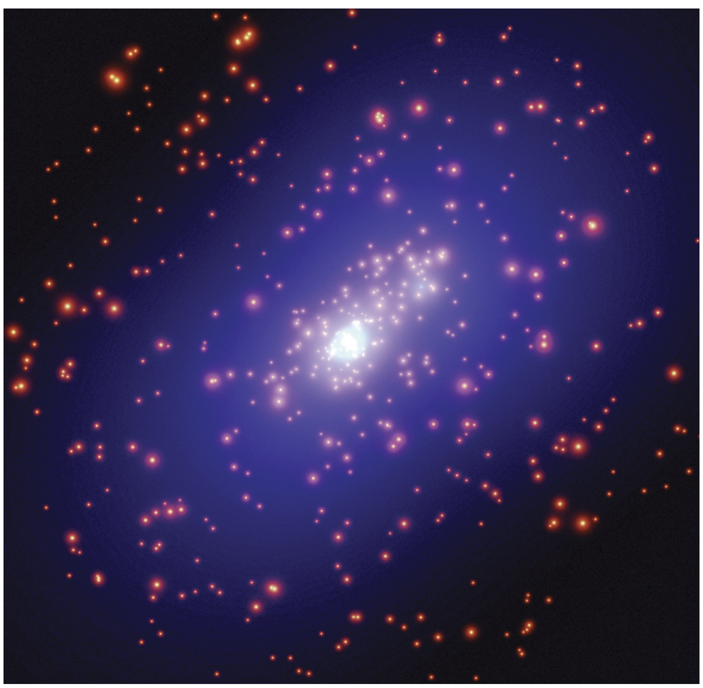
Through a Lens, Darkly

European Space Agency, NASA, and Jean-Paul Kneib (Observatoire Midi-Pyrénées, France/Caltech)



This mass-distribution map of the galaxy cluster known as Cl0024+1654 was created by feeding Hubble and ground-based observations into advanced mathematical models. The galaxies' mass is shown in red, and the mass of the dark matter in blue. The lighter and brighter the color, the more mass there is at that point. The dark matter is densest where the galaxies clump, holding them together like glue. The dark matter is not uniformly distributed in a nice sphere, and a secondary blob can be seen to the upper right of the main mass.

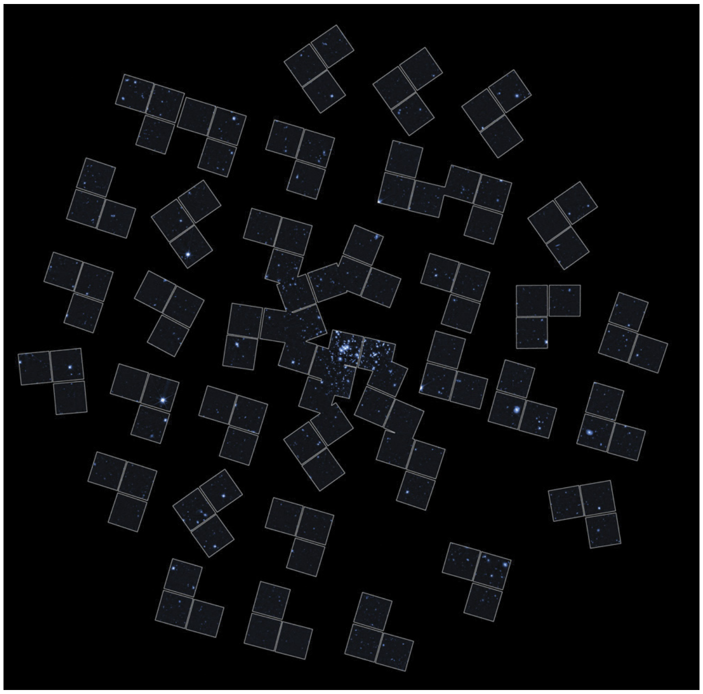
Astrophysicists have had an exceedingly difficult time charting how the mysterious stuff called dark matter permeates the universe because it's—well—dark. But a new "mass map" of a gigantic cluster of galaxies about 4.5 billion light-years from Earth shows in unprecedented detail how dark matter is distributed, and indicates how it figures into the grand scheme of the cosmos. An international group of astronomers led by Caltech Visiting Associate Jean-Paul Kneib; Richard Ellis, the Steele Professor of Astronomy and director of the Caltech Optical Observatories; and postdoc Tommaso Treu plotted how the cluster bends the light from more than 7,000 more distant galaxies behind it, distorting their shapes. This phenomenon, known as gravitational lensing, allowed the dark matter's mass contribution to be inferred by subtracting out the distortions that are caused by the matter that can be seen. About 80 to 85 percent of all matter in the universe is invisible, a fact realized by Caltech's Fritz Zwicky in 1937, based on studies of the motions of galaxies in the nearby Coma cluster.

Making over 120 hours of observations on the Hubble Space Telescope, the researchers surveyed a patch of sky almost as large as the full moon. The study achieved a new level of precision, not only for the cluster's center, which had been done for many clusters, but also for the previously uncharted outlying regions—as far as 15 million light-years from the center, a much larger range than in previous investigations. The result is the most comprehensive study to date of the distribution of dark matter and its relationship to the shining galaxies.

The study, to be published soon in the *Astrophysical Journal*, reveals that the dark matter's density falls off fairly sharply as one moves out from the cluster's center, defining a limit to the dark matter's distribution and hence the total mass of the cluster. "Although theorists have predicted this from numerical simulations based on the effects of gravity, this is the first time we've had convincing observations on large scales to back them up," says Ellis. "Some astronomers had speculated clusters might contain large reservoirs of dark matter in their outermost regions. Assuming our cluster is representative, this is not the case."

The new level of detail

European Space Agency, NASA, and Jean-Paul Kneib (Observatoire Midi-Pyrénées, France/Caltech)



European Space Agency, NASA, Jean-Paul Kneib (Observatoire Midi-Pyrénées, France/Caltech), and the Canada-France-Hawaii-Telescope

Above, left: It took five days of observations and 39 Hubble Wide Field and Planetary Camera 2 (WFPC2) images to make the map. Each WFPC2 image is about 1/150 the diameter of the full moon. This composite is 27 arc-minutes across, slightly less than the moon's diameter.
Above, right: The galaxy cluster as seen by the Canada-France-Hawaii Telescope on Mauna Kea. The group of yellow galaxies at center is the cluster's heart, but cluster galaxies actually extend to at least the photo's edge. This image measures 21 × 21 arc-minutes.

also revealed localized concentrations of dark matter associated with galaxies known to be slowly falling into the system. Overall, there's a striking correspondence between features in the dark-matter map and the visible galaxies—another important finding.

"The close association of dark matter with structure in the galaxy distribution is convincing evidence that clusters like the one studied built up from the merging of smaller groups of galaxies, which were prevented from flying away by the gravitational pull of their dark matter," says lead author Jean-Paul Kneib.

The Hubble's new camera, the Advanced Camera for Surveys (ACS), will be trained on a second cluster later this year. ACS is 10 times more efficient than the Wide Field and Planetary Camera 2, which was used for this study, and will allow finer clumps of mass to be studied in order to investigate how the clusters were assembled in the first place.

The other team members are Patrick Hudelot of the Observatoire Midi-Pyrénées in France, Graham P. Smith of Caltech, Phil Marshall of the Mullard Radio Observatory in England, Oliver Czoske of the Institut für Astrophysik und Extraterrestrische Forschung in Germany, Ian Smail of the University of Durham in England, and Priya Natarajan of Yale University. □

Deuterium, Dirt, and Ozone Damage

Two months after a pivotal study on the potential impact of a future hydrogen-based economy on the environment, further evidence is emerging on what would happen to hydrogen released by human activity. In the August 21 issue of *Nature*, a group of researchers from Caltech and other institutions report on a study of the reactions that produce and destroy hydrogen molecules in the stratosphere. The results indicate that most of the hydrogen removed from the atmosphere winds up in the ground, so the scientific community will need to focus on the destruction of hydrogen in the soil in order to accurately predict whether human emissions will accumulate in the air.

The researchers reached this conclusion through careful measurements of a rare isotope of hydrogen known as deuterium. It has long been known that atmospheric molecular hydrogen is anomalously rich in deuterium, but it was unclear why. The best explanation was that the hydrogen was being destroyed by airborne chemical reactions that were relatively slow for deuterium, causing it to accumulate like salt in an evaporating pan of water. This would mean that hydrogen-oxidizing trace gases controlled the natural hydrogen cycle, and that soils were relatively unimportant. But the Caltech group discovered that one of the main natural sources of atmospheric hydrogen—the breakdown of methane—is actually responsible for the deuterium. This implies that reactions with atmospheric oxidants are relatively unimportant to the hydrogen cycle, and that uptake by soils is really in the driver's seat.

The issue is important because of the potential for a future hydrogen economy to leak hydrogen into the air—a scenario explored in the earlier study. If such leaks are not mitigated by natural processes that destroy hydrogen, the leaked hydrogen will accumulate and inevitably find its way into the stratosphere, where it will participate in chemical reactions that damage the ozone layer. The key to predicting how this chain of events will unfold lies in knowing what natural processes destroy hydrogen, and to what extent they might counteract increases in human emissions.

Hydrogen is highly reactive, but the question of when and where it reacts, and under what circumstances, is difficult to answer precisely. This question is simplified in the stratosphere, where it's easier to single out and understand specific reactions. According to John Eiler, associate professor of geochemistry and a coauthor of both papers, the new data were gathered in the stratosphere with one of the high-flying ER-2 planes operated by the NASA Dryden Flight Research Center in the Mojave Desert. The ER-2, a reconfigured U-2 spy plane, is part of NASA's Airborne Research Program and is crucial to atmospheric chemists interested in directly collecting stratospheric samples for air-quality research.

"We wanted to look at hydrogen in the stratosphere because it's easy to study the production of hydrogen from methane separate from other influences," Eiler explains. "It may seem odd to go to the stratosphere to understand what's happening in the ground, but this was the best way to get a global perspective on the importance of soils to the hydrogen cycle."

The air samples, collected in various locales, showed extreme deuterium enrichment. With precise information on the deuterium content of hydrogen formed from methane, the researchers were able to calculate that the soils' hydrogen uptake is as high as 80 percent. It is suspected that soil-dwelling microbes use the hydrogen, but their biological processes are poorly understood.

It seems likely that the hydrogen taken up by soils is relatively free of environmental consequences, but the question still remains of how much extra hydrogen can be consumed. If there is a significant amount of leakage, then soil uptake must increase dramatically or it will be inadequate to cleanse the atmosphere, Eiler says. "An analogy would be the discovery that trees and other plants get rid of some of the carbon dioxide that cars emit, but by no means all of it. So the question as we look toward a future hydrogen economy is whether the microbes will be able to eat the hydrogen fast enough."

The research was funded in part by the National Science Foundation. Bruce Doddridge, program director in the NSF's division of atmospheric science, said, "This carefully conducted research has resulted in the most accurate information to date, and appears to account for the deuterium excess previously observed. A more accurate molecular hydrogen budget may have important implications as global fuel technology shifts its focus from fossil fuels to other sources."

The paper's lead author is Thom Rahn, a postdoc of Eiler's now at the Los Alamos National Laboratory. The other authors are Paul Wennberg, professor of atmospheric chemistry and environmental engineering science; Kristie Boering and Michael McCarthy, both of UC Berkeley; Stanley Tyler of UC Irvine; and Sue Schauffler of the National Center for Atmospheric Research in Boulder, Colorado. Other supporters of the research were the Davidow Fund and General Motors, the David and Lucile Packard Foundation, the NASA Upper Atmosphere Research Program, and the National Center for Atmospheric Research. □—*RT*

GALILEO'S WAKE

The Galileo spacecraft signed off on Sunday, September 21, and hundreds of project alumni and their families spent the day at JPL bidding it farewell. The spacecraft was plunged into Jupiter's atmosphere in order to avoid possible contamination of its moons in the distant future. An overflow crowd in Von Kármán auditorium listened to panelists recounting Galileo's triumphs over launch delays, stuck antennas, balky tape recorders, and enough other obstacles to kill several lesser missions; heard a rundown of the 14 years' worth of stupendous science that resulted; and then counted down the last five seconds to "impact" (actually, the crossing of the 1-bar depth in Jupiter's atmosphere) New Year's Eve style at 11:57 a.m. PDT. But Galileo would

The Not Ready for Real-Time Players presented *Survivor: Jupiter*, in which such things as the high-gain antenna, the probe, the flight team, and finally Galileo itself got voted off one by one. In a remarkable stroke of timing, their parodic tribute ended just when the signal did. (With apologies to the Rolling Stones, the lyrics on the screen behind them read, "They said/ You can't record the science that you want. . . .")

enjoy an afterlife of sorts for more than an hour as its signals sped to Earth.

Fittingly, it was the Deep Space Network's Goldstone station, only about 100 miles from JPL as the photon flies, that received Galileo's last transmission, at 12:43:14 p.m. The spacecraft once again defied the odds, transmitting engineering data at 32 bits per second right up to the moment it passed behind Jupiter's limb without going into "safe" mode because of the radiation. And there may be one last gift in the data, even though the instruments had been shut down: on a previous pass by the moon Amalthea in November 2002, the star scanner picked up stray flashes of light that were not cosmic-ray hits to the electronics. If the flashes turn up again this time, they could be glints from a previously unknown ring in Amalthea's orbit. The data may be hard to tease out, but, says former sequence integration engineer Bruce McLaughlin (BS '77), "It's all been recorded on tape and shipped to JPL, and if we have to sit down and scratch out the ones and zeroes with paper and pencil, we'll do it." □—*DS*

This photograph of Gilbert McCann sitting at the console of the analog computer he designed ran in his obituary in the previous issue. The unidentified man standing behind him is the late Charles Wilts (BS '40, MS '41, PhD '48), professor of electrical engineering, who was McCann's close collaborator in building the machine. Wilts's obit appeared in the Spring '91 issue of *E&S*.

Oschin's One-Twelve

A major new sky survey has begun at Caltech's Palomar Observatory. The Palomar-QUEST survey, a collaborative venture between Caltech, Yale, the Jet Propulsion Laboratory, and Indiana University, will explore the universe out to the most distant quasars, more than 10 billion light-years away.

The survey is being done using the newly refurbished 48-inch Sam Oschin (pronounced "Ocean") Telescope, first used to produce all-sky atlases on photographic plates in the 1950s. Today, the telescope's eye is a camera containing 112 digital imaging detectors known as charge-coupled devices, or CCDs. (The largest astronomical camera until now had 30 CCDs.) Designed and built by scientists at Yale and Indiana Universities, the QUEST (Quasar Equatorial Survey Team) camera captures the entire field of view of this wide-field telescope.

The survey will generate astronomical data at the unprecedented rate of about one terabyte per month. A terabyte is a million megabytes, or approximately equivalent to the amount of information contained in two million books. In two years, the survey will generate an amount of information about equal to that in the entire Library of Congress.

Unlike past surveys, Palomar-QUEST will make many observations of each portion of the sky, enabling researchers to find not only objects that move, like asteroids or comets, but also objects that vary in brightness, such as supernova explosions, variable stars, quasars, and cosmic gamma-ray bursts—and to do so at an unprecedented scale. "Previous sky surveys were essentially digital snapshots," says Professor of Astronomy S. George Djorgovski. "Now we're starting to make digital movies of the universe."

Djorgovski and postdoc Ashish Mahabal, in collaboration with the Yale group, plan to use the survey to discover large numbers of very distant quasars—highly luminous objects believed to be young galaxies with massive black holes at their centers—and to use them to probe the early stages of the universe.

Richard Ellis, the Steele Professor of Astronomy and director of the Caltech Optical Observatories, will use QUEST to search for exploding stars known as supernovae. He and his team, in conjunction with the group from Yale, will attempt to confirm or deny the recent finding that our universe is accelerating as it expands.

Shri Kulkarni, the MacArthur Professor of Astronomy and Planetary Science, studies gamma-ray bursts. A gamma-ray burst is the most energetic explosion in the cosmos. It is short-lived and unpredictable, and when first detected its exact location in the sky is uncertain. The automated Oschin Telescope, armed with the

QUEST camera's wide field of view, can pin down its position, allowing astronomers to catch and study its fading glow. (See *E&S*, 2003, No. 1.)

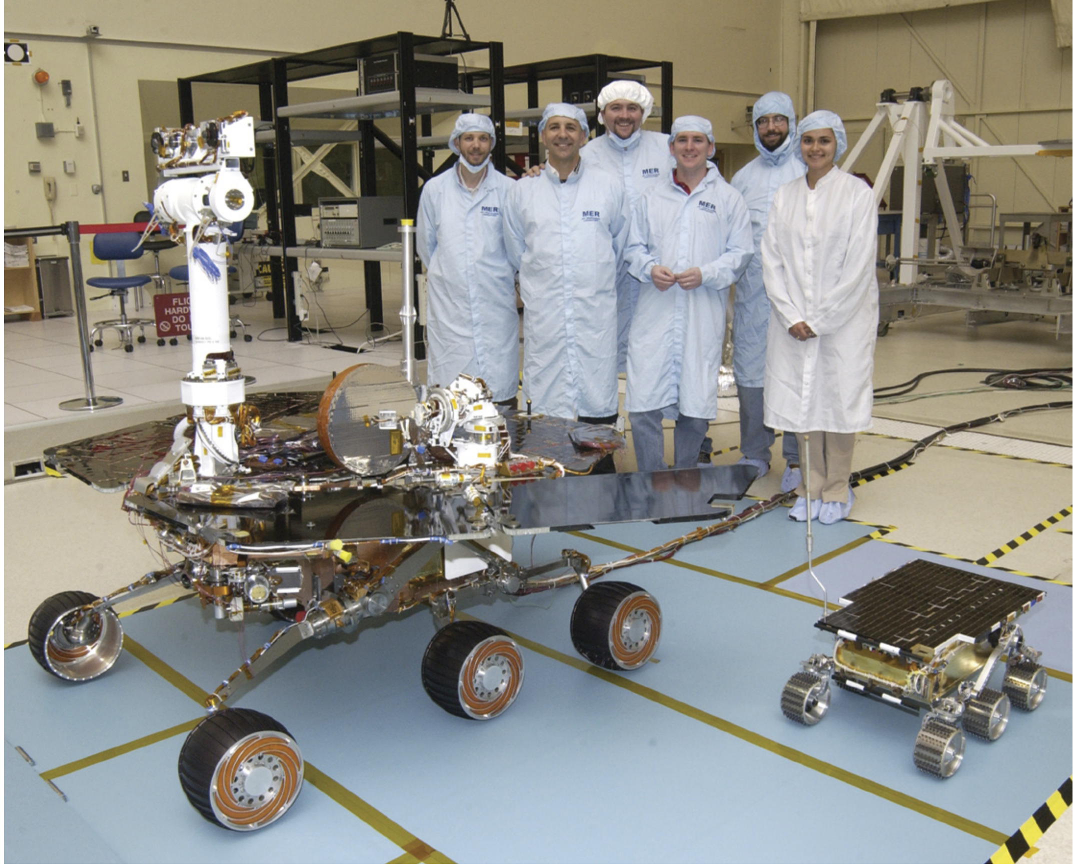
Closer to home, associate professor of planetary astronomy Mike Brown is looking for objects at the edge of our solar system, in the icy swarm known as the Kuiper Belt. Brown is convinced that there are big objects out there, possibly as big as the planet Mars. He, in collaboration with Yale's David Rabinowitz, will use QUEST to look for them.

Steve Pravdo, project manager for the Jet Propulsion Laboratory's Near-Earth Asteroid Tracking (NEAT) Project, will use QUEST to continue NEAT's search for asteroids that might one day approach or even collide with our planet. (See *E&S*, 2001, No. 1.)

The Palomar-QUEST survey will undoubtedly enable many other investigations in the years to come. The intent is to make all of the copious amounts of data publicly available in due time on the Web, as a part of the nascent National Virtual Observatory. Roy Williams, member of the professional staff of Caltech's Center for Advanced Computing Research, is working on the National Virtual Observatory project, which will greatly increase the scientific impact of the data and ease its use for public and educational outreach as well.

The QUEST team members from Indiana University are Jim Musser, Stu Mufson, Kent Honeycutt, Mark Gebhard, and Brice Adams. Yale University's team includes Charles Baltay, Rabinowitz, Jeff Snyder, Nick Morgan, Nan Ellman, William Emmet, and Thomas Hurteau. The NEAT team consists of Raymond Bambery, principal investigator; and coinvestigators Daniel McDonald, Michael Hicks, Kenneth Lawrence, and Pravdo. The camera's installation was overseen by Robert Brucato, Robert Thicksten, and Hal Petrie (BS '68). □—*SK*

Left: The Space Infrared Telescope Facility (SIRTF), the fourth and final installment of NASA's Great Observatories program, lifted off from Cape Canaveral at 1:35 a.m. EDT August 25. Now en route to an Earth-trailing orbit well away from our planetary warmth, the spacecraft is being checked out by ground controllers. So far, all systems are go to begin doing serious science sometime around Thanksgiving Day. SIRTF is managed by JPL, and its data-processing and control center is located at Caltech. The next issue of *E&S* will feature an in-depth look at the mission.



Opposite: At 1300 GMT (6:00 a.m. PDT) on May 8, as Earth and Mars were en route to their closest encounter in some 60,000 years, the Mars Orbiter Camera on JPL's Mars Global Surveyor snapped this shot of a half-Earth and its moon hanging in the Martian sky—the first time we have looked up from another planet and seen our home as a sphere, not a speck of light. Below: In the same field of view were, from left, Callisto, Ganymede, Jupiter, and Europa. Io is behind Jupiter, as is the Great Red Spot. Both images have been processed to allow the planets to be seen with their much-dimmer moons, and color has been added.

Above: Spirit and Opportunity, JPL's twin Mars Exploration Rovers, were launched on June 10 and July 7 respectively and will reach Mars three weeks apart in January 2004. The direct descendants of the 1997 Mars Pathfinder mission's Sojourner rover (*E&S* No. 3, 1997), these two robot geologists will be able to traverse more ground in a few days than Sojourner did in its entire lifetime. Along with updated versions of the camera and instruments that Sojourner and Pathfinder carried (plus two brand-new spectrometers and a microscope), these rovers have something no human geologist would leave home without—a rock hammer, or in this case an abrasion tool to remove the surface patina from specimens and expose the minerals beneath. Perhaps not surprisingly, the rovers will search for hints of ancient water. Opportunity will explore an area of the Meridiani Planum where the Mars Global Surveyor discovered signs of hematite (*E&S* No. 3/4, 2001), a mineral that on Earth typically forms in hot springs. Spirit will land on Mars's opposite side, in Gusev Crater, which appears to have once been the bed of a lake slightly smaller than New Jersey. In this photo taken in November 2002 in JPL's Spacecraft Assembly Facility, some project members pose with Spirit and Marie Curie, a Sojourner flight spare.

The Quiet Zone

In trying to predict where earthquakes will occur, few people would think to look at Earth's gravity field. What does the force that causes objects to fall to the ground and the moon to stay in orbit have to do with the unpredictable ground trembling of an earthquake? Caltech researchers have found that within subduction zones—the regions where one of the earth's plates slips below another—areas where gravity is relatively high are less likely to experience large earthquakes than areas where the gravitational force is relatively low. The study, by grad student Teh-Ru Alex Song and Associate Professor of Geophysics Mark Simons, appeared in the August 1 issue of *Science*.

Until now, says Simons, researchers studying earthquake behavior generally took one of four approaches: 1) analyzing seismograms generated by earthquakes, 2) studying frictional properties of various types of rock in the laboratory or in the field, 3) measuring the slow accumulation of strain between earthquakes with survey techniques, and 4) large-scale dynamic models of earthquakes and tectonics.

Song and Simons instead considered variations in the gravity field as a predictor of seismic behavior. A gravity anomaly occurs when gravity is stronger or weaker than the regional average. For example, a mountain or an especially dense rock would tend to increase the nearby gravity field, creating a positive anomaly. Likewise, a valley would tend to create a negative anomaly.

Song and Simons examined existing data from satellite-derived observations of the gravity field in subduction zones. Comparing variations in gravity along subduction trenches with earthquake data from two different catalogs going back 100 years, the team found that, within a given subduction zone, areas with negative gravity anomalies had more large earthquakes. In addition, most of the energy released in earthquakes was in areas of low gravity. The team looked at subduction-zone earthquakes with magnitude greater than 7.5 since 1976. They found that 44 percent of the total energy released in those earthquakes came from the regions with the strongest negative anomalies, even though these regions made up only 14 percent of the total area. Song and Simons also compared the location of large earthquakes with the topography of the subduction zones, finding that areas of low topography, such as basins, also corresponded well to areas with low gravity and high seismic activity.

So why would gravity and topography be related to seismic activity? One possible link is via the fault's frictional behavior. When plates rub up against each other, friction makes it harder for them to slide. If the friction is great enough, they'll stick. As the stuck plates continue to push against each other over long periods of time, they may deform and create spatial variations in topography and gravity. Friction also causes stress to build up until the strain is released in an earthquake. So in subduction zones, areas under high stress are likely to have greater gravity and topography anomalies, and are also more likely to have earthquakes. Simons hopes to use Global Positioning System measurements, which can show where strain is accumulating, to test the prediction that areas with high gravity will have low strain, and vice versa.

These gravity anomalies take a long time to build up, and change very little over scales of a million years or so. (Earthquakes do change the gravity field, but those variations are small compared with the long-term anomalies.) Because the topography and gravity variations persist over periods much longer than the typical time between earthquakes, which is generally 100 to 1,000 years, large earthquakes should be consistently absent from areas with large positive gravity anomalies, say Song and Simons. "This study makes a strong connection between long-term tectonic behavior and short-term seismic activity," says Simons, "and thereby provides a new class of observations for understanding earthquake dynamics."

The team points out that there are low-gravity areas in subduction zones with no seismic activity. Furthermore, the research concentrates on subduction zones, and so makes no predictions about other types of faults. Nonetheless, within a subduction zone known to be earthquake-prone, high-gravity areas do tend to have few earthquakes. So while the research does not offer a way to predict where earthquakes will happen, it can predict where they won't happen, says Simons. □—*ET*

Fall Watson Lectures Set

This fall's Watson lecture series opened with Caltech President and Professor of Biology David Baltimore talking about "Viruses, Viruses, Viruses" on October 15. Then on November 5, Thomas Sterling, a visiting associate in Caltech's Center for Advanced Computing Research and inventor of the Beowulf method for turning clusters of PCs into supercomputers, takes us on a tour "From PCs to Petaflops—The Future of Really Big Computers." Jean Ensminger, professor of anthropology and chair of the division of the humanities and social sciences, will be "Experimenting with Social Norms" on November 19. And finally, James Heath, the newly arrived Gilloon Professor and Professor of Chemistry, will chart the future of "NanoSystems Biology" on January 14, 2004. All Watson Lectures are at 8:00 p.m. in Beckman Auditorium; no tickets or reservations are required. The lectures also become available online at Caltech's Streaming Theater, http://today.caltech.edu/theater/, about a week after the event.

On Sunday, September 28, the Caltech/JPL Flying Club (more properly the Aero Association of Caltech, or AACIT) hosted a barbecue at the El Monte airport, where their fleet of two club-owned and five leased airplanes lives. The club ran a shuttle to campus, some eight miles away, and nearly 100 people were treated to aerial tours of the Rose Bowl, JPL, Caltech, and the Santa Anita racetrack. AACIT membership is open to the entire Caltech/JPL community and their families—for more information, see http://aacit.caltech.edu. At least three past members have gone on to become astronauts: Jay Apt, formerly at JPL, flew four shuttle missions before leaving NASA for the Carnegie Museum of Natural History; John Grunsfeld, late of Caltech's Space Radiation Lab, has also flown four missions, including two service calls to the Hubble in which he made five spacewalks; and Garrett Reisman (MS '92, PhD '97) has completed training and awaits assignment.

Voices of Vision: A Couple of Books, a Movie, and Some TV

The Voices of Vision series, which "brings innovative thinkers to campus who explore ideas in an inspiring fashion and express themselves through different media," in the words of Denise Nelson Nash, director of Caltech Public Events, returns for its second season. Leading off was Garrison Keillor, reading from his latest novel, *Love Me*, on Monday, October 6, 2003. Keillor, author of nearly a dozen books, is founder and host of *A Prairie Home Companion* and *The Writer's Almanac*, both on National Public Radio, and is a regular contributor to *Time* magazine. Then on Wednesday, October 22, 2003, Al Franken read from *Lies and the Lying Liars Who Tell Them: A Fair and Balanced Look at the Right*. Franken's previous books include *Rush Limbaugh Is a Big Fat Idiot and Other Observations*; *Oh, the Things I Know!*; *Why Not Me?*; and *I'm Good Enough, I'm Smart Enough, and Doggone It, People Like Me!* Book signings followed both readings, which were presented in collaboration with Vroman's Bookstore and Caltech's Words Matter series.

Next, Howard Rosenberg will examine "Media Ethics" on Thursday, November 6. A Pulitzer prize–winning television critic for the *Los Angeles Times* until this past August, Rosenberg was named one of the nine national media critics "with clout" by the Freedom Forum Media Studies Center at Columbia University in 1995. And for those of us who will never get a 3:00 a.m. telephone call from Stockholm, Marc Abrahams, founder of the Ig Nobel Prizes and cofounder of the science-humor magazine *Annals of Improbable Research*, will appear on Tuesday, January 27, 2004. Ten Igs have been given each year since 1991 for "achievements that cannot or should not be reproduced."

On Tuesday, March 2, Josefina Lopez, the author of *Real Women Have Curves*, discusses "Real Women and Other Unseen Images in Hollywood." Be sure to arrive in time for the 6:00 p.m. screening of *Real Women Have Curves* that precedes her talk. And finally, David Silverman will appear on Tuesday, April 6. From 1990 to 1997, Silverman was the supervising animation director for the runaway TV hit *The Simpsons*, overseeing one of five directing teams that supervised the work of nearly 100 animators.

The season is cosponsored by the Caltech Employees Federal Credit Union and the San Gabriel Valley Newsgroup, publishers of the *Pasadena Star-News*. All events except the screening begin at 8:00 p.m. in Beckman Auditorium. Admission is free on a first-come, first-served basis. No tickets or reservations are required. □