pixel.

TÊTE-À-TECH

POP QUIZ: The French word *collisionneur* refers to

(a) a part of a locomotive;
(b) a particle accelerator;
(c) a particularly inept driver;
(d) a part-time Roller Derby jammer.

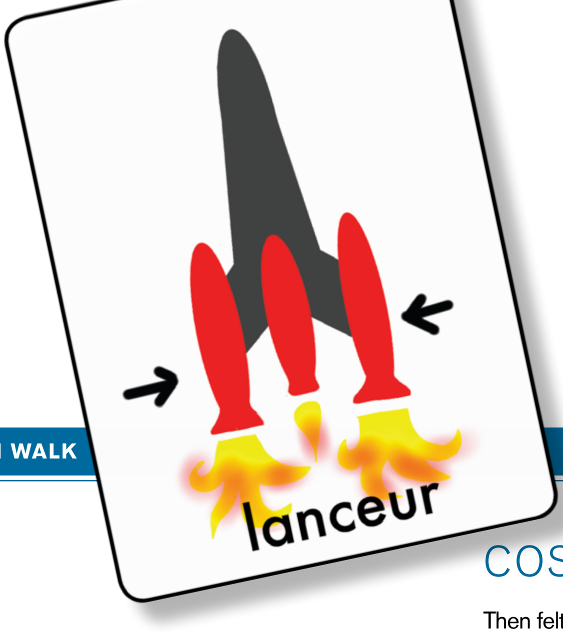
Though it's doubtful you'll ever be called on to provide a precise translation,[1] the same can't be said for Caltech seniors Eva Nichols and Sylvia Sullivan. Both are spending the fall of 2011 in the suburbs of Paris, as exchange students at École Polytechnique. Classes at the elite research institution are conducted entirely in French—and at a level rather higher than the *"J'ai mal aux dents," "C'est la vie,"* or whatever else you might half-remember from high school. Nichols and Sullivan come prepared, however. Earlier this year, they took part in a brand-*nouveau* Caltech language course tailored especially for them: 10 weeks of rigorous immersion in technical French, both spoken and written.

"This isn't a typical conversation course," cautions its creator, Lecturer Christiane Orcel. "There's no 'Have you an unabridged edition of *Les Liaisons Dangereuses?'* or 'Never again shall I order the *pâté*.' We're specifically preparing students to engage in detailed scientific discussions." Lauren Stolper, the director of Caltech's Study Abroad program, explains the course's origins: "Last fall, we had a list of 20 students who had expressed interest in studying at l'École Polytechnique. But at our first informational meeting, only seven showed up." She wondered whether some of the no-shows might have succumbed to doubts *vis-à-vis* their own mastery of the language. Orcel suspected that Stolper's hunch was right: "Americans can sometimes decode French phrases like *une plate-forme pétrolière*,[2] but other technical terms are much more inscrutable. Lauren and I felt that students who were already strong in French could benefit from scientific discussions with native speakers. We brainstormed with Cindy Weinstein, executive officer for the humanities, and then sent a proposal to [Vice Provost] Melany Hunt, who approved funding for a trial term."

And so, twice a week last spring, a handful of students met *en masse* in a Baxter classroom to hear guest lecturers giving technical presentations in French. Each lecture was followed by a Q&A session (naturally, English was *prohibé* in class), and then by a discussion of a scientific article related to the topic *du jour*. Orcel unearthed many of the articles from a journal called *Pour la Science*—the French version of *Scientific American*—but how, so far from Montmartre, Montreux, and Montréal, did she track down lecturers with native or near-native French fluency? "That was the easy part," smiles the native of Nice. "It turns out that we have many, many francophones in the Caltech/JPL community. I just e-mailed every one I knew of. The response was overwhelming."

The makeup of that first class represented an interesting *mélange*: half a dozen undergraduates, one grad student, one postdoc, and a JPL scientist, all of whom met the course prerequisite of two years of French in college or three years in high school. Sullivan, who has been *au fait* with the language since fifth grade, says her newly enlarged vocabulary will come in handy when she's researching ocean sedimentation as part of her studies in France: "I'll be studying in the Département de Mécanique des Fluides, which is a very impressive group. Eventually I'd like to do graduate work in applications of fluid mechanics to environmental questions." And she can, too, since in addition to its undergraduate exchange program, École Polytechnique also conducts a dual master's degree program with Caltech's Graduate Aerospace Laboratories (GALCIT).

Still, a cynic might say, given that English is the *lingua franca*[3] of modern science, isn't knowledge of a foreign language superfluous? *Au contraire*, says Caltech physics professor Harvey Newman[4]: "The predominance of English in scientific discourse is historical fact now. But many of the CERN subcommunities, when they aren't participating in major meetings or multinational working groups, speak among themselves in their



own languages: Italian, German, Russian, Spanish, French. In fact, given the rise of China, Latin America, and other regions, I'm not sure that the exclusive use of English will persist to the same degree over the next few decades."

Will Orcel see an *encore* of her class in the future? It all depends on the funding, she says. Stolper, for her part, is in favor: "This course makes the study of a foreign language truly relevant to Caltech scientists and engineers. It gives them the confidence to put their language training to use in their professional lives." And Newman points out a subtler benefit: "Recalling what it was like to be a student reading original papers and PhD theses in French or German, I think something has been lost. Scientific discourse was once richer in this respect. Anyway, conversing with a scientist in his native language helps build partnerships, friendships, and mutual understanding—all of which are so important in modern life." *—DZ*

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[1] And if you ever are, the French Ministry of Culture cheerfully directs you to its technical terminology database at http://franceterme.culture.fr.

[2] Oil rig.

[3] Actually, this is Italian.

[4] And researcher at the five-mile-diameter *Grand collisionneur de hadrons* (LHC) at CERN.

COSINE CUISINE

Then felt I like some watcher of the skies
When a new planet swims into his ken.
—John Keats, *On First Looking into Chapman's Homer*

It's a common enough story. Harold McGee (BS '73) majored in English (well, for a Techer that part's not so common), earned his PhD in literature at Yale, and had every intention of spending his life writing about writers (Keats, for one). But as so often happens with creative minds, interests trumped intentions. McGee's perpetual curiosity about what happens when food is cooked—the physics, the chemistry—kept diverting his attention. He soon found himself eschewing Grecian urns and nightingales for double boilers and pheasant under glass.

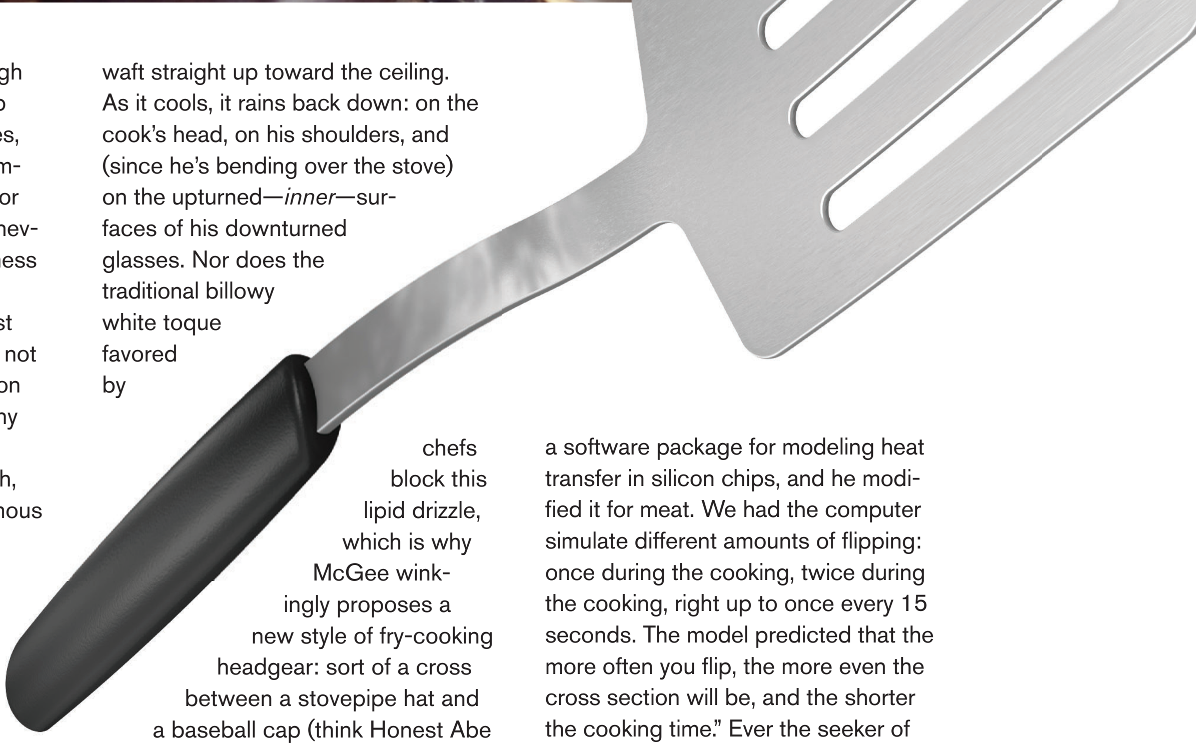
Today, he's a world-renowned expert on kitchen science, with a monthly column in *The New York Times*, frequent media appearances, and a spot in *Time* magazine's list of "10 ideas that are changing the world." At Caltech, his first book, the encyclopedic *On Food and Cooking*, is the textbook for the perennially popular class PA 16, Cooking Basics. Senior Director of Student Activities and Programs Tom Mannion, who created the course, finds that the book's material resonates strongly with the Institute's undergraduates: "Our students want to know: Why does a soufflé rise? Why does a banana turn black in the refrigerator? What happens to lettuce when you cut it with a knife instead of tearing it? They want to understand all the basics—so that they can create and not copy."

Last May, McGee delivered the keynote address at Caltech's 74th Annual Seminar Day. Over the growing borborygmus of a thousand rapt listeners (it was right before lunchtime, after all), he reviewed four centuries of research in food science: through haute cuisine, nouvelle cuisine, and nueva nouvelle cuisine, right up to the modern era of molecular gastronomy. To hear him tell it, his first scientific contribution to the field of cooking ("practical chemistry," in his words) came rather unexpectedly: "I was reading *Mastering the Art of French Cooking*, where Julia Child recommends using a copper bowl for making meringues and soufflés. She says the copper acidifies the egg white, giving you a better foam. But I remembered enough chemistry to know that copper ions can't change the pH of a protein solution much, so I thought this was just a crazy old cooks' tale."

Months later, he happened across an 18th-century illustration of a French pastry kitchen, featuring (so the caption proclaimed) a boy whipping egg whites—in a copper bowl. Galvanized (McGee, not the bowl), he decided to try the experiment himself, using a spectrophotometer to analyze the resulting foam. He and his coinvestigators, among them Sharon Long (also class of '73, also Blacker House), published their findings in an elegant paper that vindicated Julia while pointing the finger at the metal-binding protein conalbumin. The paper, whose citations include Plato and Boswell, appeared in *Nature*, where "one reviewer said the science was fine—but the subject was fluffy."

The Curious Cook, McGee's second book, might almost be thought of as a culinary lab notebook, taking

Chrome on the Range: While investigating why droplets of frying oil were preferentially attracted to the inside surface of his eyeglasses, McGee created this experimental setup and used it to test a wide (kitchen) range of parameters.



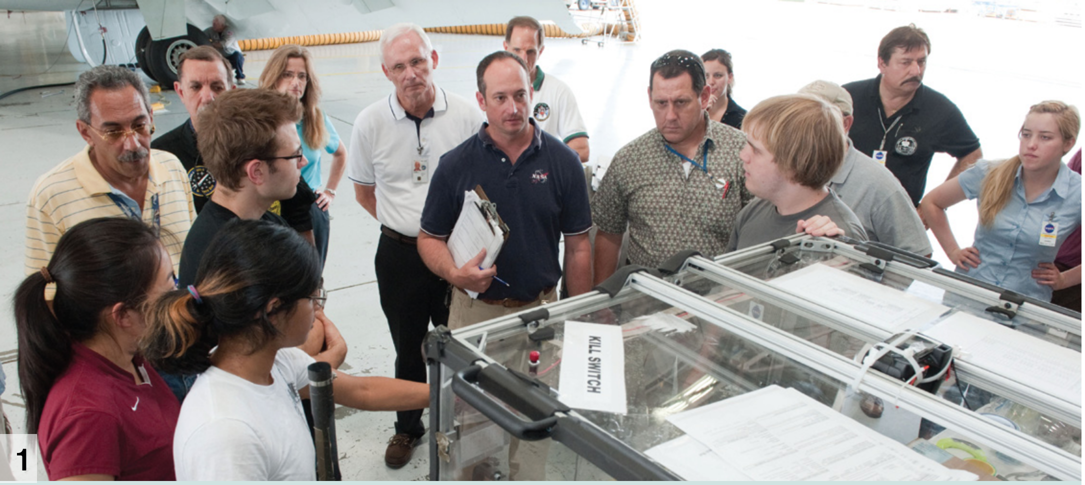
the reader on a happy romp through the world of experimental stovetop physics: boiling points, microwaves, convection, and more. McGee summarized one of his investigations for the Seminar Day audience: "Whenever I fry, I always make a spattery mess all over the place, including on my eyeglasses. But I noticed that most of the oil droplets were ending up not on the outside of the glasses but on the inside. And that didn't make any sense to me."

His mind drifted back to Caltech, long affiliated with some Very Famous Oil Droplets Indeed. Was there a link? Were his detouring droplets perhaps being diverted by stray charges of static electricity? "Drawing a connection between kitchen spatter and Millikan's classic experiment was thrilling," he confessed. "I thought maybe there was something funny about the electrical field around the head of a cook. So I made masks out of aluminum foil. I tried grounding myself with a chain. Nothing made a difference—and that really bothered me!"

The explanation, when McGee finally uncovered it, turned out to be more meteorological than electrical. Heated oil, it seems, tends to waft straight up toward the ceiling. As it cools, it rains back down: on the cook's head, on his shoulders, and (since he's bending over the stove) on the upturned—*inner*—surfaces of his downturned glasses. Nor does the traditional billowy white toque favored by chefs block this lipid drizzle, which is why McGee winkingly proposes a new style of fry-cooking headgear: sort of a cross between a stovepipe hat and a baseball cap (think Honest Abe on Opening Day), along with epaulets for aprons.

Last year, McGee received Caltech's Distinguished Alumni Award and also released *Keys to Good Cooking*, a compendium of kitchen tips and tricks. One of its revelations evolved out of an investigation he had performed for *Physics Today* on how often to flip grilled steaks. Analysis preceded experimentation: "I had a friend with a software package for modeling heat transfer in silicon chips, and he modified it for meat. We had the computer simulate different amounts of flipping: once during the cooking, twice during the cooking, right up to once every 15 seconds. The model predicted that the more often you flip, the more even the cross section will be, and the shorter the cooking time." Ever the seeker of empirical evidence, McGee procured some raw steaks and a thermocouple, took them to the grill, and began tirelessly flipping. And? "It worked. It was a wonderful discovery—not the most practical, but it helped us understand how rotisseries work."

KEATS. . . STEAK . . . the anagram may be a little forced, but it nicely sums up Hal McGee's ever-cooking mind.
—DZ e&s



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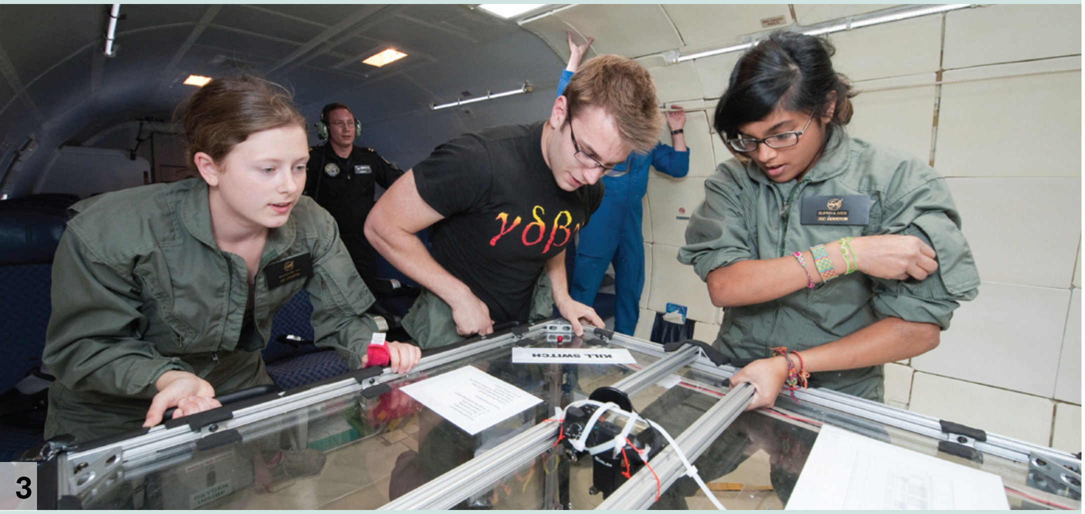

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1 In the final check before boarding, the team explains their project and the operating procedure to the Test Readiness Review committee, which decides if projects are safe to fly.

2 Mackenzie Day, currently a senior studying geology; Colin Ely (BS ’11); and Supriya Iyer, a junior in mechanical engineering, board the first flight of the “vomit comet.”

3 Day, Ely, and Iyer watch a hinge unfold on the first flight.

4 On the second flight, Robert Karol anchors himself with the aluminum and Plexiglas box that houses the experiment as Connie Sun keeps a close eye on the action inside. Both Karol and Sun are seniors in mechanical engineering.

4

2

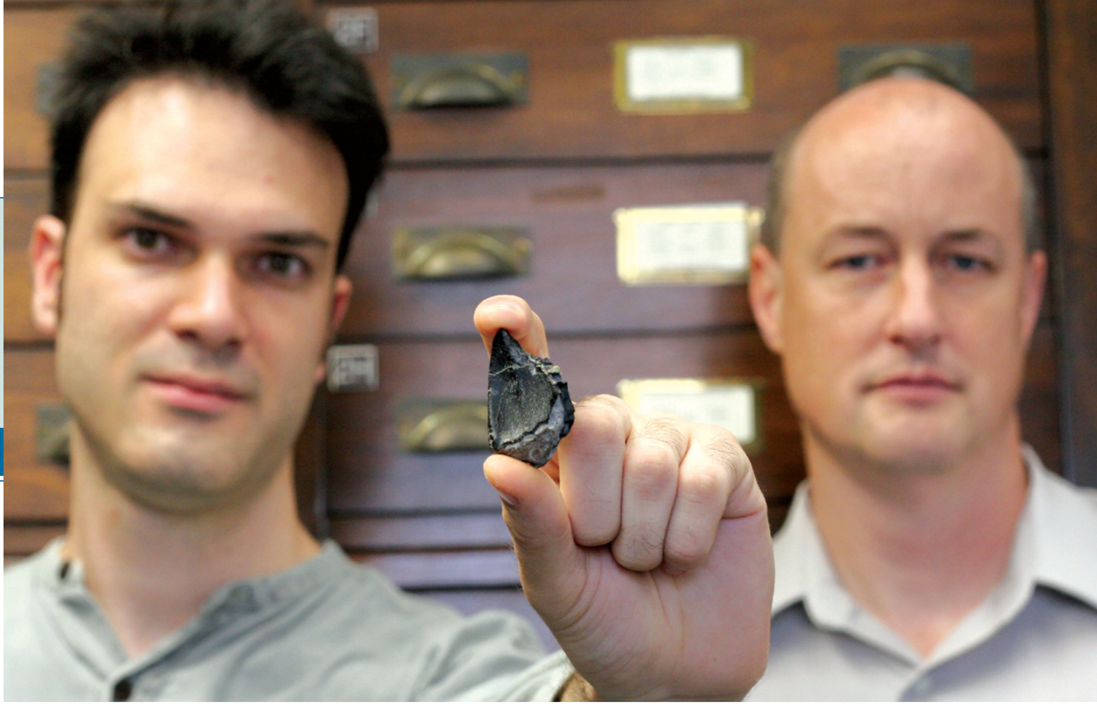
FLIGHT OF THE TECHERS

While zero-gravity flights have recently become available to the common person, they are still a distant dream for most of us—unless, of course, you have an extra $5,000 or so to burn. Luckily, Caltech students aren’t common people. In fact, five undergrads got the chance this spring to experience weightlessness at 34,000 feet in the name of science.

During the week of June 6 the team—Mackenzie Day, Colin Ely, Supriya Iyer, Robert Karol, and Connie Sun—tested thin-walled carbon-fiber hinges aboard NASA’s “vomit comet,” a Boeing 727 modified by the Zero Gravity Corporation for microgravity flights. It was the final, exhilarating step in a six-month process in which the students proposed, designed, and fabricated their experiment.

Each team member rode one of two flights high above the Gulf of Mexico, with the flights consisting of 30 parabolas of about 20 seconds of microgravity each. During the flights the students tested how the hinges behaved at different initial angles under various loads (achieved via attached weights) and with different thermal histories. The hinges were designed by grad student Chinthaka Mallikarachchi and fabricated in Caltech’s Space Structures Laboratory, with Sergio Pellegrino, the Kresa Professor of Aeronautics and professor of civil engineering, as faculty advisor. The experiments were recorded via high-speed video cameras for detailed analysis on the ground later.

—*KN* e&s



Rob Eagle (left) and John Eiler with a new kind of oral thermometer: a dinosaur tooth used to take the creature's temperature.

HOT OR NOT?

Were dinosaurs slow and lumbering, or quick and agile? The answer depends largely on whether they were cold- or warm-blooded. When dinosaurs were first discovered in the mid-19th century, paleontologists thought they were plodding beasts that had to rely on their environments to keep warm, like modern-day reptiles. But in the last few decades several lines of evidence have suggested that they were faster, nimbler creatures, more like the velociraptor stars of *Jurassic Park*. Maintaining such levels of activity in turn implies a warm body whose temperature is self-regulated. But how to know for sure?

New work by a Caltech-led team essentially lets us "stick a thermometer in an animal that has been extinct for 150 million years," says postdoc Robert Eagle, the lead author of the Science paper describing the research. By measuring the levels of rare isotopes in dinosaur teeth, the team has shown that some sauropods—a group that includes the biggest land animals to have ever lived—were about as warm as most modern mammals.

"The consensus was that no one would ever measure dinosaur body temperatures, that it's impossible to do," says coauthor John Eiler, the Sharp Professor of Geology and professor of geochemistry. And yet, using a technique pioneered in Eiler's lab, the team did just that.

The researchers analyzed 11 teeth, dug up in Tanzania, Wyoming, and Oklahoma. Three of the teeth belonged to *Brachiosaurus brancai*, which at some 25 meters from nose to tail tip was as big as the much better-known *Apatosaurus*, a.k.a. *Brontosaurus*. The other eight teeth were from *Camarasaurus*, a smaller creature that averaged some 15 meters long. The results showed that *Brachiosaurus* had a body temperature of about 38°C (100°F) and that *Camarasaurus* was about 36°C (97°F), warmer than crocodiles but cooler than birds.

Previous studies of dinosaur metabolism and thus body temperature have, of necessity, consisted of chains of inference—for example, figuring out how fast the creature ran based on the spacing of its footprints, studying predator-to-prey ratios, or measuring the growth rates of bone. But these various lines of evidence were often in conflict. "For any position you take, you can easily find counterexamples," Eiler says. "How an organism budgets its energy—there are no fossil remains for that. You just have to make your best guess based on indirect arguments."

The new method relies on direct measurements of so-called clumped isotopes, eliminating the guesswork. The researchers analyze the concentrations of carbon-13 and oxygen-18 in bioapatite, the mineral that makes teeth hard and bones strong. Carbon-13 and oxygen-18 atoms are heavier than their run-of-the-mill brethren, carbon-12 and oxygen-16. When a carbonate ion (CO_3^{-2}) ion forms in a warm liquid, the heavy and light isotopes intermingle at random; but as the solution cools the heavier isotopes tend to seek one another out. Then, when the carbonate-containing mineral—oh, say bioapatite—precipitates from the liquid—blood, for example—to, perhaps, form the enamel of a tooth, the isotope clumps are locked into the crystal structure to create a permanent record of the temperature of their surroundings, which might be the inside of a dinosaur's mouth.

Eiler says, "What we're doing is thermodynamically based, and thermodynamics, like the laws of gravity, is independent of setting, time, and context." In other words, thermodynamics worked the same way 150 million years ago as it does today. "We're getting at body temperature through a line of reasoning that I think is relatively bulletproof, provided you can find well-preserved samples."

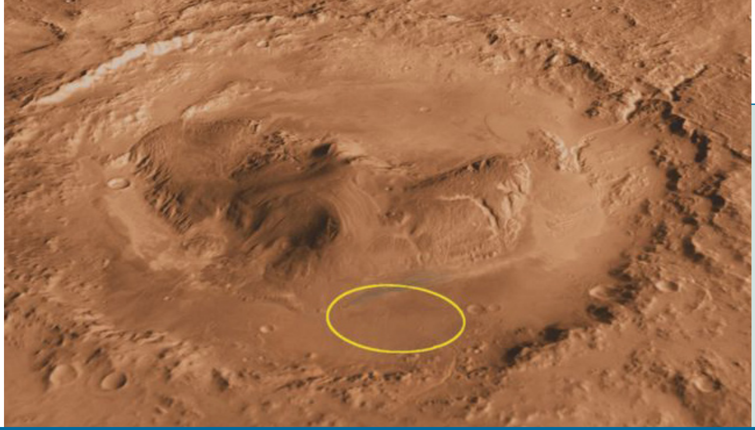
Identifying well-preserved dinosaur teeth was indeed a challenge, and the researchers used several ways to find the best samples. One method compared the bioapatite in the tooth enamel with the more easily altered dentin in the tooth's interior. If both materials had the same concentrations of the heavy isotopes, the odds were that the enamel had been compromised.

So, were the dinosaurs warm-blooded? It's hard to say. Huge sauropods would retain their body heat very efficiently. "If you're an animal that can be approximated as a sphere of meat the size of a room, you can't be cold unless you're dead," Eiler explains. So even if dinosaurs were cold-blooded in the sense that they depended on a sunny afternoon to heat themselves, they could still be warm-bodied—so-called gigantotherms that stay warm through sheer bulk. In fact, some physiological models based on the meat-sphere approximation predict temperatures four to seven degrees higher than those measured. This might be a hint that these dinosaurs had a slower metabolic rate than assumed by the models, which in turn would raise a fresh set of questions.

The team hopes to find out whether body temperature does indeed increase with size by looking at teeth from young sauropods and from adults from species that might only get as big as a St. Bernard. The researchers also intend to take the temperatures of the feathered dinosaurs that gave rise to birds, which may shed light on when warm-bloodedness evolved.

The paper appeared online in the June 23 issue of *Science Express*. The other authors are Thomas Tütken from the University of Bonn, Germany; Caltech undergraduate Taylor Martin; Aradhna Tripati, an assistant professor at UCLA and a visiting researcher in geochemistry at Caltech; Henry Fricke from Colorado College; Melissa Connely from the Tate Geological Museum in Casper, Wyoming; and Richard Cifelli from the University of Oklahoma. Eagle also has a research affiliation with UCLA. The work was supported by the National Science Foundation and the German Research Foundation.—*MW*

THE CRATER-TO-CANYON TOUR



Gale Crater is at 4.5 degrees south latitude, 137.4 degrees east longitude. The The target ellipse (yellow) is 20 by 25 kilometers. This southward-looking view of the landing site was created by combining images from JPL's Mars Odyssey and Mars Reconnaissance Orbiter with elevation data from JPL's Mars Global Surveyor. The vertical dimension is not exaggerated.

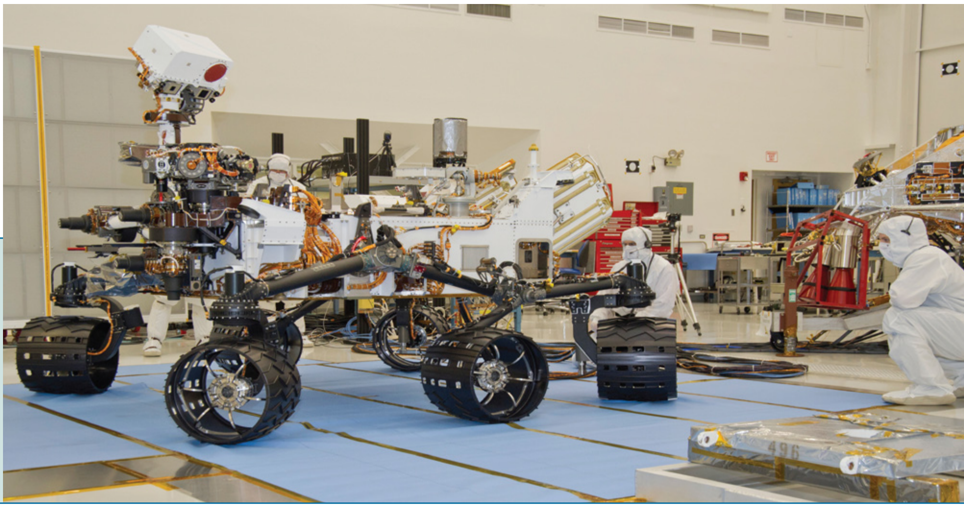
Watch a video of the landing site, narrated by Grotzinger, at http://www.jpl.nasa.gov/video/index.cfm?id=1005

JPL's latest rover, Curiosity, is now at Cape Canaveral awaiting its November 25 to December 18 launch window. On July 22, NASA announced its destination: Gale Crater, 154 kilometers in diameter (about the combined area of Connecticut and Rhode Island) and with an imposing central mountain five kilometers tall that looms higher over the crater floor than Mount Rainier does over Seattle. The plan is to set the rover down on an alluvial fan formed of loose material washed down from the crater walls. After studying the soil, Curiosity should be able to drive to the mountain, whose lowest layers contain clay minerals and sulfate salts usually formed in wet conditions on Earth. "Gale Crater is very low," says John Grotzinger, the Fletcher Jones Professor of Geology and Curiosity's project scientist. "It's a place where water might have pooled and formed lakes."

And where there was water, there may have been life; if microbes once flourished there, they may have left organic molecules behind. Unlike its predecessors, Sojourner, Spirit, and Opportunity, Curiosity is equipped with a mass spectrometer, a gas chromatograph, and a tunable laser spectrometer, all for detecting these molecules.

A canyon cuts deep into the mountain; as Curiosity trundles up the sloping canyon floor, rock layers representing tens or even hundreds of millions of years of Martian history will be exposed to its view. Curiosity's primary mission will last one Martian year, or very nearly two Earth years, during which Earthbound scientists will be able to chronicle unprecedented eons of environmental change on our sister planet.

After the primary mission ends, Grotzinger hopes Curiosity will climb to a region of lighter-colored rocks near the top of the mountain. These rocks appear to be very soft and easily eroded by the wind, unlike the rock layers lower down, and their composition is a mystery; if Curiosity can make it that far, the rover will be able to determine their makeup and possibly their origin. —*DS*



On June 3, Curiosity was still in the JPL clean room where it was built, undergoing some final tests before being shipped to Cape Canaveral.

Many scientists, including Eileen Stansbery of the Johnson Space Center, spent weeks in a set of clean rooms extracting the shards of the shattered solar-wind collection plates from Genesis's mangled remains.

AND THE EARTH WAS WITHOUT FORM . . .

Scientists have found that the sun is different from the earth—no, really! You see, the sun and the planets all condensed out of roiling clouds of dust and gas that were presumably well stirred—and should therefore have been the same throughout—so these differences contain important clues as to how the solar system came to be, says emeritus professor of nuclear geochemistry Don Burnett. Burnett is the principal investigator for NASA's Genesis mission, which returned samples of the solar wind to Earth in 2004. The solar wind is a high-speed stream of charged particles "blown" from the sun's outer layers, which are believed to be a fossil remnant of that primordial solar nebula.

The work was done by two teams, both of which included Burnett. One team, led by Kevin McKeegan of UCLA, analyzed the samples' oxygen levels. The other team, led by Bernard Marty from the Centre de Recherches Pétrographiques et Géochimiques at Nancy, France, looked at nitrogen levels. The results appeared in companion papers in the June 24 issue of *Science*.

Atoms of oxygen and nitrogen come in various forms, called isotopes, which differ in the number of neutrons they contain; these isotopes are chemically identical but have different masses. In both cases, the researchers found that the solar samples had fewer atoms of the heavier isotopes than does Earth.

Oxygen, for example, is the third most common element in the sun, and the chief component—in the form of silicon and other oxides—of the rocky planets. Oxygen-16 is the usual isotope, but Earth rocks, moon rocks, and rocky meteorites all have significant traces of the heavier oxygen-17 and oxygen-18, and the ratios of the isotopes are all roughly consistent, regardless of the rock's origin. The ratio of oxygen-18 to oxygen-16 in the solar-wind samples, on the other hand, is about 7 percent less.

Nitrogen is the fifth most common element in the sun, and makes up about 78 percent of Earth's atmosphere. The ratio of nitrogen-15 to nitrogen-14 in the sun proved to be roughly 40 percent less than in our atmosphere. Giant gasbag Jupiter, however, appears to have the same nitrogen-isotope ratio as the sun.

As the solar system formed, the sun would have condensed first, from the thickest part of the cloud, leaving a thin disk of material around itself like the rings around Saturn. One popular explanation for the different isotope ratios holds that, as the sun began shining outward onto the disk, the ultraviolet light capable of breaking up molecules of carbon monoxide containing oxygen-16 got absorbed near the disk's surface. Meanwhile, the wavelengths able to dissociate the heavier isotopes penetrated more deeply, releasing oxygen-17 and oxygen-18 into the materials that would form the inner solar system. Alternatively, the heavier isotopes might have already sought out the dustier regions that would become rocky bodies—which then, of course, raises the question of how *that* happened.

Genesis, launched in August 2001, spent 886 days collecting solar-wind samples at Earth's L1 Lagrange point—a locale about a million miles to the sunward side of Earth, where the two bodies' gravitational forces balance. On September 8, 2004, the spacecraft's sample-return capsule came to rest in the Utah desert after executing what might euphemistically be described as a geobraking maneuver when the parachute failed to deploy. But, as Burnett told *E&S* in 2007, "We went out and picked up the pieces. You couldn't destroy the atoms in the crash—the only thing you can do is contaminate them." Almost a decade invested in salvaging, sorting, and decontaminating the samples is now starting to pay off. —*DS* E&S

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