Research Highlights

Embryology

Deciphering the Complexity of Cellular, Developmental, and Genetic Biology

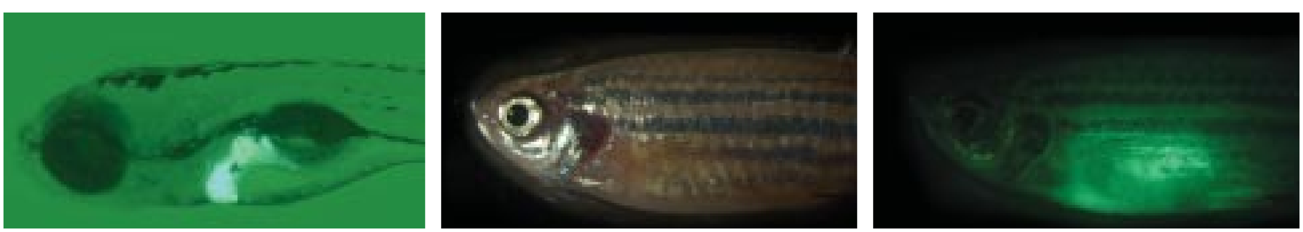
Watching Estrogen Turn On

Sex hormones bind to receptors, activating genes that play roles in many physiological activities. For example, estrogen receptors are activated when bound by naturally occurring estrogens as well as by synthetic chemicals that mimic estrogen. In turn, bound receptors enter the cell's nucleus, where they bind to specific sequences of DNA and activate genes. Carnegie scientist Daniel Gorelick in Marnie Halpern's laboratory has developed a new method for observing estrogen-receptor activity in live fish. The tool could help scientists understand the reason for the high number of intersex fish—males that show female characteristics—recently found in rivers and streams across the United States. Of particular interest to Gorelick and Halpern, however, is the possibility that this tool might also help elucidate currently unappreciated roles of estrogen in brain development and behavior.

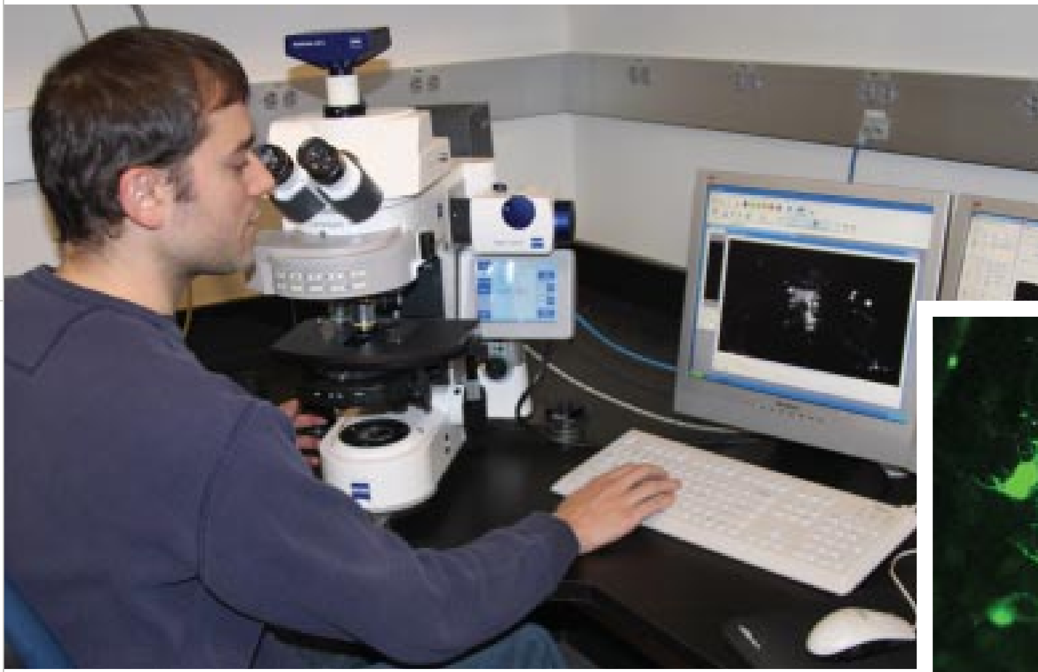
The estrogen-response system is involved in lipid metabolism, bone growth, glucose metabolism, and reproduction. Estrogen and estrogen receptors also modulate mating behaviors and aggression. To understand the physiological effects of estrogen, it is crucial for scientists to develop the best tools and processes for observing when and in which cells receptors become activated and for learning the consequences of activation.

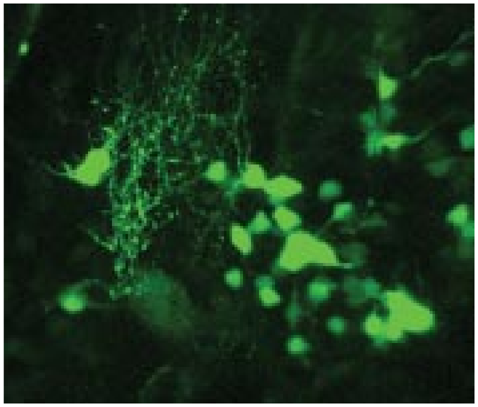
Gorelick created transgenic zebrafish larvae that turn on a green fluorescent protein in cells where estrogen receptors are activated in the presence of estrogen. Activation was observed in the liver and the brain, as expected. Green cells were also found in other tissues, such as olfactory neurons and heart valves, where less sensitive tests have not detected activated estrogen receptors.

The researchers recognized the importance of proving that the new method was specific as well as sensitive. Fluorescent labeling was activated by natural and synthetic estrogens, but not by other sex hormones. Also, fluorescence was inhibited by compounds that are known



(Left) In a five-day-old zebrafish larva, the liver glows as estrogen receptors are activated. The Gorelick-Halpern method is the first of its kind for observing estrogen signaling in live fish. (Center and right) After swimming in water containing estrogen, the liver glows in an adult fish. On the right, a special fluorescence microscope is used to visualize estrogen receptor activation.





(Above) Daniel Gorelick uses a fluorescence microscope to image estrogen-responsive neurons in the zebrafish brain.
Image courtesy Bill Kupiec

(Right) Neurons sensitive to estrogen are shown in the brain of this live larva.
Image courtesy Daniel Gorelick and Marnie Halpern

to antagonize estrogen receptors. Together these results demonstrate that the system designed by Gorelick and Halpern is specific to estrogen and estrogen receptors.

There are many potential applications for these specially designed zebrafish. One of the most exciting is studying how water pollution by estrogenic compounds acts on susceptible animals, for example, by identifying affected tissues. Another use of these fish of particular interest to Gorelick and Halpern will be to monitor how different populations of nerve cells are activated during behaviors modulated by estrogen.

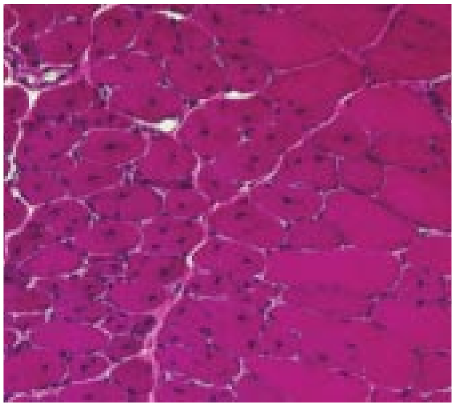
Muscle Stem Cell Surprise

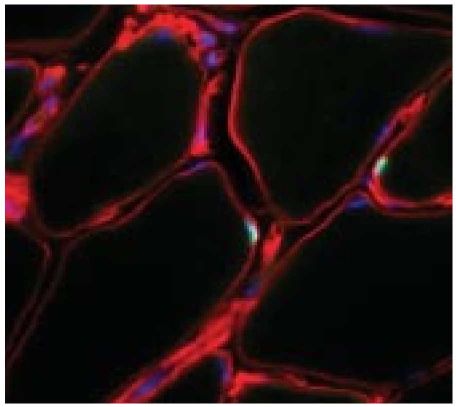
Some surprising results from Carnegie molecular biologists may have important implications for the treatment of muscular dystrophy, aging-related muscle atrophy, and regenerative medicine. Chen-Ming Fan and Christoph Lepper have demonstrated that the genes in charge of regulating the production of embryonic muscle stem cells are not necessary to regenerate adult skeletal muscles after injury or damage.

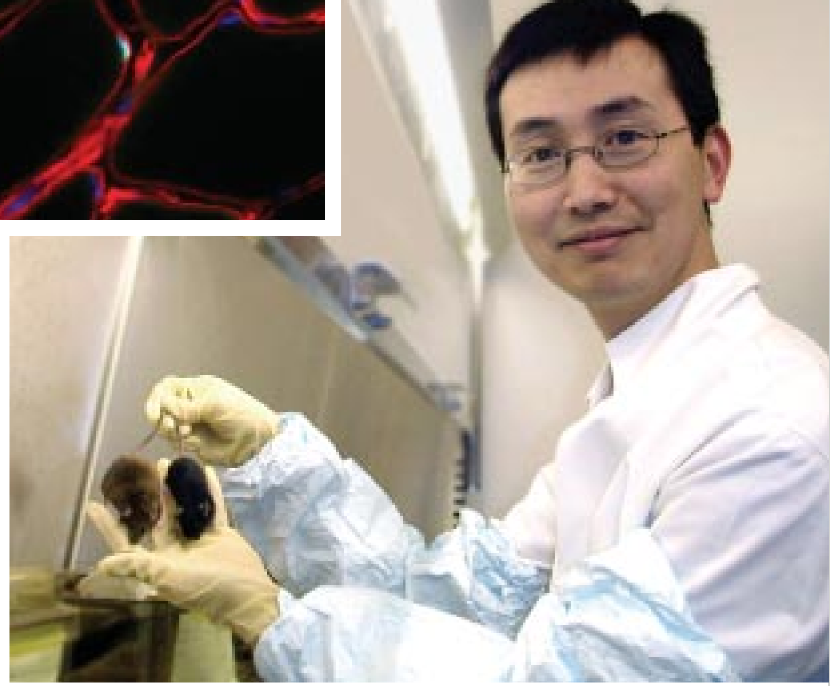
Conventional wisdom had led researchers to believe that regeneration of skeletal muscle tissue would mimic the process of embryonic muscular development. Following this logic, the Carnegie team studied *Pax3* and *Pax7*, two "master regulator" genes that previous research had demonstrated are essential for making embryonic and neonatal muscle stem cells in mice.

Using sophisticated genetic tools, the team was able to look at the activities of these two genes at various stages of muscle growth in live mice. Their results showed that specialized embryonic protomuscle cells directly regulated by *Pax3* and *Pax7* do develop into adult muscle stem cells. But, contrary to expectations, shortly after the mice were born these genes were found to be no longer necessary for adult muscle stems cells to make new muscles. This finding surprised Lepper and Fan, and was a big shock for muscle researchers worldwide.

Further study allowed the team to narrow down the period of time when *Pax3* and *Pax7* are still important for







(Above left) This image is a stained cross section of skeletal muscle tissue 10 days after an intra-muscular injection of toxic snake venom. The fibers on the left show centrally located nuclei, a hallmark of regenerative muscle fibers. The fibers on the right are old, mature fibers that weren't injured by the toxin injection.

(Above right) This is a cross section of mature skeletal muscle, which was reacted with anti-bodies and stained to label all nuclei. The two green nuclei were bound to the Pax7 antibody, indicating that they are so-called satellite cells. Their name comes from their location, which is "orbiting" the muscle fiber.

Images courtesy Christoph Lepper

(Far right) Chen-Ming Fan of the Department of Embryology holds research mice in the laboratory.

Image courtesy Chen-Ming Fan

generating muscle stem cells after birth. It turns out that these embryonic stem cell genes are required only during the first three weeks of life. Afterward, *Pax3* and *Pax7* apparently hand their duties off to a different set of genes.

In mice older than three weeks, this second, unidentified, set of genes would be activated to rebuild muscles after damage due to trauma or exercise. Going forward, the researchers hope to better understand this transitional period when the embryonic genes become inactive and a new set of regulators takes over.

The finding that some adult tissues use genes that are different from the ones juvenile tissues use to repair themselves is fundamentally important. Fan and Lepper's discovery also illustrates the importance of understanding the intricacies of stem cell biology before making clinical decisions about cell-based therapies for muscle diseases. □

Geophysical Laboratory

Probing Planetary Interiors, Origins, and Extreme States of Matter

Whiskers 'n' Water on the Moon

It was a big year for the Moon. Researchers at the Geophysical Laboratory (GL) found evidence for more water in its interior than previously known. They also discovered carbon in the form of graphite "whiskers." The whiskers could have formed only in high temperatures, so presumably they were produced by the impactors from the late heavy bombardment of 3.8 billion years ago. That also means the Moon potentially holds a record of the carbon input to the Earth-Moon system as life was beginning to emerge.

For several decades scientists have thought the Moon was dry. Its bulk water content was thought to be less than 1 part per billion—a million times drier than the interiors of Earth and Mars. The team of scientists examined the mineral apatite in two Apollo samples and in a lunar meteorite. GL postdoctoral fellow Francis McCubbin and team enlisted Erik Hauri of Terrestrial Magnetism to help with the aid of his secondary ion mass spectrometer. The researchers combined their measurements with models that characterize how the material crystallized as the Moon cooled and found that the water content ranged from 64 parts per billion to 5 parts per million.

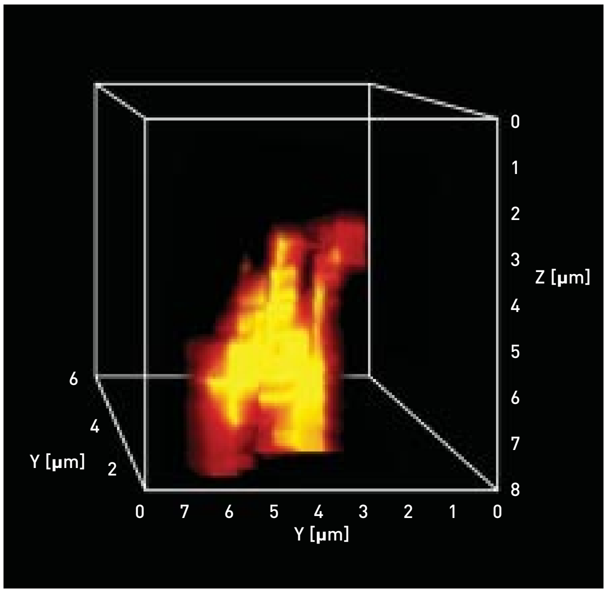
The prevailing belief is that the Moon was created by a giant-impact event; a Mars-sized object hit the Earth some 3.8 billion years ago and the ejected material coalesced into the Moon. The Carnegie scientists determined that water was likely present as the hot magma started to cool and crystallize—meaning water is native to the Moon. This result was unexpected, because volatiles like water and carbon were vaporized under the heat and shock of the impact.

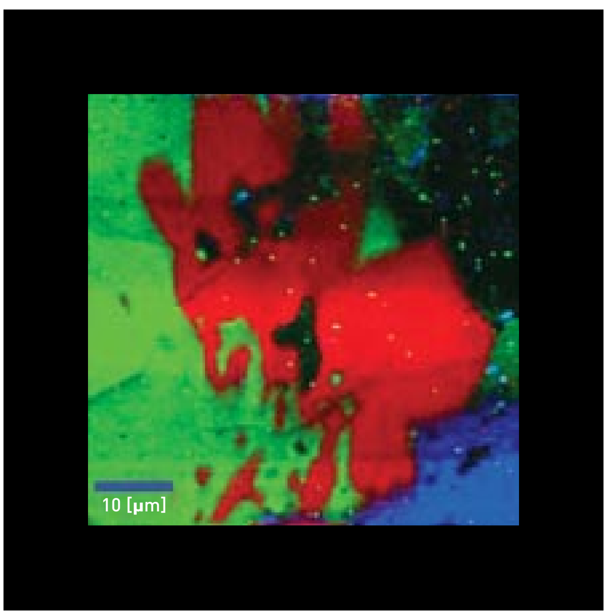
Until now, scientists thought that the trace amounts of carbon on the Moon's surface came from the solar wind. Andrew Steele's team analyzed thin lunar rock slices and determined that carbon also survived the impact. They found minerals and carbon beneath the surface and were very surprised to find graphite and graphite whiskers. Previously, the only carbon identified on the Moon came from solar wind implantation.

The scientists ruled out that the graphite was from contamination because it is imbedded in the minerals and because graphite whiskers in the absence of water form only under very hot conditions, between 1830°F and 6500°F (1273-3900 K). The particles are also much larger than those of any solar-wind-implanted carbon. They think the graphite either came from the impacting object or that it condensed from the carbon-rich gas that was released during impact.

(Top right) This three-dimensional image is a depth profile of graphite from a lunar sample to 8 millionths of a meter. From *Science*, vol. 329, 5987, p. 51, July 2, 2010.
Reprinted with permission from AAAS.

(Bottom right) This is a Raman multispectral image of Apollo sample 15058. The hydroxyl-bearing apatite is shown in red.
Image courtesy American Mineralogist.





Getting to the Core of the Matter

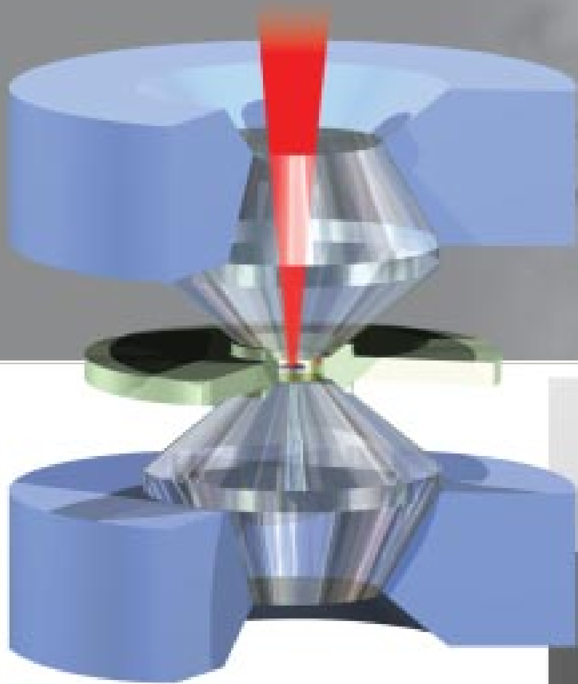
Bizarre behavior emerges when matter is subjected to extreme pressures and temperatures—chemical bonds morph, crowded electrons become erratic, and new materials can be forged. One method for analyzing samples at extreme conditions is squeezing them in a diamond anvil cell and using X-ray diffraction to reveal atomic structure; but X-ray diffraction has its limitations. Currently, a team at the GL is revolutionizing the field by harnessing the next-generation neutron sources for studies of materials at unprecedented pressures and temperatures.

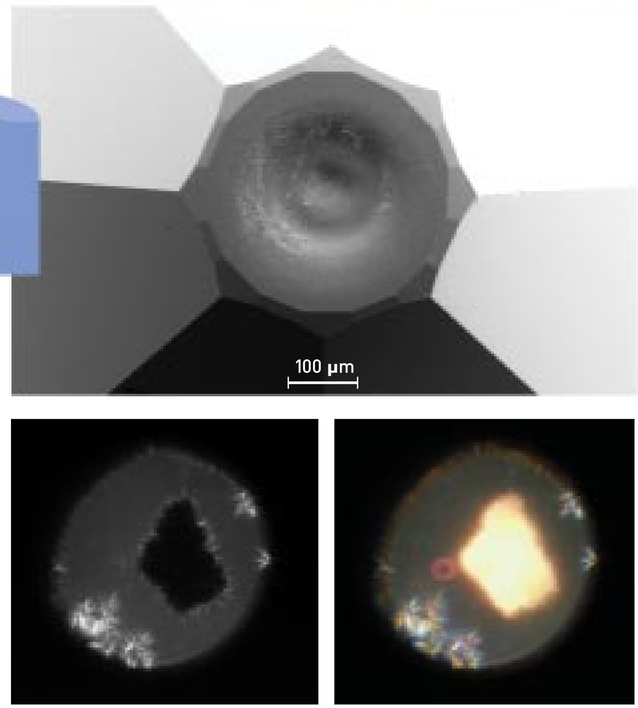
X-ray diffraction works by interacting with the electron cloud surrounding an atom. In contrast, neutrons interact directly with the nucleus, yielding many advantages: enabling the detection of positions of the lighter elements (particularly hydrogen, which is invisible to X-rays) near heavier ones, directly measuring magnetism, and facilitating the study of liquids, nanocrystals, and glasses. Neutrons are not widely used because of the comparative weakness of neutron sources relative to those of X-rays. The neutron landscape changed dramatically in August 2009, however, when the new Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL) exceeded 1 megawatt of power, eclipsing the European 163-kilowatt record. Malcolm Guthrie is leading the Carnegie neutron team at the new source as part of the DOE-supported center for Energy Frontier Research in Extreme Environments at GL.

The great potential of this program was recognized by the science directorate of the SNS, which established a formal relationship with GL. The relationship was cemented by the opening of a center for high-pressure science in the newly opened Joint Institute for Neutron Sciences

Geophysical Laboratory, *Continued*

The decades-old tradition of neutron science at Oak Ridge National Laboratory (ORNL) has been catapulted toward new frontiers by the opening of the $1.4 billion Spallation Neutron Source (SNS) facility (top left, image courtesy ORNL). Using a completely new generation of liquid-mercury targets, the SNS is able to generate neutron fluxes greatly in excess of any other neutron scattering source in the world. Inserts: The new Joint Institute for Neutron Sciences building (top middle), the high-pressure beamline at the SNS, which GL scientists help design and build (top right). Malcolm Guthrie (top) and Reinhard Boehler are aligning a cell.





New high-pressure devices for neutron diffraction experiments (above) allow large forces on large samples. This new geometry provides the necessary high diffraction angles. The sample volume is increased by ablating the diamond anvil tip with an excimer laser (right). These diamond anvil cells will allow neutron diffraction experiments on samples heated by a laser to several thousand degrees.

Image courtesy Reinhard Boehler

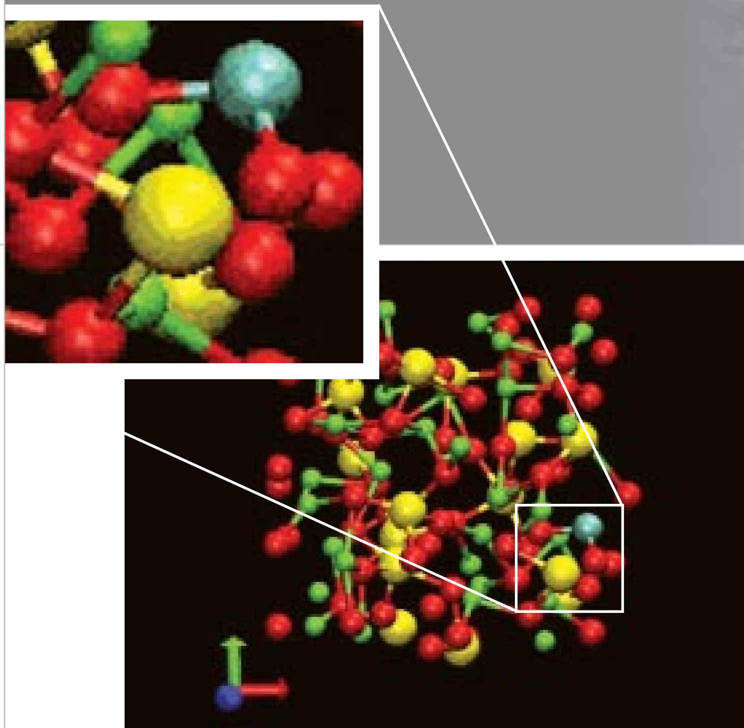
building. The SNS provides office and laboratory space and a generous investment in equipment, while operations are conducted by Carnegie staff.

The endeavor's success depends on the development of novel high-pressure devices tailored for the neutron environment. Reini Boehler is leading this effort, building on the long-standing expertise in extreme-conditions technology at GL. The need for state-of-the-art materials and fabrication techniques maps directly onto existing programs in diamond growth and laser machining.

The very high SNS neutron flux will allow the use of drastically smaller samples than are customary in neutron diffraction studies, and an increase in the pressure range of neutron diffraction experiments. Because these samples are still larger than those in conventional X-ray diamond cell experiments, novel techniques are being developed. For increased anvil strength, the anvil geometry has been completely reconfigured, avoiding the necessity for very large, expensive anvils. Furthermore, the sample size is increased by modifying the anvil shape by ion beam milling or UV laser ablation. A high-power laser will be used to heat these large samples uniformly to several thousand degrees.

From Electrons to Planets

The ability to compute properties of atoms, molecules, crystals, and fluids from fundamental physics is flourishing because of advances in computing. Ronald Cohen and team harness this computer power to understand the behavior of minerals and fluids in the Earth and to design new materials. Simulating the behavior of electrons



(Above) This image is a frame from a movie simulating carbonated melts at roughly 1.3 million times atmospheric pressure (130 gigpascals) and 4900°F (3000 K). The blue is a carbon atom, red is oxygen, yellow is magnesium, and green is silicon.

Image courtesy Razvan Caracas

(Left) The Geophysical Laboratory's Ronald Cohen

Image courtesy Ronald Cohen

with quantum mechanics can reveal properties of minerals, rocks, and even planets.

Two exciting computational capabilities have emerged. One is the ability to simulate large systems as well as dynamical processes in time and at different temperatures. The other is improvements in the accuracy of first-principles methods, especially in systems where conventional methods fail. First-principles methods use only fundamental physics to predict molecular and material properties, without the input of experimental data.

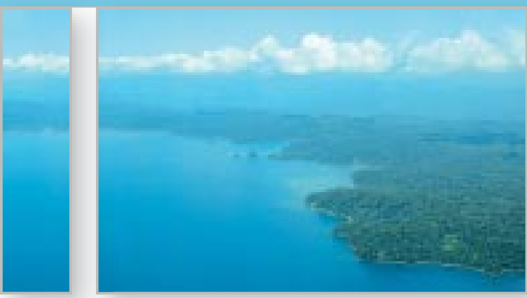
The simulations of large systems use high-performance computers and modern computer codes. For example, with former Carnegie Fellow Razvan Caracas, Cohen is using the QBOX code developed by François Gygi at U.C. Davis to simulate carbonated silicate melts in order to understand how carbon dissolves in the melt and how the melt changes with pressure. These calculations enable Cohen to unravel carbon transport in the Earth and to understand the partial melting of subducted slabs in the Earth's mantle.

Using Quantum Monte Carlo simulations—a more exact numerical solution of the Schrödinger equation—former Carnegie postdoctoral associate Ken Esler, Cohen, and others developed an accurate fundamental pressure scale for ultra-high-pressure experiments. Standard theory predicts that iron oxide (FeO) is a metal, but experiments show that it is an insulator. Some models predict it is an insulator, but those models predict different behavior than is observed under pressure. The researchers consider the problem using the Quantum Monte Carlo method and dynamical mean field theory, which includes the dynamical quantum fluctuations from electrons hopping among orbits. Preliminary results suggest that FeO may become metallic at high temperatures, such as those found in the Earth. In the Earth, FeO mixes with magnesium oxide making ferropericlase, Earth's second most common mineral.

The critical question for the researchers is how metallization depends on composition, pressure, strain, and temperature. Using these powerful tools, Cohen is teasing out a theoretical understanding of these complex materials and is able to confirm his predictions with experimental results by GL colleagues, including Viktor Struzhkin and Yingwei Fei. □

Global Ecology

Linking Ecosystem Processes with Large-scale Impacts



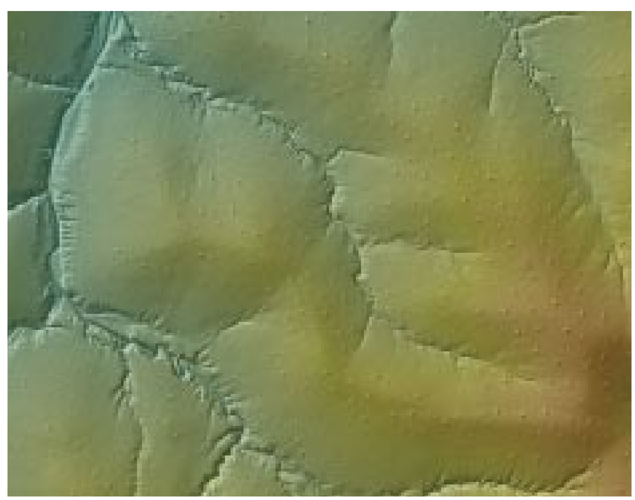
Termites, Big Game, and Fire

Some surprising results about termites, fire, and wildlife browsing in the African savanna are coming out of Greg Asner's lab courtesy the Carnegie Airborne Observatory (CAO). The CAO is a unique airborne mapping system that penetrates the vegetation canopy to map the 3-D structure of the plants. Led by Asner, Shaun Levick and team are using it to reveal how termite mounds, large-animal browsing, and fire affect the vegetation structure and thus the savanna's ecology. The research could revolutionize land management and conservation.

The CAO uses a light detection and ranging (LiDAR) system to map the three-dimensional structure of vegetation. It combines that information with high-fidelity spectroscopic imaging to reveal the chemical fingerprints of the species below, and then renders the data in spectacular 3-D maps. The team conducted a number of different studies in the Kruger National Park in South Africa. They looked at the relationship of termite mounds to vegetation patterns, how the distribution of termite mounds affects browsing by large herbivores, the differences between fire and browsing impacts on the vegetation structure, and how herbivores affect the structural diversity of African savannas.

The CAO revealed that mound-building termites construct their nests in well-drained areas and on the slopes of savanna hills. Woody trees prefer the well-drained upslope side, while grasses dominate the wetter areas downslope. The scientists found that precipitation, elevation, and hydrological and soil conditions determine whether grasses or woody vegetation dominate and that different sizes and densities of termite mounds correlate with these environmental conditions. The spatial distribution of termite mounds is an excellent indicator of hillslope water properties, thereby providing a unique avenue for monitoring vegetation changes in a changing climate.

In addition, termite mounds create fertile foraging "hotspots." The researchers compared browsed areas with protected areas to see if the mounds were correlated with foraging behavior. They found that animals prefer to consume the higher-quality woody plants at and near



The little dots on this LiDAR map are termite mounds distributed over the African savanna.

(Left) A team of researchers approaches a termite mound surrounded by grasses and woody vegetation in the African savanna.

(Above) Large herbivores, such as this elephant, prefer to eat higher-quality woody vegetation at and near termite mounds.

Images courtesy Shaun Levick

the mounds and that the difference in vegetation structure between protected and unprotected areas was greatest for plants taller than 9 feet (3 meters), indicating that elephants favor tall plants.

The group also looked at the relative influence of fire and browsing on the vegetation. They found that browsing had a greater influence than fire. Their work is the first to be able to explicitly quantify the extent to which herbivores affect vegetation diversity.

Farming Advances Versus Carbon Emissions

The Green Revolution, which took place in the second half of the 20th century, allowed developing nations to improve agricultural production through the use of pesticides, fertilizers, and high-yield crops, as well as through access to machinery and improved irrigation techniques. This helped feed an expanding global population, but issues such as chemical runoff and water diversion have made the environmental impact of the revolution unclear. New research from Carnegie scientist Steven Davis, along with researchers from Stanford University, shows that since 1961 the high crop yields resulting from the Green Revolution have prevented the release of up to 161 gigatons of carbon dioxide into the atmosphere.

Agriculture is a major source of greenhouse gases. Emissions are caused by the conversion of natural areas into farmland, as well as by fertilizers, livestock, and fires, among other factors. Davis and his co-researchers investigated the effect that the advanced farming techniques promoted during the Green Revolution had on greenhouse gas emissions from 1961 through 2005.

The research team created two theoretical alternative scenarios for what actually happened agriculturally during that period. One alternative assumed that while the world's population increased and standards of living improved just as they did in the real world, agricultural technology remained at 1961 levels. The second alternative assumed that farm production only increased enough to maintain a 1961 standard of living through 2005.

In both scenarios, the use of fertilizers would have been much lower than is observed today. However, feeding the world without the use of advanced techniques would have required converting vast swaths of natural areas such as forests and scrubland to farmland, which would have drastically increased greenhouse gas emissions. These findings challenge the idea that industrial agriculture, with its use of pesticides and fertilizers, is worse for the environment than the old-fashioned way of farming.

The team also looked at the cost-effectiveness of agricultural research on reducing greenhouse gas emissions. They found that research is one of the cheapest ways of preventing greenhouse gas emissions, particularly compared with improvements in energy efficiency or transportation. What's more, the team says this research shows that efforts to increase agricultural yields are crucial to preventing the conversion of natural areas into farmland going forward, particular in carbon-rich tropical forests.

Old-fashioned farming does use fewer pesticides and less fossil-fuel-burning technology than modern agriculture, but feeding the world using old techniques would require converting large swaths of forests, scrubland, and other natural areas to farmland. As a result, feeding the world's population using old-fashioned farming techniques would actually emit more greenhouse gases than agriculture using modern techniques. The picture above shows hooded sprayers directing herbicide between rows of grain sorghum.

Image courtesy courtesy Jack Dykinga and the U.S. Department of Agriculture

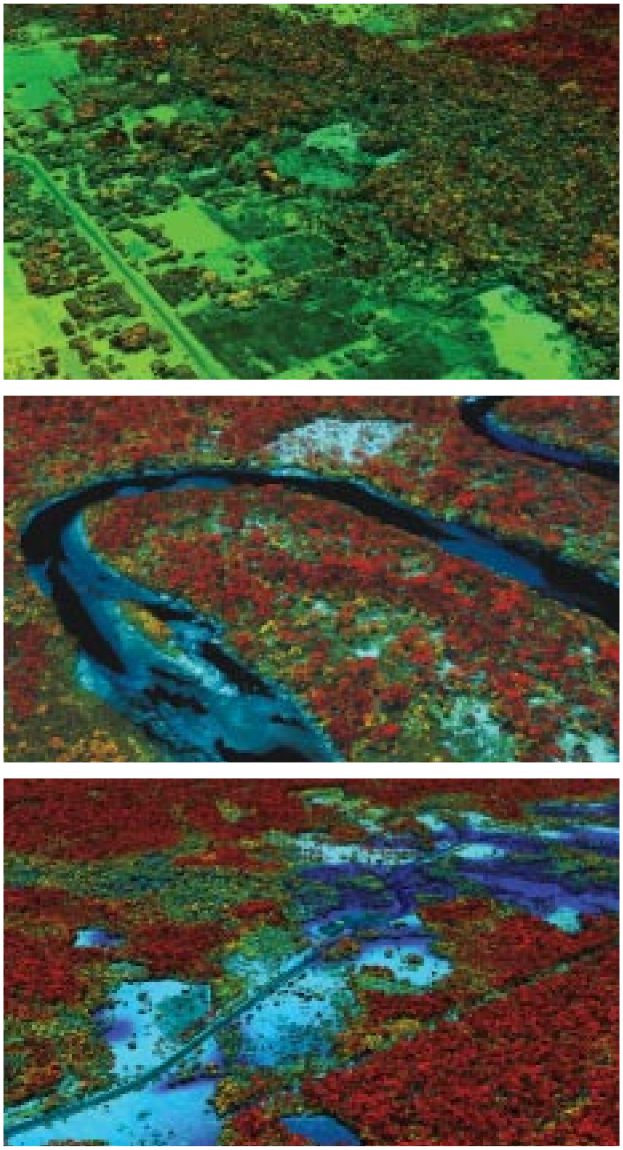
Global Ecology's Steve Davis

Road to REDD

Until the Asner team recently developed a new high-resolution 3-D mapping system, there was no way to reliably measure carbon locked up in tropical forest vegetation and emitted by land-use practices—a prerequisite for accurate monitoring of carbon storage and emissions for the new United Nations initiative on Reduced Emissions from Deforestation and Degradation (REDD).

REDD is designed to create financial incentives to reduce carbon emissions from deforestation and degradation so farmers and others in developing countries can be compensated for good climate practices. But carbon monitoring programs have been hindered by a lack of accurate, high-resolution methods.

Asner lab scientists, with colleagues, married satellite mapping, airborne-laser technology, and ground-based plot surveys to yield the first large-area, high-resolution maps of carbon locked up in tropical forest vegetation and emitted by land-use practices. The Asner team also



The colors in these images represent the height above ground in the Peruvian tropical forest. Blue is the ground level. Red areas are the tallest structures. Secondary and/or degraded forests are in greens and yellows; intact forest is red.

(Top) Roads and dwellings dominate the left side of this image in green. The farther away from habitation, the less destruction there is to the forests (red, upper right). (Center) The river (dark blue) dominates this image. (Bottom) The road shown in this image is the highly destructive Interoceanic Highway. Degraded areas appear in light blue; intact trees are red.

Images courtesy Greg Asner

developed new software for accessing this information so that governments, nongovernmental organizations, and academic institutions can monitor forests.

Their mapping study covered over 16,600 square miles of the Peruvian Amazon—an area about the size of Switzerland. The researchers mapped vegetation types and disturbance by satellite; developed maps of 3-D vegetation structure using a LiDAR system (light detection and ranging) from the Carnegie Airborne Observatory; converted the data into carbon density using a small network of field plots on the ground; and integrated the data to produce high-resolution maps. They combined historical deforestation and degradation data with 2009 carbon stock information to calculate emissions from 1999 to 2009 for the Madre de Dios region.

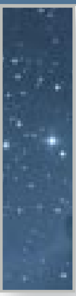
They found that the total regional forest carbon storage was about 395 million metric tons and that emissions reached about 630,000 metric tons per year. They were surprised by how carbon storage differed depending on forest types and underlying geology, finding important interactions among geology, land use, and emissions—the first such patterns from the Amazon.

Their software package, called CLASlite, automatically identifies deforestation and forest degradation from the satellite imagery, so the detailed maps can be easily searched for problem areas. Carnegie is teaming up with Google.org to provide “CLASlite Online” via Google’s Earth Engine, which greatly extends the ability of users to monitor their forests. The method will have a major impact on the implementation of REDD in tropical regions around the world.

□

Observatories

Investigating the Birth, Structure, and Fate of the Universe



Planet Hunting Just Got Better

A collaborative effort between Terrestrial Magnetism's Paul Butler and researchers at the Observatories has created one of the most precise tools for planet hunting in the world. It began in 2004, when then-research associate Jeff Crane joined Steve Shectman, Ian Thompson, and the Observatories team to design the Planet Finder Spectrograph (PFS), now installed and operational on the Magellan Clay telescope.

Radial velocities are the speeds and directions of stars moving away from or toward the Earth. Butler and team use them to detect the telltale wobbles of stars that are gravitationally tugged by orbiting planets. Astronomical spectrographs take collected light from a telescope and disperse it, splitting it into a spectrum of wavelengths. Elements in stellar atmospheres absorb light at specific wavelengths, creating narrow absorption lines in the spectra. The instrument measures shifts in these lines that are caused by changes in the star's motion. Astronomers observe velocity trends and infer planet orbital masses and other parameters. The necessary precision to detect small planets like Earth is very difficult to achieve.

The original goal for the PFS was to measure velocities to within 1 meter per second, currently considered state-of-the-art. Although velocity measurements precise to 3 meters per second had been demonstrated by Butler by the late 1990s, only one other instrument in the world had achieved 1-meter-per-second precision prior to 2010. Results from the PFS have exceeded expectations. The velocity precision may be as good as 66 centimeters per second, making this instrument a superb planet-hunting machine.

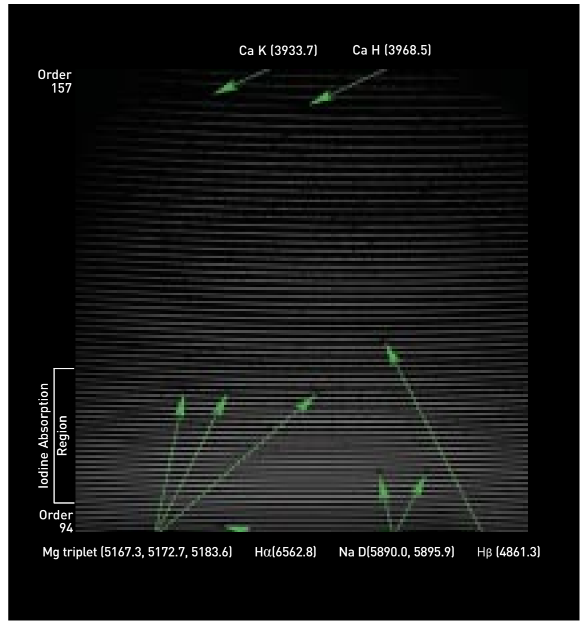
To calibrate the data, the team uses a wavelength reference developed by Butler and collaborators. The starlight collected by the telescope passes through a glass cylinder containing molecular iodine gas. The iodine absorbs light

This photograph shows the Planet Finder Spectrograph on the instrument platform with part of the 6.5-meter-diameter Magellan Clay telescope (blue circular component) behind it. The unique thermal enclosure (white exterior with black interior) is temporarily open on one side.

Image courtesy Jeff Crane

Observatories, *Continued*

Observatories staff associate Jeff Crane modifies the instrument's control electronics enclosure to accept a new component.
Image courtesy Paul Butler



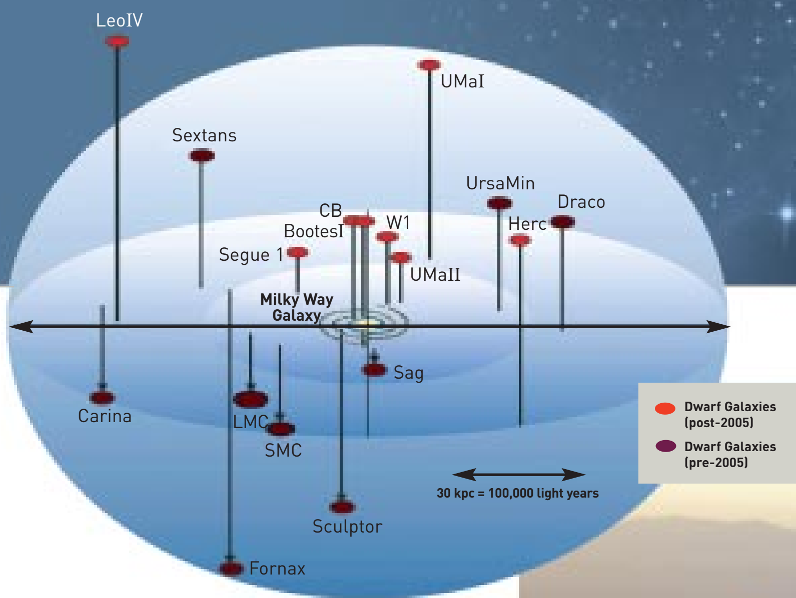
This spectral image was taken by the Planet Finder Spectrograph. Several chemical absorption line signatures are indicated by the green arrows.
Image courtesy Jeff Crane

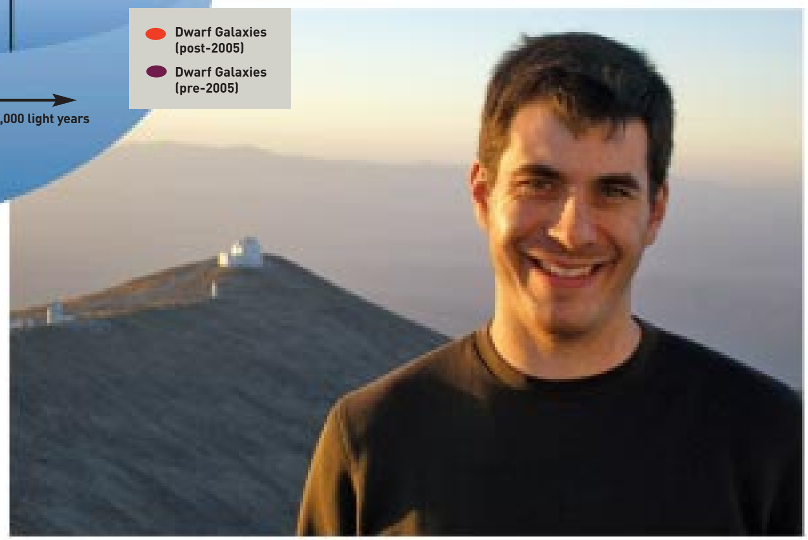
at specific wavelengths. The iodine spectra—the wavelength reference—are superimposed on the stellar spectra to help establish the velocity shift of the moving star. The iodine lines also help calibrate certain atmospheric and instrumental effects.

The PFS is exceptionally stable. The instrument is in a unique thermally controlled enclosure that keeps it near 77°F, regardless of the outside temperature, stabilizing the spectra constant over time. Shectman's optical design has yielded superior image quality, and the spectra are widely spread out so that fine features can be measured more easily.

The Darkest Galaxy Known

Some galaxies are so dark they glow with the light of just a few hundred Suns. Josh Simon and colleagues have determined that a tiny, very dim galaxy orbiting the Milky Way, called Segue 1, is the darkest galaxy ever found and has the highest dark matter density currently known. His team has also laid to rest a debate about whether Segue 1 really is a galaxy or a globular cluster—a smaller group of stars that lacks dark matter. Their findings make Segue 1 a promising laboratory to study dark matter, particularly the possibility that dark matter





Dwarf galaxies neighboring the Milky Way are depicted in this diagram. Segue 1 is the darkest and densest galaxy discovered so far.

Image courtesy Marla Geha

Josh Simon (right) is at Carnegie's Las Campanas Observatory.

Image courtesy Wendy Simon

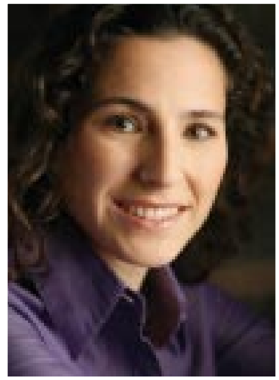
can be seen by the detection of gamma rays emanating from colliding dark matter particles.

Dark matter is the mysterious nonluminous material that makes up about 25% of the universe. Nearby dwarf galaxies have the highest measured densities of dark matter, making them ideal for dark matter studies, but that proximity also has a downside. Star systems so close to the massive Milky Way are subject to the acceleration of their stars by our galaxy's tidal forces, an effect that can mimic the presence of dark matter. The lack of bright stars in dim dwarfs also makes it difficult to measure the velocities of enough stars for sufficient certainty. Simon and company overcame these hurdles with a comprehensive program that measured and analyzed the speed and chemistry of 393 stars in the vicinity of Segue 1.

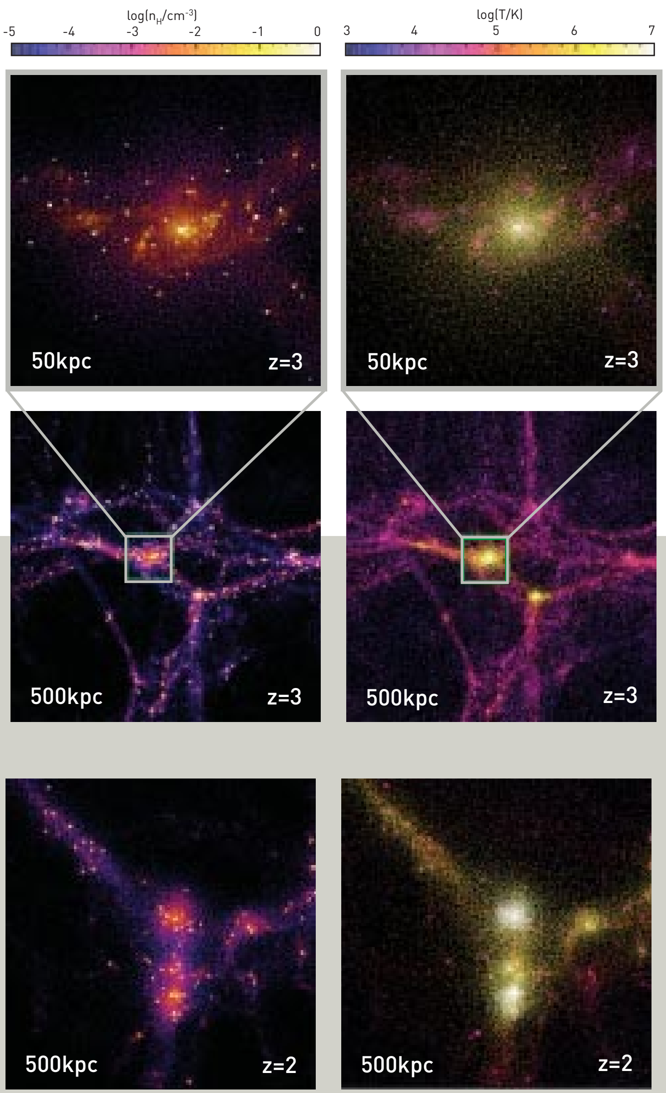
A major difference between galaxies and globular clusters is that the stars in galaxies contain widely varying amounts of iron and other heavy elements, while stars in clusters do not. The new observations revealed that some Segue 1 stars have 50 times less iron than other Segue 1 stars, demonstrating conclusively that Segue 1 cannot be a globular cluster.

In collaboration with astronomers at the University of California, Irvine, Simon also showed that the high speeds of the Segue 1 stars are not caused by invisible binary companion stars, firming up the estimates of the amount of dark matter in the galaxy. Ongoing observations with NASA's Fermi Gamma-ray Space Telescope are searching for signals from Segue 1 and other dwarfs, which would provide astronomers with concrete proof that their dark matter theories are on the right track.

Observatories, *Continued*



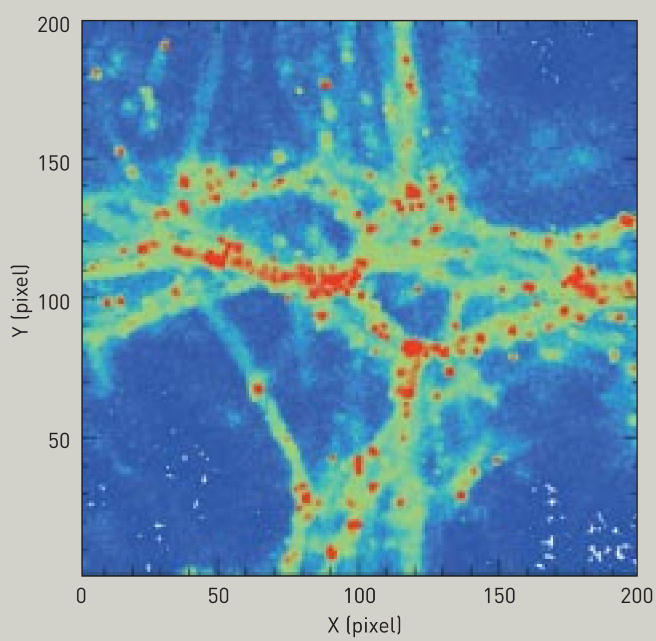
Juna Kollmeier



(Left) This simulation at 2.2 billion years after the Big Bang is for an area that is approximately 4.9 million light-years on a side. The left figures show the gas density and the right show the temperature. The top images are blowups of the central patch in the middle images. They reveal a single galaxy system at the intersection of multiple gas filaments shown at bottom.

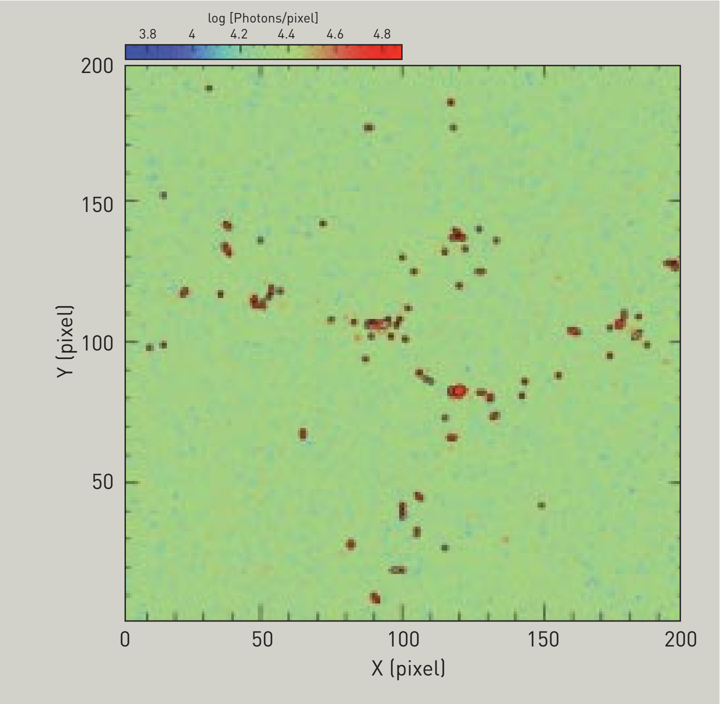
(Below) The image simulates the area of multiple gas filaments from the images at left through Lyman-alpha "eyes."

(Below right) The figure on the right shows what an observer would see with the current generation of telescopes after many hours of integration. It includes foreground noise. Each red dot corresponds to the gaseous regions surrounding simulated galaxies. Kollmeier can compare the simulated images with images obtained by real telescopes and see if her theoretical models are correct.



Unraveling the Cosmic Web

The universe is mayhem. Gravity drags galaxies toward each other, while dark energy pushes them apart. Stars explode as supernovae, ejecting elements and gas, while at the same time enormous filaments resupply material for star formation. Stars are born and stars die. Although visually stunning, the universe is messy. Juna Kollmeier is unraveling the chaos of structure formation by combining state-of-the art cosmological hydrodynamic simulations with astronomical observations of the Intergalactic Medium (IGM). The results are beautiful images showing what the universe once was.



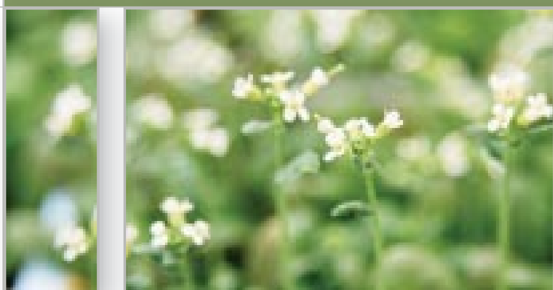
The IGM is the directly observable material that resides between galaxies; it is mostly hydrogen and can be traced by measuring that gas. The IGM is the best-understood component of the currently favored cosmological model of the universe. It is a source for galaxy formation and a sink for its by-products—photons, heavy elements, and kinetic energy. It also reveals the underlying distribution of dark matter—the unobservable material that is more abundant than ordinary matter and is crucial to galaxy formation. These features make the IGM ideal for studying the complex processes of galaxy formation and evolution.

Kollmeier looks at the chemical fingerprints revealed by analyzing light as it passes through the IGM. Each element absorbs or emits light at specific wavelengths, producing unique absorption or emission patterns. One-dimensional absorption studies have been around for a long time. But the future lies with three-dimensional emission-line mapping of the IGM, which will provide a critical new picture of structure formation. Kollmeier has taken the lead in producing predictions for 3-D emission-line maps of the young universe.

Using spectral observations to test cosmological models requires accurate predictions of the emission signature from the IGM. Kollmeier has developed software that makes these predictions possible. She performs radiative transfer calculations of Lyman-alpha photons—the photons that trace the state of intergalactic material as energy from stars and quasars gets reprocessed by the intergalactic gas. Kollmeier's combination of software and computing power provides necessary tools to make accurate predictions that address the most fundamental questions about how galaxies get their fuel and use it over their life cycle. □

Plant Biology

Characterizing the Genes of Plant Growth and Development



Adapting by Computing

In the wake of epic floods and fires, are famines on the horizon? Many say yes and are looking at ways to adapt to climate change. One way may be through faster identification and manipulation of crop genes to resist or tolerate environmental extremes. Sue Rhee and team created a new computational model, called AraNet, to predict the function of uncharacterized plant genes with unprecedented speed and accuracy. She, with colleagues, used it to predict a drought-related function of one previously uncharacterized gene and confirmed with follow-up experiments that it is involved in the drought response.

AraNet encompasses over 19,600 genes of the tiny, experimental mustard plant *Arabidopsis thaliana,* which are associated to each other by over 1 million links. AraNet can increase the discovery rate of new genes affiliated with a trait tenfold. It is based on the notion that genes near each other, or that turn on in concert with one another, are probably associated with similar traits. The model is based on the evidence gathered from some 50 million scientific observations, which enables the map of associations to be made. Researchers propose that uncharacterized genes are linked to specific traits based on the strength of their associations with genes already known to be linked to those characteristics. They then follow up with experiments that suppress the activity of the uncharacterized gene to see what normal characteristics in the plant go awry.

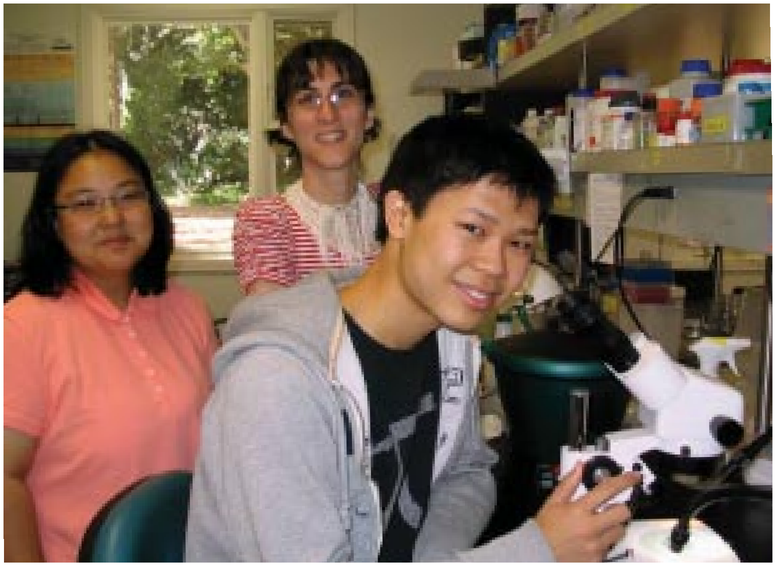
AraNet suggested that a gene called *AT1G80710* could be involved in the response to water deprivation. The researchers found that under drought conditions mutant plants lacking this gene held in only 80% of the water that normal plants did; they were "blind" to drought.

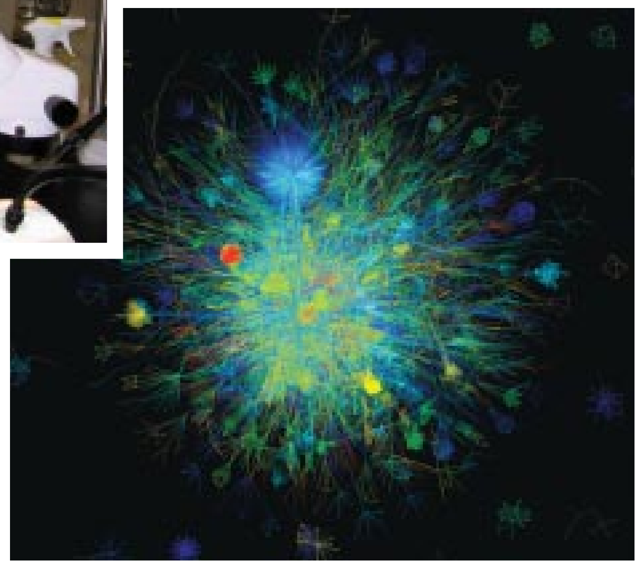
The plant hormone abscisic acid (ABA) controls numerous physiological processes, including responses to stresses. It is also part of a molecular relay that mediates drought response by keeping water loss in check. The researchers looked to see if response to ABA was affected in the mutant plant by examining the effect of the hormone on transpiration—the process of "exhaling" water vapor from leaves to the atmosphere. Transpiration in the mutant was not affected by the hormone, with the result that the mutant lost significantly more water than the normal plants. The experiments confirmed what AraNet identified—that the gene is involved in sensing drought. The group renamed the gene *DROUGHT SENSITIVE 1(DRS 1).*

Watching Molecular Scaffolds Take Shape

For the first time scientists have witnessed how proteins common to both plants and animals build specialized molecular scaffolds that are essential for creating the shapes of plant cells. The study, by David Ehrhardt and Takashi Hashimoto, is important in advancing cell biology research and crop engineering.

Plants, animals, and fungi all use hollow protein rods called microtubules to support cell shape, movement, and





(Above) Team members working on Rhee's research into the mechanisms of the drought response are (left to right) Hye-In Nam, Flavia Bossi, and Nathaniel Leu.
Image courtesy Sue Rhee

(Right) The AraNet model contains some 50 million scientific observations, from which a map of associations is made. Each line of this network represents a functional link between two genes. The colors indicate the strength of the link using a red-blue heat map scheme.
Image courtesy Insuk Lee of Yonsei University

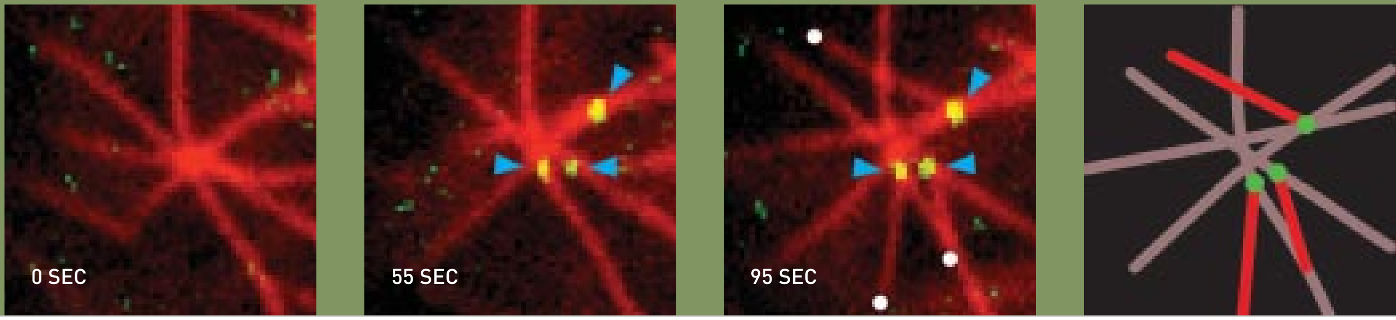
division. These rods are arranged in a specific configuration, a molecular scaffolding, which organizes other proteins and cell processes. Much has been discovered about how microtubules are arranged from a central hub in animals cells known as a centrosome. However, microtubules can be arranged in configurations that do not utilize a central hub. How these other configurations are created has remained a mystery. Plant cells are appropriate for studying this problem because they lack centrosomes.

An essential function of the centrosomal hub is to serve as a platform for nucleating complexes, proteins that give birth to new microtubules. To determine where these nucleating complexes are and how they function in plant cells, the Ehrhardt and Hashimoto team tagged them with a jellyfish fluorescent protein and introduced them into plant cells.

They saw that most nucleating complexes are recruited to the sides of other microtubules and that new microtubules are much more likely to arise from these complexes than from those that are recruited to other locations. These observations suggest that the microtubules are important for locating and regulating their own formation proteins. The researchers also found that the molecular complexes formed newborn microtubules at two distinct orientations. The scientists believe that this orientation choice may play a role in organizing the microtubules.

In a previous study, the Ehrhardt lab discovered that new microtubules are separated from their sites of birth shortly after they are created, after which they migrate to new locations in the cell. The researchers speculated that this process was important for organizing the microtubules.

The scientists thought that a protein called katanin



The Ehrhardt lab previously found that the scaffolding that shapes plant cells, called microtubules, is born along the inside of the cell membrane. To visualize the birthing process, the team tagged molecular complexes that give rise to microtubules and observed the construction of the microtubule network. Red is tubulin, the protein that makes up the microtubules. Green is tagging the molecular complex (which appears yellow where it overlaps the tubulin). The time series shows the recruitment of molecular complexes to the sides of a microtubules (blue arrows) and the birth of new microtubules from the complexes (growing ends marked with white circles at 95 seconds). The diagram highlights the locations of the complexes and new microtubules.

Images courtesy of Viktor Kirik and David Ehrhardt.

might be responsible for the separation process, so they introduced their probes into a mutant plant lacking the katanin protein. Without katanin, the newborn microtubules failed to detach from the nucleating complex, and the complex remained in place. These results demonstrated that katanin is required for freeing new microtubules and liberating the nucleating complex so that it can be used in a new location.

Cutting the Green

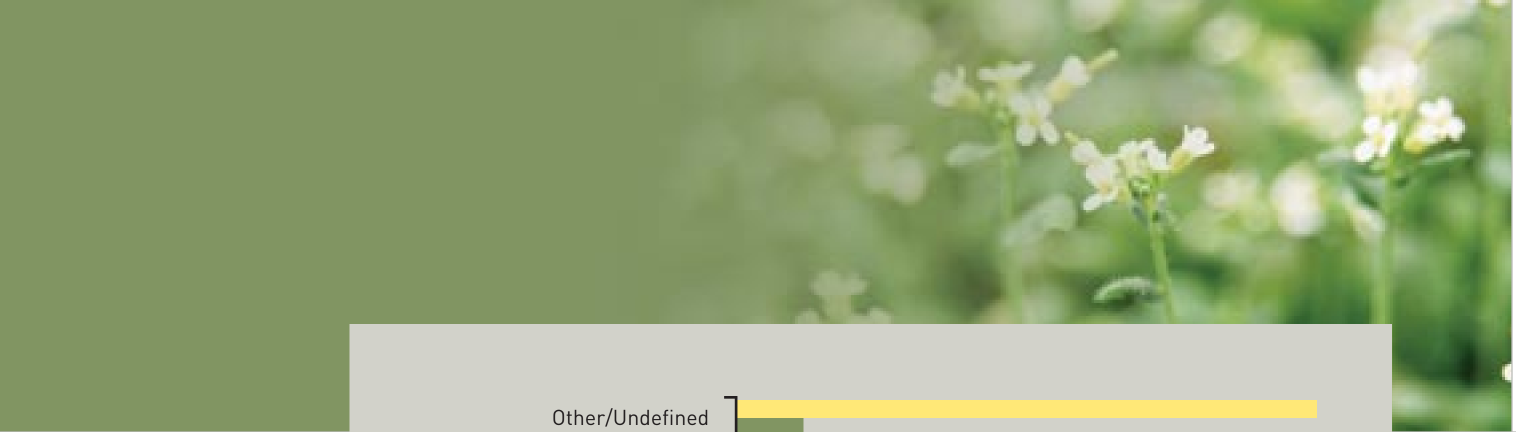
Although scientists have been able to sequence the genomes of many organisms, they still lack a context for identifying the biological processes to which these genes contribute. Furthermore, understanding how groups of genes are shaped by environmental forces, developmental processes, and transfer among species could give researchers important insights into key biological processes. To this end, Arthur Grossman and colleagues generated a list of proteins that are present in members of the plant kingdom and in green algae but not in nonphotosynthetic organisms. Many of these proteins have no known biological function, but are localized to a cellular organelle called the chloroplast and have features that suggest a function in photosynthesis. The researchers hope to reveal the roles of the genes that encode these proteins in green-lineage organisms and learn how these genes might affect photosynthesis.

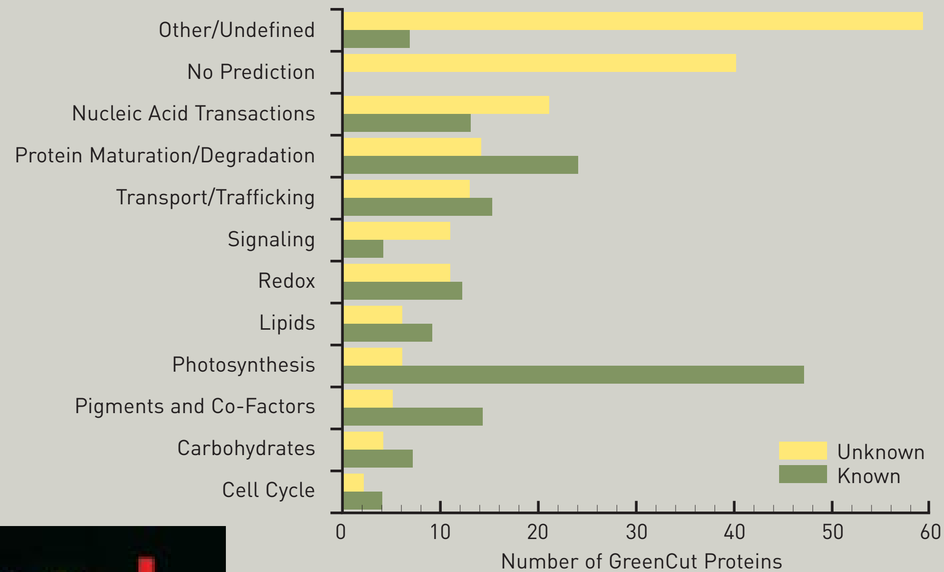
It is believed that chloroplasts originated as photosynthetic, single-celled bacteria (called cyanobacteria), which were engulfed by eukaryotic, nonphotosynthetic cells more than 1.5 billion years ago. While the relationship between the two organisms was originally symbiotic, over evolutionary time the bacterium lost its ability to live without its partner. It eventually turned into a chloroplast, the compartment in the cell that performs photosynthesis.

Using a variety of computational techniques, Grossman and colleagues at UCLA and the Joint Genome Institute were able to generate a list of 597 proteins specifically present in members of the plant kingdom and in green algae but not in nonphotosynthetic organisms. They named these proteins the GreenCut.

The biological functions of a large portion of the 597 GreenCut proteins are not known. However, the team has been able to narrow down potential activities for several by figuring out when and where they are expressed. Genetic and biochemical research is being performed to continue piecing together clues about GreenCut proteins that will reveal their roles in green-lineage organisms, especially how they might affect photosynthetic function.

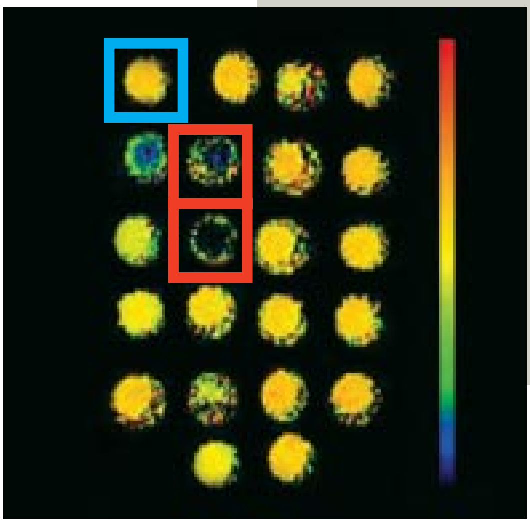
Many GreenCut proteins are in red algae, other single-celled algae called diatoms, and ancient chlorophyll-containing cyanobacteria. Comparisons of GreenCut proteins in these organisms open a window for potential key discoveries about the evolution of chloroplasts and the roles they perform in photosynthetic cells. □





The bars along the y-axis represent the GreenCut proteins classified by function. The number of proteins in each functional classification is shown on the x-axis. Green bars represent proteins with known functions; yellow bars represent proteins of unknown function. Note that while the physiological functions of many proteins in the Photosynthesis and Pigments and Co-Factors sections are known, the functions of many proteins associated in the Signaling and Nucleic Acid Transactions categories are not.

Images courtesy Arthur Grossman



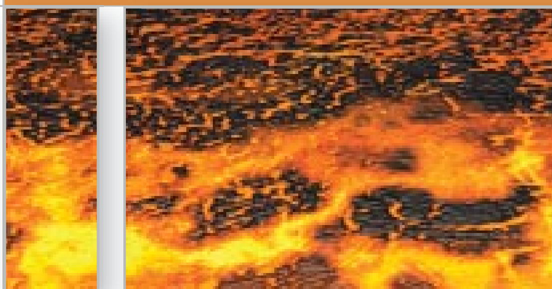
(Above) Strains of algae with mutations in genes encoding GreenCut proteins can have observable characteristics that indicate a defect in the use of the light energy necessary for photosynthesis. Fluorescence-emission tests indicate that some GreenCut-defective mutants have reduced activity in major photosynthetic protein complexes compared with nonmutant algae (blue box). The mutant strains in the red boxes show very low photosynthetic efficiency.

(Right) Plant Biology's Arthur Grossman

Images courtesy Arthur Grossman

Terrestrial Magnetism

Understanding Earth, Other Planets, and Their Place in the Cosmos



The Case of the Mysterious Volcanic Islands

A long-standing geological mystery, the origin of the volcanic Hawaiian Islands, could soon be solved. Plate tectonics explains the existence of volcanoes at boundaries where plates spread apart or collide, but midplate volcanoes, such as those that built the Hawaiian island chain, have been harder to fit into that theory.

New research carried out by Sean Solomon and Erik Hauri and led by former Department of Terrestrial Magnetism (DTM) postdoctoral fellow Cecily Wolfe (now at the University of Hawaii) lends support to one proposed explanation for the Hawaiian volcanoes. This nearly 40-year-old model suggests that magma is supplied to the volcanoes from upwellings of hot rock, called mantle plumes, which originate deep in the Earth's mantle.

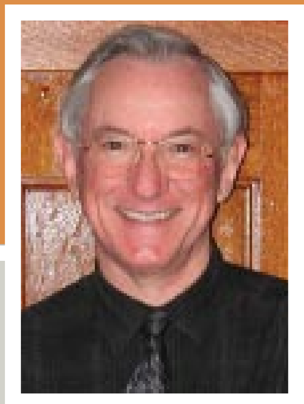
Although evidence for these types of plumes has been sketchy in the past, two years' worth of data from seismometers placed both on land and on the seafloor have provided an unprecedented glimpse of the roots of the Hawaiian hot spot. This sophisticated array of seismometers was able to show the first high-resolution seismic images of a mantle plume extending to depths of at least 900 miles (1,500 kilometers).

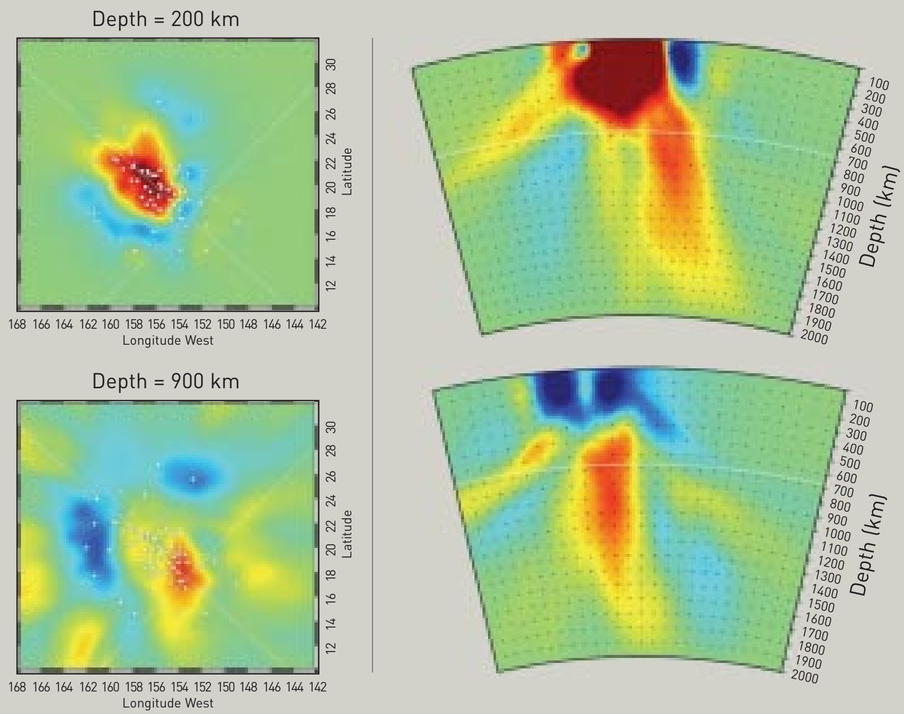
The research project is known as PLUME, for Plume-Lithosphere Undersea Melt Experiment. The development of broadband seismic instruments capable of being set on the seafloor for long periods was integral to gathering these new data, since many of the major hot spots are in the oceans and far from major landmasses.

The seismic images show that the volume of low seismic velocities is approximately the size of the island of Hawaii, which is positioned near the center of the upper mantle portion of the velocity anomaly. These results match expectations from the plume model.

Critics of the plume explanation have argued that the magma in hot spot volcanoes comes from relatively shallow depths, not from deep upwellings. But the depth of the hot spot roots observed in this research lends strong support to the plume hypothesis.

Researchers retrieve an ocean-bottom seismometer in May 2007. The dangling silver sphere houses the actual seismic sensor; orange containers house the electronics and batteries.
Image courtesy Gabi Laske, University of California, San Diego





(Above) Sean Solomon is director of the Department of Terrestrial Magnetism.

(Right) These images show anomalous seismic velocities beneath the Hawaiian Islands. The orange and red colors indicate low S-wave velocities, which imply higher rock temperatures. The left two images are horizontal cross sections at depths of about 125 miles (200 kilometers) and nearly 560 miles (900 kilometers); boxes represent the locations of seismometers on the overlying seafloor. The right two images show vertical cross sections through the region. The upper of the two is oriented northwest to southeast, and the lower southwest to northeast.

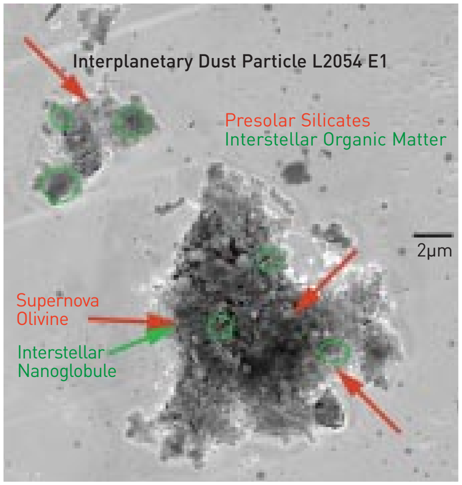
Image from Science 326, *1388, 2009.*
Reprinted with permission from AAAS.

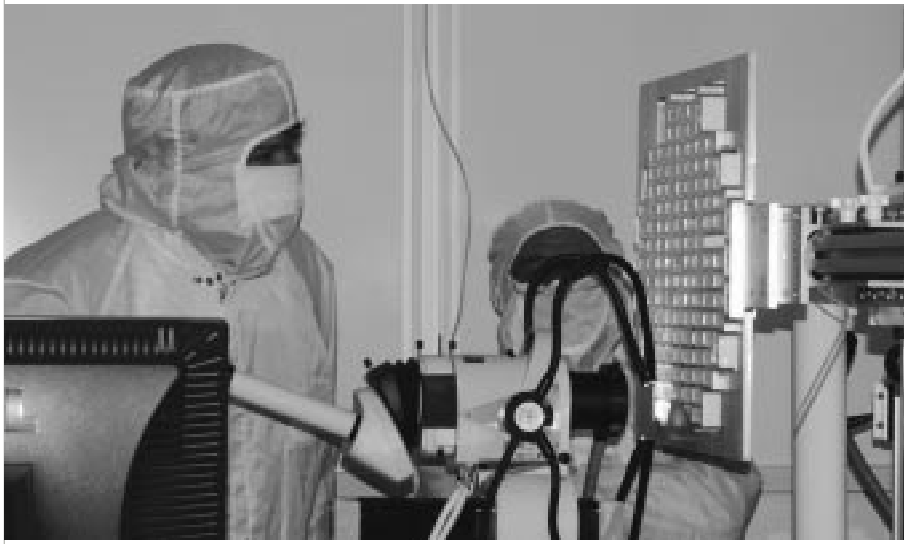
Spaced-Out Dust

Particles floating in Earth's upper atmosphere generally come from space—not from the planet's surface—and can help scientists understand the Solar System's history. Collected using specialized NASA planes, these interplanetary dust particles, or IDPs, likely originated from comets and asteroids. Carnegie scientists Larry Nittler and George Cody, with former DTM postdoctoral fellows Henner Busemann (now at the University of Manchester) and Ann Nguyen (now at the Johnson Space Center) and colleagues from the U.S. Naval Research Laboratory, the Lawrence Berkeley National Laboratory, and the Max Planck Institute for Chemistry in Germany, found that a few special IDPs came from the dust trail of a comet called Grigg-Skjellerup and entered our atmosphere as Earth passed through the comet's tail in 2003. This was the first time researchers could tie a single particle of dust found in Earth's stratosphere to a specific comet.

Comets, which come from the frigid outer reaches of the Solar System, are believed to be repositories of unaltered material left over from the system's formation. Their dust, protected from the heating and chemical processing that has affected other bodies such as asteroids

Terrestrial Magnetism, *Continued*





(Left) Larry Nittler inspects the Stardust collection grid at the NASA Johnson Space Center. Interplanetary dust particles gathered by NASA's Stardust mission were compared with dust particles from the Grigg-Skjellerup comet gathered by Nittler's team.

Image courtesy Larry Nittler

(Above) This is a scanning electron image of interplanetary dust particles containing presolar silicate grains and interstellar organic matter.

Image courtesy Henner Busemann

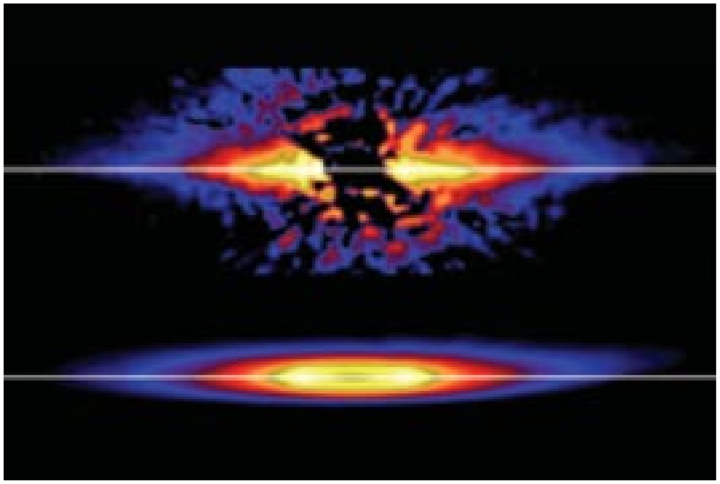
and planets, provides scientists with a glimpse of some of the primitive matter that formed the Sun and the planets.

The stratospheric dust from Grigg-Skjellerup exhibited a number of ultraprimitive characteristics, notably a surprisingly high abundance of presolar grains—minute particles that likely formed inside stars that lived and died long before the Sun's birth. Presolar grains have much more unusual isotopic compositions than anything else in the Solar System. They are extremely rare in meteorites from the asteroid belt and even in most stratospheric IDPs, making their high concentration in Grigg-Skjellerup dust very exciting. The dust also showed an abundance of disordered organic matter with isotopic compositions that point to an origin in interstellar space.

The team compared the Grigg-Skjellerup dust with dust from a comet called 81P/Wild 2, which was collected in space by NASA's Stardust mission and returned to Earth in 2006. Scientists had expected that the Wild 2 dust would be primitive, but the samples included more altered material than expected. The dust from the Grigg-Skjellerup comet was much more primitive than the Wild 2 dust. This result potentially indicates a vast diversity in the materials that make up comets, as well as in the degree of thermal and chemical processing that comets and dust have experienced in the eons since their formation.

Supersonic Ballistic Drag

Alycia Weinberger's lab is light-years away. She probes the dusty disks surrounding nearby young stars—with their own cometary and asteroidal dust—for clues to how our own Solar System formed. Recently, she and her team made multicolor images of a disk around the star HD 32297, which is 365 light-years from the Sun—nearby as disks go. She wanted to learn about the composition of the disk to see what it could teach us about the primitive Solar System. Using the Hubble Space Telescope (HST),



(Left) Terrestrial Magnetism's Alycia Weinberger. (Right) The dusty disk observed around the star HD 32297. Weinberger's team found the density of gas in the Interstellar Medium (ISM) and collision velocity between the star and the ISM cloud that could reproduce the disk's shape. Although not obvious in the image, careful measurements show that starting about 150 astronomical units (AU) from the star (1 AU is the distance from the Earth to the Sun), one side of the disk is curved away from the star creating a warp.This model is presented in the lower panel.
(Left) Image courtesy Alycia Weinberger / (Right) Image courtesy Alycia Weinberger and The Astrophysical Journal

she looked for variations in composition within the disk.

Her team found a complicated color variation in a strangely shaped, warped disk. Former DTM postdoctoral fellow John Debes (now at NASA Goddard) developed a model of gas/grain interactions and showed that the shape probably came from the interactions between disk grains and hydrogen gas in the interstellar medium (ISM). The dust likely experiences supersonic ballistic drag as it hits the ISM gas—similar to what meteorites encounter when they enter Earth's atmosphere—warping the disk's shape. The ISM dust could also sandblast the outer parts of the disk, changing the sizes of the dust grains and their reflective colors.

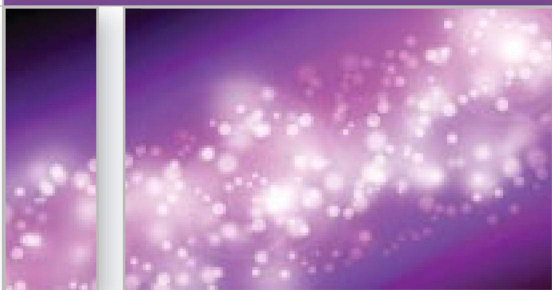
The astronomers used the coronagraph in the near-infrared camera on the HST to block the light of the star so that disk grains scattering starlight would be visible. The color of the scattered light depends on the composition and size of the grains. Their observations probed parts of the disk comparable to the distance between our Sun and Neptune and beyond in our own system. The disk grains are gray in the innermost portion of the image—they scattered all three wavelengths equally. The color gray suggests large silicate grains perhaps coated with water ice. At the disk's warp, the researchers saw a change to a bluer color, suggesting small and eroded grain remnants from collisions with the ISM.

The same processes at work for HD 32297 could have shaped our outer Solar System. For the young stars that Weinberger observes, the interaction of a disk and the ISM is pivotal to understanding the environment in which planets form. □

Weinberger and team use the Hubble Space Telescope for observing dusty disks around nearby stars. This image shows Hubble drifting over Earth in 2009.
Image courtesy NASA

First Light & The Carnegie Academy

Teaching the Art of Teaching Science



DC STARs

The CASE DCBiotech Project and Carnegie's NASA Astrobiology Institute (NAI) team forged a new partnership—Student Teacher Astrobiology Researchers (STARs). Eleven Ballou Senior High School students and their teacher met the NAI team and learned firsthand about the variety of research expeditions to Svalbard, Norway, to prepare for the search for life elsewhere in the universe. During a two-week institute at the Carnegie labs, the STARs learned to apply methods used in the Arctic expeditions to design an expedition to Ballou to collect extremophiles—organisms that live in extreme conditions, such as in a hot water system and on rooftops. Scientists from Andrew Steele's laboratory advised the STARs researchers back at Ballou through computer-mediated videoconferencing. The students presented their findings at an August miniconference.

Branching Out

DC Biotech has established biotechnology career pathways at Ballou and McKinley Technology high schools in Washington. Now, with support from the Shippy Foundation and the Association of American Medical Colleges, students citywide will experience exciting biotech research through a new Lab Loaner Program. Middle and high school science teachers from the D.C. area, trained by CASE, can borrow four different teaching kits for two to three weeks. Each features a biotechnology lesson, complete with curriculum guides.

With support from the National Human Genome Research Institute DNA DAY Program, CASE introduces adults and children to the increasingly accessible world of online bioinformatics research through the simple yet elegant craft of beading bracelets. Four bead colors represent the four DNA bases. The jewelry models real DNA sequence information three ways: by randomly stringing 15 to 18 beads and looking up the DNA sequence on GenBank; by retrieving a selected gene's DNA sequence from GenBank, then beading a segment; or by using the genetic code to bead a secret DNA message.

Going Global

For several years Carnegie has cohosted the Royal Embassy of Norway Transatlantic Science Week. Serendipity sparked a DC Biotech–Norwegian partnership with Ullern High School, Oslo University, and the Oslo Cancer Cluster. The partners visited each other's sites and are designing curricula for students to explore nutrition and diabetes, crime scene investigation, and genomics. Conducting collaborative research projects through videoconferences, the high school students will experience real-world international scientific teamwork while learning about biotechnology careers and each other's cultures. □

for Science Education

(Top left) STARs students Juwanna Douglas and Linda Jamison and teacher John Solano discuss the results of a sampling method they piloted during the two-week institute at Carnegie.

Image courtesy Toby Horn

(Below left) Children bead DNA bracelets at a local science festival. The CASE DNA DAY project sends kits upon request to high schools and community colleges around the country. Kits include beads in the schools' colors along with lessons, teaching PowerPoints, reference materials such as genetic code sheets, and a "Budding Bioinformatician" Certificate of Participation.

Images courtesy Toby Horn

(Above) DCBiotech members went to Oslo, Norway, in May 2010, to visit their Norwegian biotech partners. Members from the U.S. include Marti Jett (in blue jacket, standing on left) and Debra Yourick (sitting second from right) of the Walter Reed Army Institute of Research. They were joined by Ballou teacher John Solano (crouching, right), McKinley teacher Joseph Isaac (standing, right), and J. Craig Venter Institute partner Lisa McDonald (next to Isaac). The Oslo Cancer Cluster and the Royal Norwegian Embassy sponsored CASE codirector Toby Horn (front) and the teachers from the D.C. Public Schools.