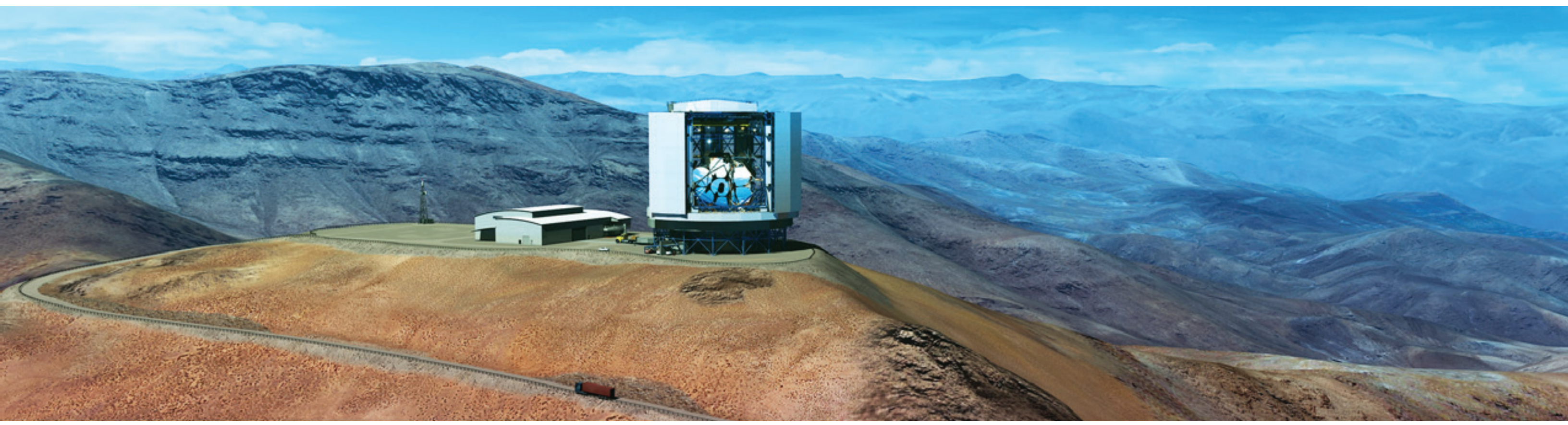
CarnegieScience

The Newsletter of the Carnegie Institution for Science

SPRING 2017

EMBRYOLOGY ▫ GEOPHYSICAL LABORATORY ▫ GLOBAL ECOLOGY ▫ THE OBSERVATORIES ▫ PLANT BIOLOGY ▫ TERRESTRIAL MAGNETISM ▫ CASE: CARNEGIE ACADEMY FOR SCIENCE EDUCATION

On the Inside



CARNEGIE SCIENCE

CARNEGIE INSTITUTION FOR SCIENCE

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Boundless Curiosity Builds a Strong Nation

A strong nation stands on the shoulders of scientific and technological breakthroughs. The U.S. has been the economic engine of the world for generations because of its investment in research and development—both public and private. This investment has yielded vast agricultural harvests, astonishing medical advances, critical new security technologies, revolutionary computing power, spectacular new industrial materials and processes, and world-leading space exploration, to name just a few advances.

Carnegie Science has, therefore, become a proud supporter of the *March for Science* in Washington D.C. The *March for Science* represents the perfect opportunity to showcase the connections between scientific discovery, technology, economic strength, global security, human and animal health, and the condition of our planet. We fully endorse the official *March for Science* mission, which "champions robustly funded and publicly communicated science as a pillar of human freedom and prosperity."

The discoveries now being made in physics, biotechnology, and engineering will underpin the future of our country—and of all countries. Never have we had such a comprehensive view of our planet's quite possibly unique evolutionary and dynamic processes, nor of our shared dependency on the health of the tiny blue dot on which we live.

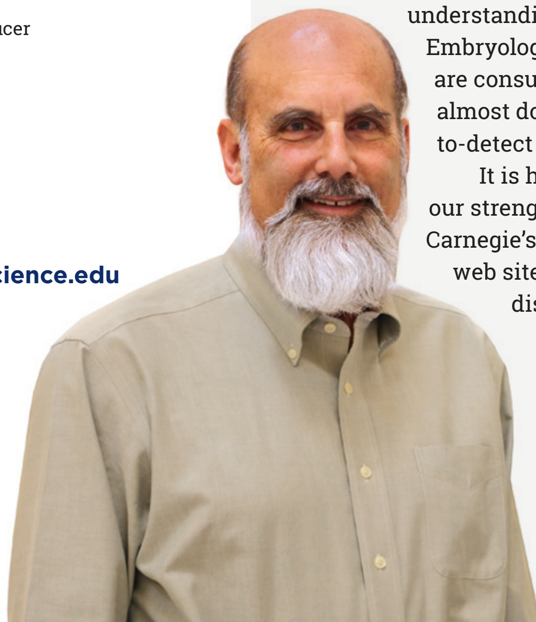
To accomplish our research, Carnegie Science has always depended on people from all over the world. The kinds of natural phenomena we study have no political boundaries and there should be no boundaries on our researchers. They would stifle progress.

As I write this letter, there is talk of sweeping cuts to climate science, threatening our nation's position as a global leader in this area. It's too soon to know what the outcome will be, but we will forge ahead with the science that better informs our understanding of the impact of climate change. This issue of *Carnegie Science* features two stories about climate science. Global Ecology's Anna Michalak studies how toxic water events, which are becoming increasingly common, require improved management tools for reducing nitrogen runoff. Their work is pivotal for developing strategies to reduce this noxious pollution.

Global Ecology's Ken Caldeira and team have taken a new approach to understanding how fast we will have to adapt to the changing climate. Using sea-level rise as a case study, they developed a quantitative model that considers different rates of sea-level rise, in addition to economic factors, to show how rates of change affect optimal adaptation strategies.

Other discovery stories, in this issue, span the realms of the subatomic and subcellular to the most distant reaches of our cosmos. Guoyin Shen's team at HPCAT discovered new properties of matter that could be important for developing new materials and for understanding planetary interiors. Discoveries by Steve Farber's team at Embryology show how gut cells are remodeled when particularly fatty foods are consumed. And work by Eduardo Bañados' group at the Observatories has almost doubled the number of ancient quasars discovered. These difficult-to-detect objects are the most distant and luminous of any in the universe.

It is heartening to realize that the diversity of Carnegie Science is as much our strength as is the diversity of our researchers. You can keep up with Carnegie's exciting discoveries by following us on social media, or visiting our web site (www.carnegiescience.edu). Our independence ensures that this discovery science can continue in these uncertain times.



Matthew Scott, *President*

Before Carnegie trustees with Carnegie and Argonne staff broke into groups for the tours, they posed for a group shot. First row (from left): George Cody (Carnegie), Peter Littlewood (Argonne director), Bruce Ferguson (trustee), Sandra Faber (trustee), Michael Wilson (trustee), Michael Duffy (trustee), Rush Holt (trustee), Katie Lapp (trustee), Deborah Rose (trustee), Matthew Scott (Carnegie). Second row (from left): John Mulchaey (Carnegie), Michael Long (trustee), Richard Meserve (trustee), Dennis Mills (Argonne), Craig Barrett (trustee), Cristián Samper (trustee), Benjamin Aderson (Carnegie), John Crawford (trustee). Third row (from left): George Srajer (Argonne), Guoyin Shen (HPCAT), Christopher Stone (trustee), Rick Carlson (Carnegie), Tim Doyle (Carnegie), Viktor Struzhkin (Carnegie), Stanuskav Sinogeikin (HPCAT), Margaret Moerchen (Carnegie), Ann McElwain (Carnegie), Sue Rhee (Carnegie). Back row (from left): Suzanne Nora Johnson and Steve Fodor (Carnegie board cochairs), Deborah and Marshall Wais (trustee), Paul Kerns (Argonne), Lara Budeit (Carnegie), Jessica Cima (Carnegie), Ben Barbin (Carnegie), Michael Stambaugh (Carnegie), Joe Berry (Carnegie), Dave Mao (Carnegie), Yixian Zheng (Carnegie).

TRUSTEE NEWS

Board Meets in Chicago

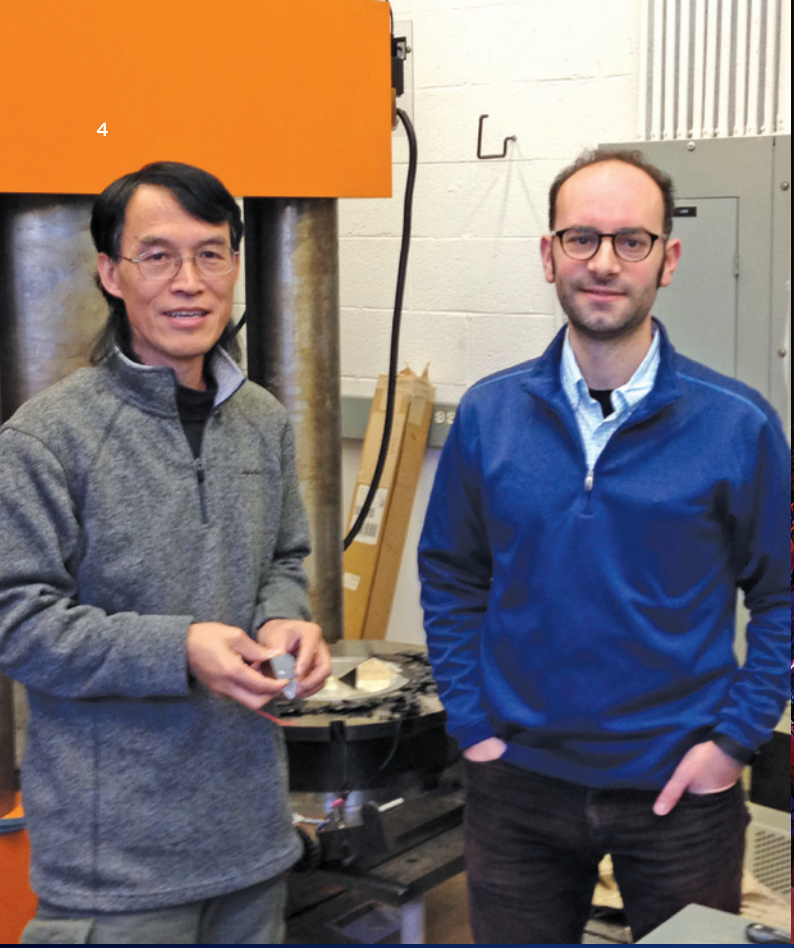
The Carnegie board of trustees met in Chicago on November 17 and 18, 2016. In addition to committee meetings and reports, Carnegie department directors John Mulchaey of the Observatories, Rick Carlson of Terrestrial Magnetism, and George Cody, acting director for the Geophysical Laboratory, updated trustees on research highlights for their respective areas.

The highlight of the meetings was a tour of the High Pressure Collaborative Access Team (HPCAT) beamline facility at the nearby Advanced Photon Source (APS) at Argonne National Laboratory, where Carnegie researchers study extreme states of matter. The APS generates ultra-bright, high-energy X-ray beams, which are accelerated around an enormous ring. The X-rays are so powerful they can determine the structure of matter at minute scales for many different scientific purposes. Different groups of trustees and staff toured the beamline with HPCAT and APS staff on Thursday, November 17. ■

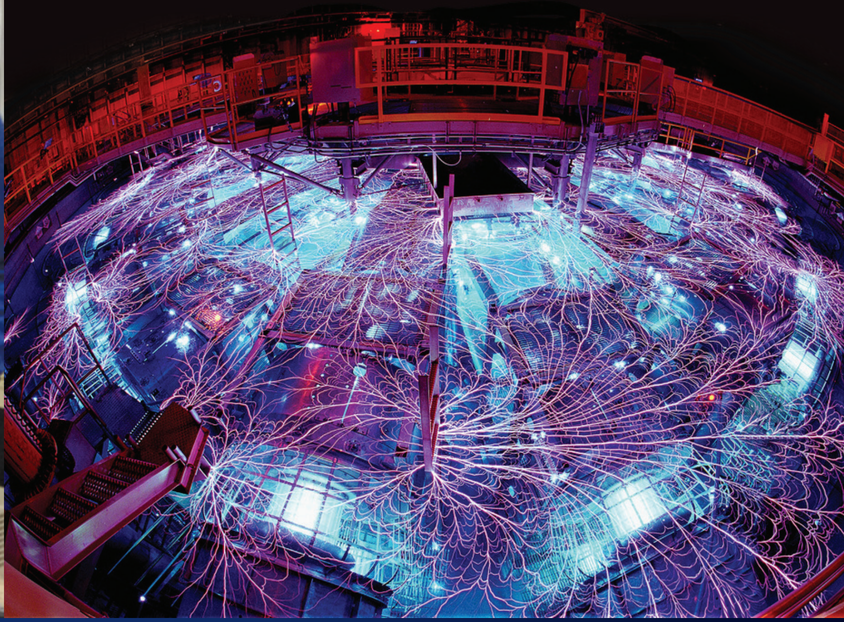
Images courtesy Argonne National Laboratory

Carnegie trustee and former Carnegie postdoc Sandra Faber (front left) toured the facility with Carnegie staff scientist and high-pressure pioneering researcher Dave Mao (front center), acting director of Global Ecology Joe Berry (front right), and others.

Among the sites the groups toured were the areas, or sectors, where experiments are conducted. The high-energy X-rays are collected from the large ring into different sectors for experiments ranging from biological and pharmacological research to materials and chemical science, such as the work undertaken by Carnegie researchers.



"Scientists want to know more about the interior processes and conditions of giant exoplanets."



Yingwei Fei and Peter Driscoll Awarded 7th Carnegie Science Venture Grant

Yingwei Fei, a high-pressure experimentalist at the Geophysical Laboratory, and Peter Driscoll, a theoretical geophysicist at the Department of Terrestrial Magnetism, have been awarded a Carnegie Science Venture Grant for their project "Direct Shock Compression of Pre-synthesized Mantle Mineral to Super-Earth Interior Conditions."

The project is an entirely new approach to investigate the properties and dynamics of super-Earths—extrasolar planets with masses between one and 10 times that of Earth. They will use the world's most powerful magnetic, pulsed-power radiation source, called the Z Machine, at Sandia National Laboratories, to generate shock waves that can simulate the intense pressure conditions of these enormous bodies. Reaching such high pressures has not been possible before. The results will be used to develop models and predictions of super-Earth interiors.

Carnegie Science Venture Grants ignore conventional boundaries and bring together cross-disciplinary researchers with fresh eyes to explore different questions. Each grant provides $100,000 support for two years. These grants are generously supported, in part, by trustee Michael Wilson and his wife Jane.

Scientists want to know more about the interior processes and conditions of giant exoplanets. Earth's lowermost mantle reaches pressures of some 1.3 million times standard atmospheric pressure (136 GPa). A super-Earth ten times the mass of Earth would have pressures of almost 13 million atmospheres (1300 GPa). The Sandia facility is capable of reaching pressures above 10 million atmospheres (1000 GPa).

The new work requires new technical development. Experiments, led by Fei, will provide new data on the density distribution and thermal conditions in super-Earths that will be used for thermal evolution modeling and predictions by Driscoll. ■

Above left: Yingwei Fei (left), a high-pressure experimentalist at the Geophysical Laboratory, has partnered with Peter Driscoll, a theoretical geophysicist at the Department of Terrestrial Magnetism.
Image courtesy Yingwei Fei

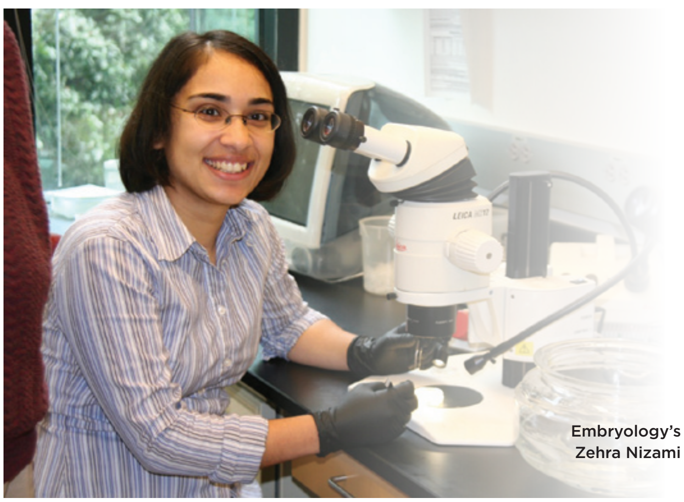
Above right: The Department of Energy has only recently allowed a few academic institutions to use the Z Machine seen here. Fei's team was granted access through a highly competitive application process.
Image courtesy Sandia National Laboratory

FOURTH AND FIFTH POSTDOCTORAL

INNOVATION AND EXCELLENCE

(PIE) AWARDS BESTOWED

ZEHRA NIZAMI HAS BEEN A GRADUATE STUDENT AND POSTDOC IN JOE GALL'S LAB AT THE DEPARTMENT OF EMBRYOLOGY. SHE IS THE FOURTH RECIPIENT OF THE POSTDOCTORAL INNOVATION AND EXCELLENCE (PIE) AWARD. GLOBAL ECOLOGY NATIONAL SCIENCE FOUNDATION (NSF) FELLOW MARY WHELAN IN JOE BERRY'S LAB IS THE FIFTH RECIPIENT. THE PIE AWARDS ARE MADE THROUGH QUARTERLY NOMINATIONS FROM THE DEPARTMENT DIRECTORS AND CHOSEN BY THE OFFICE OF THE PRESIDENT.



Embryology's Zehra Nizami

ZEHRA NIZAMI codiscovered a new class of RNA molecules, called stable intronic sequence (sis) RNA, in amphibian egg cells. It was believed for decades that introns—bits of DNA that scramble the sequence encoding a protein—are "junk" DNA and that their RNA products are usually quickly destroyed in the nucleus during the unscrambling process known as splicing.

Nizami's discovery required exceptional skill in the latest deep-sequencing methodology—which sequences a genomic region hundreds or even thousands of times—coupled with a thorough understanding of cell biology of the giant egg cell of the frog *Xenopus*. Nizami is also known for her outstanding structural analysis of the giant "lampbrush" chromosomes in the egg cells of frogs and salamanders. She applied super-resolution microscopy and genomics-based probing to examine details of the transcription—the first step to turning on a gene—and the splicing of specific genes at the single molecule level. It is a unique approach to chromosome analysis. Nizami has also been heavily involved in educational and community service. Recently she participated in the BioEYES K-12 science education program at Embryology.

Global Ecology's Mary Whelan

MARY WHELAN works on atmospheric trace gas biogeochemistry with an unusual breadth of skills, knowledge, and curiosity. She spends hours of fastidious work on innovative techniques and technology development to measure carbonyl sulfide—which plants consume with carbon dioxide and which can be used to quantify gas flow into plants during photosynthesis. She applies these techniques in the field. Whelan's work has resulted in insights that are novel and were not possible before.

In addition to trying new approaches to her research, Whelan shows an extraordinary knack for collaboration, blending lab work, fieldwork, and modeling that spans multiple domains that most early career scientists can only partly master. Throughout her career, she has been extremely involved in mentoring. She's trained undergraduate research assistants in laboratory-based and field-based gas analyses and was very involved in college educational outreach. At Carnegie, Whelan has been especially successful in assuring that grant and project collaborations go smoothly through her good-natured inclusivity, grace, and humor. She also spearheads many of Carnegie's extracurricular social activities. ■

This algal bloom is in Virginia's Sassafras River.
Image courtesy U.S. Environmental Protection Agency; photo by Eric Vance

"...algal blooms and dead zones in coastal regions across the United States, including the Gulf of Mexico, the Chesapeake Bay, and around Florida have received extensive news coverage"

Rainfall Variation and Nitrogen Runoff Management

New research from two Carnegie Global Ecology scientists has serious implications for management strategies to reduce nutrient runoff in waterways and coastal areas.

Human activities, including agriculture and fossil fuel use, have completely altered the biochemical cycle of nitrogen, where nitrogen circulates in various forms through terrestrial, aquatic, and atmospheric systems. In the United States, the amount of nitrogen originating from human sources, particularly fertilizer, is four times the amount that comes from natural sources. The U.S. Environmental Protection Agency estimates that 28 percent of streams and 20 percent of lakes around the country experience high nitrogen levels.

This is important because, when nitrogen gets into waterways, it can cause harmful, toxin-producing algal blooms. These blooms impact human health, as well as kill fish and other organisms and create dangerous low-oxygen dead zones called hypoxia. Over the past several years, algal blooms and dead zones in coastal regions across the United States, including the Gulf of Mexico, the Chesapeake Bay, and around Florida have received extensive news coverage.

These toxic water events require improved management tools for reducing nitrogen runoff. So Carnegie's Anna Michalak and Eva Sinha developed a modeling tool that provided the first comprehensive estimates of the amount of nitrogen entering U.S. waterways each year over a 20-year period.

Their findings, published in the journal *Environmental Science & Technology*, reveal the complications of developing management strategies to reduce nitrogen runoff.

The straightforward part of their research was mapping the patterns of where nitrogen enters the waterways. Unsurprisingly, this is primarily dependent on where humans deploy nitrogen, especially through fertilizer use. Regions such as the country's Corn Belt clearly stick out.

The complex part was determining what controls the year-to-year fluctuations in nitrogen runoff. Their research showed that year-to-year variability is due primarily to changes in precipitation, and the occurrence of precipitation extremes. Further complicating the issue, the areas where the most nitrogen is being released by human activity are also the most subject to precipitation variability.

"These results mean that although we can control how much nitrogen we apply to soils, the impacts that we observe in a given year are inextricably tied to weather. This makes the design of effective strategies for managing water quality particularly tricky," Michalak said. "There is no doubt that we need to reduce inputs of nitrogen to the environment, but reaping the rewards of these actions may take a while."

"What's more, climate change will likely only exacerbate the management difficulties that our estimates revealed," added Sinha. ■

Carnegie's Anna Michalak (top) and Eva Sinha (bottom) developed a modeling tool that provided the first comprehensive estimates of the amount of nitrogen entering U.S. waterways each year over a 20-year period.
Images courtesy Robin Kempster and Eva Sinha

SUPPORT:
The National Science Foundation supported this work.

NEARLY DOUBLING ANCIENT QUASARS

This artist's rendering shows a very distant quasar.
Image courtesy ESO/M. Kornmesser

Eduardo Bañados is a Carnegie-Princeton Fellow.

A team led by Carnegie's Eduardo Bañados has discovered 63 new quasars from when the universe was only a billion years old. Today, the universe is about 14 billion years old. Quasars are supermassive black holes that sit at the center of enormous galaxies, accreting matter. They shine so brightly that they are often referred to as beacons; they are among the most-distant objects in the universe that we can study.

The result of the team's work is the largest sample of such distant quasars in a single scientific article, almost doubling the number. *The Astrophysical Journal Supplement Series* published their findings.

"Quasars are among the brightest objects and they literally illuminate our knowledge of the early universe," Bañados said.

Until now, the population of known ancient quasars was fairly small, so their study was limited. One of the main challenges is finding these distant, rare objects. Scientists have searched for them for decades, but it's like finding a needle in a haystack.

The quasars discovered by Bañados and his team will provide valuable information from the first billion years after the Big Bang, which is a period of great interest to astronomers.

Here's why: hot matter exploded everywhere after the Big Bang. As protons and electrons coalesced into hydrogen atoms, the universe cooled off. It became dark for a long time. When gravity condensed the matter, these atomic nuclei formed larger structures—perhaps including quasars—and light was able to shine.

There is still a lot about this illuminated era that scientists do not understand. But having more examples of ancient quasars will help them unravel what happened in those first billion years after the Big Bang.

"The formation and evolution of the earliest light sources and structures in the universe is one of the greatest mysteries in astronomy," Bañados said. "Very bright quasars such as the 63 discovered in this study are the best tools for helping us probe the early universe. But until now, conclusive results have been limited by the very small sample size." ■

SUPPORT AND DATA:
A Carnegie-Princeton Fellowship, the European Research Council, the National Science Foundation, and a NASA Hubble Fellowship supported this work. This work includes data obtained from the following telescopes and facilities: Pan-STARRS1 (GPC1), Very Large Telescope:Antu (FORS2), New Technology Telescope (EFOSC2), Large Binocular Telescope (MODS), Max Planck:2.2m (GROND), Magellan: Baade (FIRE), Magellan: Clay (LDSS3), Keck:I (LRIS), Hale (DBSP), Calar Alto Observatory (CAO):3.5m (Omega2000), CAO:2.2m (CAFOS), MMT (SWIRC), and du Pont (Retrocam).

New Leadership at the Giant Magellan Telescope Organization

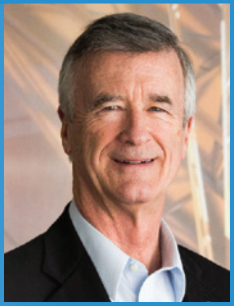
In November 2016, the Giant Magellan Telescope Organization (GMTO) announced the appointments of Walter E. Massey and Taft Armandroff to the positions of board chair and vice chair, respectively. They will guide the GMTO board, oversee the construction of the 24.5-meter Giant Magellan Telescope (GMT) at Carnegie's Las Campanas Observatory in Chile, and work to complete the partnership of universities, research institutions, and private donors who will contribute to the GMT. In January, the GMTO announced that Robert N. Shelton was appointed president of the organization.

Walter E. Massey

With more than 40 years of leadership in science and education, physicist Massey will transition from a member of the board to board chair, where he will supervise the management team and chart the strategy and direction for the organization. Massey brings an expansive portfolio of experience including involvement with the Laser Interferometer Gravitational-Wave Observatory, leader of the National Science Foundation, president and chancellor of the School of the Art Institute of Chicago, and director of the Argonne National Laboratory, among other positions.

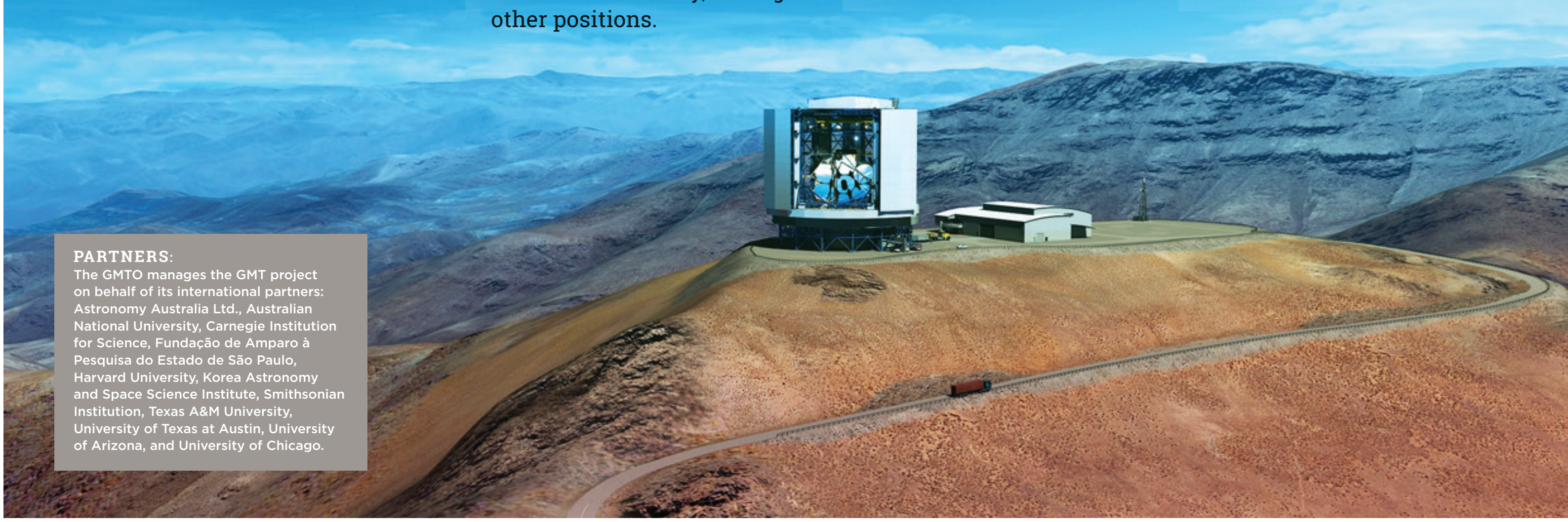
Taft Armandroff

Astronomer Armandroff was director of the University of Texas at Austin's McDonald Observatory and a Professor in the Department of Astronomy. Before that he was director of the W. M. Keck Observatory in Hawaii. Previous to that, he was an astronomer and associate director at the National Optical Astronomy Observatory in Arizona.



Robert Shelton

Physicist Robert Shelton joins the GMTO from the Research Corporation for Science Advancement where he was president. He has been the executive director of the Arizona Sports Foundation, the 19th president of the University of Arizona, and provost and executive vice chancellor of the University of North Carolina at Chapel Hill, among other leadership roles. ■



PARTNERS:
The GMTO manages the GMT project on behalf of its international partners: Astronomy Australia Ltd., Australian National University, Carnegie Institution for Science, Fundação de Amparo à Pesquisa do Estado de São Paulo, Harvard University, Korea Astronomy and Space Science Institute, Smithsonian Institution, Texas A&M University, University of Texas at Austin, University of Arizona, and University of Chicago.

PLANTS SHOW DAY/NIGHT CHANGES IN RESPONSE TO HEAT

Climate change and recent heat waves have put agricultural crops at risk, which means that understanding how plants respond to elevated temperatures is crucial for protecting our environment and food supply.

For many plants, even a small increase in average temperature can profoundly affect their growth and development. In the often-studied mustard plant *Arabidopsis,* elevated temperatures cause the plants to grow longer stems and thinner leaves to cope with heat.

New work, published by *Nature Communications* and led by Carnegie's Zhiyong Wang, uncovers the system by which plants regulate their response to heat differently between daytime and nighttime.

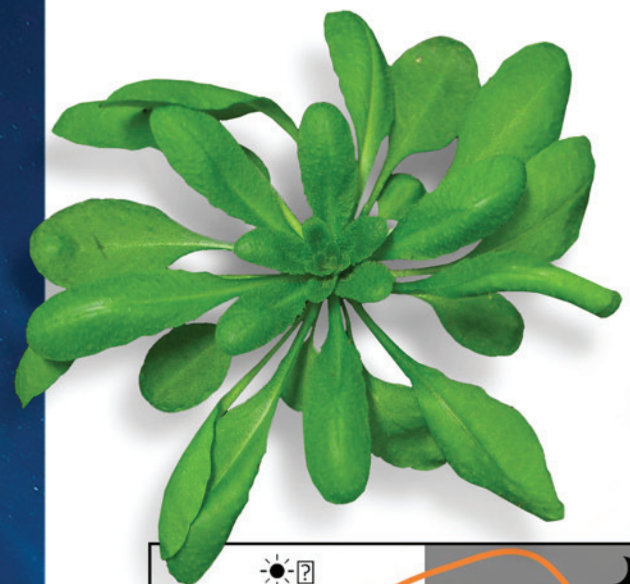
One protein called phytochrome-interacting factor 4 (PIF4) is crucial to coordinating a plant's response to high temperature by activating the genes that help dealing with heat stress. But it only seems to be active during daylight hours. Wang and his team set out to find out why just during the day?

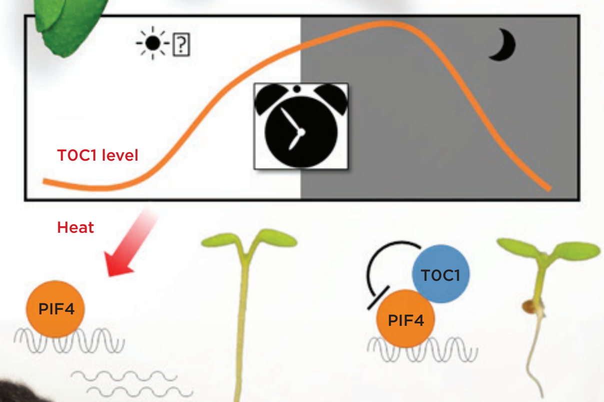
"Until now, how the circadian clock helps a plant's survival of heat stress was unknown."

They found that PIF4 is, in turn, regulated by another protein called timing of CAB expression 1 (TOC1), which is a part of the biological circadian clock proteins that accumulate at the end of the day. TOC1 binds to PIF4 and inhibits its activity in the evening and through the night. The disappearance of TOC1 at dawn allows PIF4 to respond to warm temperature in the morning.

Until now, how the circadian clock helps a plant's survival of heat stress was unknown.

"Since the hottest temperatures usually occur around noon and continue through the early afternoon, a plant's survival during a heat wave is most threatened during this period," Wang explained. "By tying the heat response to the circadian clock, plants maximize their chances of survival during heat waves." ■





Top: The model plant *Arabidopsis Thaliana* is a standard tool for many biological studies.
Image courtesy NIH

Above: This illustration shows how a plant responds to elevated temperatures changes between daytime and nighttime as regulated by the interactions of the proteins PIF4 and TOC1.
Image courtesy Eunkyoo Oh

Zhiyong Wang studies the genetic processes behind many plant functions.
Image courtesy Robin Kempster

SUPPORT:
The U.S. National Institutes of Health, the National Research Foundation of Korea, and the Korean government supported this work.

Carnegie's Vera Rubin Dies

Vera Rubin is shown examining images in 1974.

When Vera Rubin was a teenager, her father, an engineer, helped her build a telescope.
Image courtesy Rubin Family

Renowned astronomer and National Medal of Science awardee Vera Rubin passed away in Princeton, N.J., the evening of December 25, 2016, at the age of 88. Rubin, with collaborator Kent Ford, provided the critical evidence for the existence of dark matter—the invisible material that makes up more than 80% of the mass in the universe. She was a retired staff astronomer at Carnegie's Department of Terrestrial Magnetism in Washington, D.C. The far-reaching media coverage reported on her contributions to astronomy, feminism, and mentoring.

"Vera Rubin was a national treasure as an accomplished astronomer and a wonderful role model for young scientists," remarked Carnegie president Matthew Scott. "We are very saddened by this loss."

Rubin and Ford toppled what we thought we knew about the universe. Their measurements of orbital speeds of stars in galaxies, during the 1960s and 70s, revealed the existence of invisible dark matter. The first inkling of this mysterious material came in 1933 when Swiss astrophysicist Fritz Zwicky of Caltech proposed it. The dark matter study advanced via radio observations by scientists including Morton Roberts and Albert Bosma during the 1970s. But it was not until Rubin and Ford's work that observational evidence for its existence was accepted by the astronomical community.

In the 1960s, Rubin's interest in how stars orbit their galactic centers led her and Ford to study the Andromeda galaxy, M31, a nearby spiral (above right) galaxy. The two scientists wanted to determine the distribution of mass in M31 by looking at the orbital speeds of stars and gas at varying distances from the galactic center. They expected the speeds to conform to Newtonian gravitational theory, whereby an object farther from its central mass orbits slower than those closer in. To their surprise, the scientists found that stars far from the center traveled as fast as those near the center.

After observing dozens more galaxies by the 1970s, Rubin and colleagues found that something other than the visible mass was responsible for the stars' motions. Each spiral galaxy is embedded in a "halo" of dark matter—material that does not emit light and extends beyond the optical galaxy. They found these halos contain 5 to 10 times as much mass as the luminous galaxies.

Besides her remarkable scientific contributions, colleague Neta Bahcall of Princeton University noted, "Vera was an amazing scientist and an amazing human being. A pioneering astronomer, the 'mother' of flat rotation curves and dark matter, a champion of women in science, a mentor and role model to generations of astronomers."

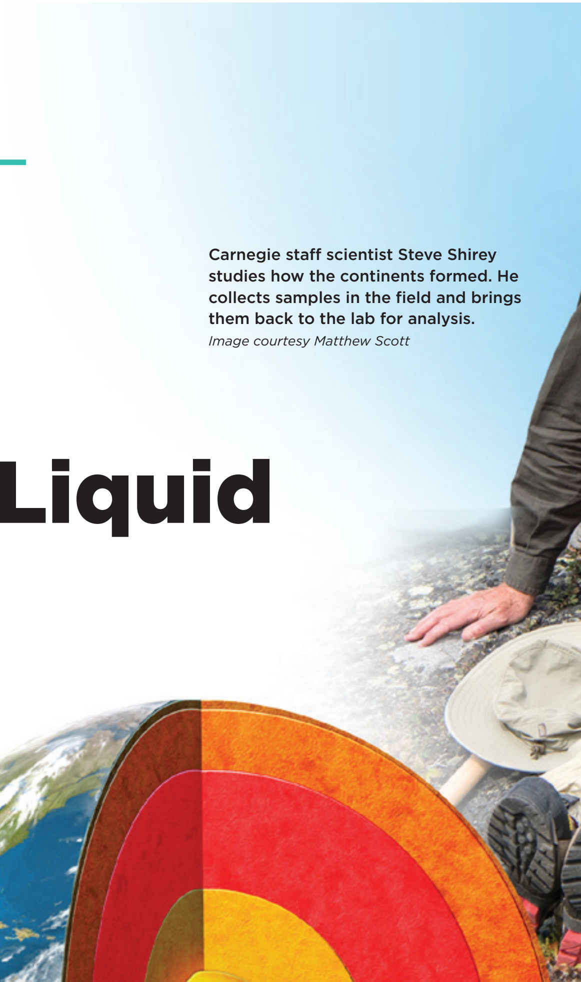
She was an ardent feminist, advocating for women observers at the Palomar Observatory—Rubin was the first woman allowed to observe at the Palomar Observatory—and women at the Cosmos Club and Princeton. She even advised the Pope to have more women on his committee.

Rubin was born July 23, 1928. A Washington, D.C., native, she graduated from Calvin Coolidge High School and went on to receive her B.A. from Vassar College. She obtained her M.A. from Cornell University and her Ph.D. from Georgetown University, where she taught for 10 years. She arrived at Carnegie's Department of Terrestrial Magnetism in 1965.

In 1993 Vera Rubin received the National Medal of Science—the nation's highest scientific award. She was elected to the National Academy of Sciences in 1981, and in 1996 became the first woman to receive the Royal Astronomical Society's Gold Medal since Caroline Hershel, who was awarded the prize in 1828. Rubin's husband Robert J. Rubin, a mathematician and physicist, died in 2008. The couple's four children all acquired Ph.D.'s in the sciences or mathematics. ■

Vera Rubin was awarded the highest scientific honor in the U.S., the National Medal of Science. She accepted the award from then-President Clinton in 1993.
Image courtesy U.S. Government

BIGGEST, Best Diamonds from Deep Mantle Metallic Liquid



Carnegie staff scientist Steve Shirey studies how the continents formed. He collects samples in the field and brings them back to the lab for analysis.

Image courtesy Matthew Scott

New research from a team including Carnegie's Steven Shirey and Jianhua Wang explains how the world's biggest and most-valuable diamonds formed: from metallic liquid deep inside Earth's mantle. *Science* published the findings.

The research team, led by Evan Smith of the Gemological Institute of America, studied large gem diamonds by examining their so-called offcuts, which are the pieces left over after the gem's facets are cut for maximum sparkle. They determined that these diamonds sometimes have tiny metallic grains trapped inside them, called inclusions, that are made up of a mixture of metallic iron and nickel, along with carbon, sulfur, methane, and hydrogen.

These inclusions indicate that the diamonds formed, like all diamonds, in the Earth's mantle, but they did so under conditions in which they were saturated by liquid metal. As unlikely as it sounds, the team's research shows that pure carbon crystalized from this pool of liquid metal to form the large gem diamonds.

Diamonds form deep in the Earth's mantle and shoot to the surface in minor volcanic eruptions of magma. Impurities contained inside diamonds teach geologists about deep Earth chemistry under the pressure, temperature, and chemical conditions in which the diamonds were formed. Diamonds, once formed, protect and shield minerals contained inside their crystal structures, giving scientists a special, protected sample of the mantle mineralogy and a glimpse at conditions miles beneath the planet's surface.

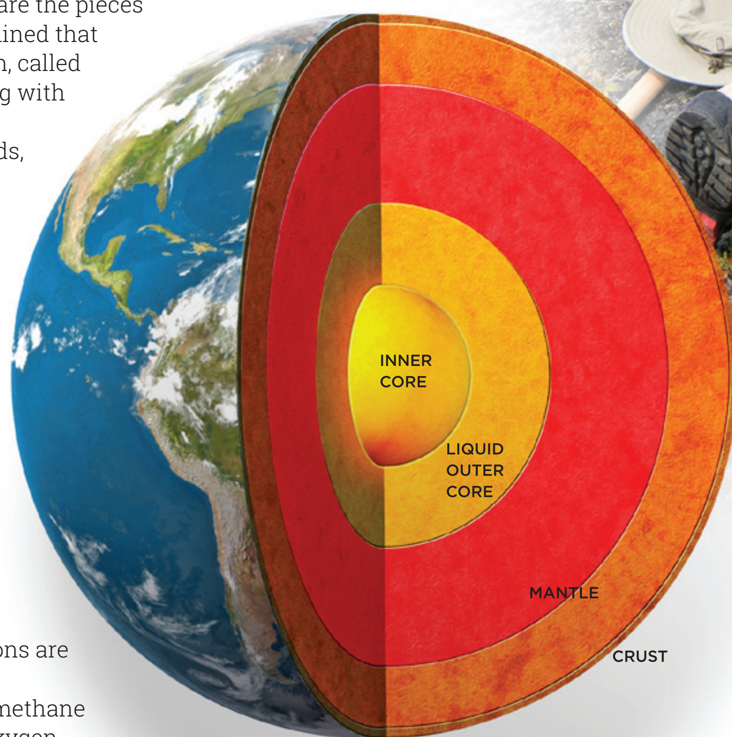
Most diamonds form at depths around 90-150 miles under the continents. But so-called superdeep diamonds form much deeper—at depths below 240 miles. From the team's work analyzing tiny samples of silicate found inside, we now understand for the first time that large gem diamonds are a group of superdeep diamonds. These tiny silicate inclusions are also associated with the metal.

So what do these tiny samples of metal, along with their associated methane and hydrogen, tell scientists about the deep mantle? It tells them about oxygen availability in different parts of the mantle. Near the surface, the mantle chemistry is more oxidized, which scientists can tell from the presence of carbon in the form of carbon dioxide in magmas erupted in volcanoes (among other indications). But deeper down, according to the team's findings, some regions of the mantle are the opposite of oxidized, or reduced, which is what allows the iron-nickel liquid metal to form there.

"The fact that reduced regions can be found in the Earth's mantle has been theoretically predicted, but never before confirmed with actual samples," Shirey explained.

"The existence of this metal mixture has broad implications for understanding deep Earth processes," Smith said.

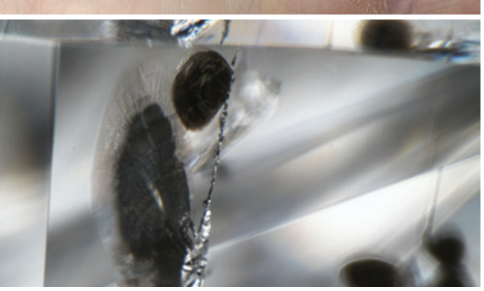
"This result provides a direct link between diamond formation and deep mantle conditions, addressing a key goal of the Deep Carbon Observatory," said Executive Director and Carnegie scientist Robert Hazen. "The fact that it was made possible by a hugely successful collaboration between our Diamonds and Mantle Geodynamics of Carbon group and the Gemological Institute of America is also very exciting, highlighting the importance of academic connections with industry and industry's important role in providing postdoctoral funding and the key specimens for this research." ■



Above: This cutaway diagram shows the layers of the Earth. Diamonds form deep in the Earth's mantle and erupt to the surface via volcanoes. They contain impurities, which act like tiny time capsules telling geologists about deep Earth chemistry under the pressure, temperature, and chemical conditions in which the diamonds were formed.

Right: This assortment of diamond offcuts was used in this study; the largest is 9.6 carats. These diamonds could be analyzed by destructive means (polishing to expose inclusions), whereas many other studied diamonds were polished gemstones that were borrowed and analyzed non-destructively. The impurities, or inclusions of interest, can be seen close up in the image to the right.

Images courtesy Evan Smith



PARTNERS:
The Deep Carbon Observatory, the National Science Foundation, and the European Research Council supported this work.

Carnegie's José Dinneny Selected HHMI-Simons Faculty Scholar

The Howard Hughes Medical Institute (HHMI) and the Simons Foundation have awarded José Dinneny of Carnegie's Department of Plant Biology an HHMI-Simons Faculty Scholar grant. Dinneny is one of 84 scientists chosen out of some 1,400 applicants in a new program that the HHMI, the Simons Foundation, and the Bill & Melinda Gates Foundation have created. The grant will provide $250,000 per year for five years, in addition to overhead expenses, for an award total of $1,500,000.

The award will be funded by the Simons Foundation and administered by HHMI. Faculty Scholars are "early-career researchers who have strong potential to make groundbreaking contributions to the life sciences."

"It's a great honor to be recognized by these important foundations. This award will allow me to pursue my passion to a much greater extent and break into new areas of basic discovery and crop engineering," remarked Dinneny.

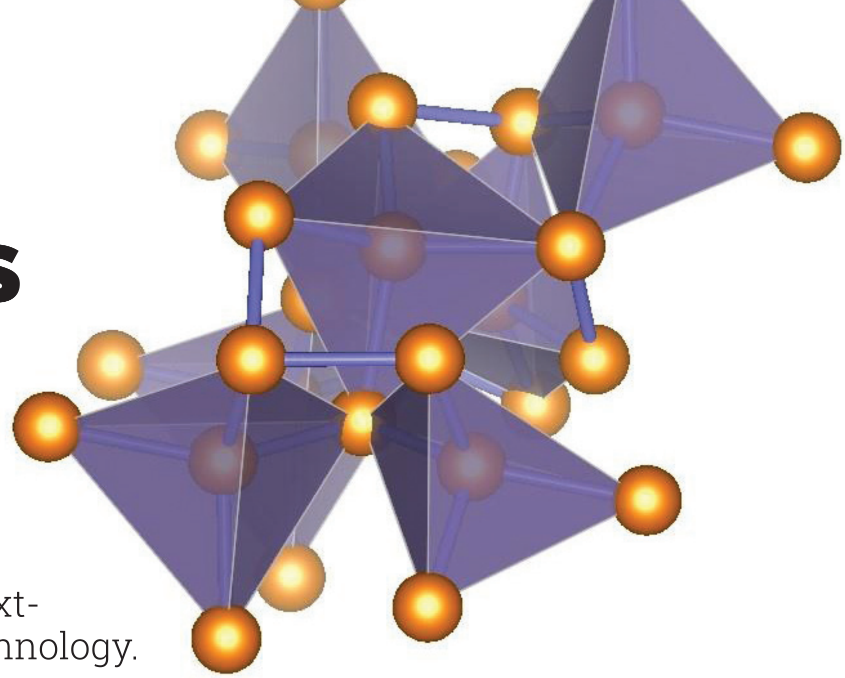
Dinneny looks at the mechanisms plants use to sense water availability in their environment and survive stressful conditions such as drought and salinity. He investigates developmental pathways and molecular genetic mechanisms involved in sculpting the plant to suit the environment. His team has discovered novel adaptive mechanisms used by roots to capture water, and he has invented novel imaging methods for these studies of this system.

"We could not be more excited that José has received this prestigious recognition," remarked Carnegie president Matthew Scott. "He is proof that Andrew Carnegie's original idea—that supporting exceptional and imaginative scientists leads to paradigm-changing discoveries—is a winning and timeless formula." ■

José Dinneny is one of 84 scientists, chosen out of some 1,400 applicants, selected to be an HHMI-Simons Faculty Scholar.
Image courtesy Robin Kempster

"Faculty Scholars are accomplished early career researchers who have strong potential to make groundbreaking contributions to the life sciences."

Germanium's Technology Promise



No, not the flower. Germanium is an element with great potential for next-generation electronics and energy technology.

Some forms of germanium can be synthesized in the lab under extreme pressure conditions. However, one of the most-promising forms of germanium for practical applications, called ST12, has only been created in tiny sample sizes—too small to definitively confirm its properties.

"Attempts to experimentally or theoretically pin down ST12-germanium's characteristics produced extremely varied results, especially in terms of its electrical conductivity," said Zhisheng Zhao, the first author on a new paper about this form of germanium.

The study's research team, led by Carnegie's Timothy Strobel, was able to create ST12-germanium in a sample size large enough to confirm its characteristics and useful properties. *Nature Communications* published their work.

"This work will be of interest to a broad range of readers in the field of materials science, physics, chemistry, and engineering," explained Carnegie's Haidong Zhang, the co-leading author.

ST12-germanium has a tetragonal structure—the name ST12 means "simple tetragonal with 12 atoms." It was created by putting germanium under about 138,000 times normal atmospheric pressure (14 gigapascals) and then decompressing it slowly at room temperature.

The millimeter-sized samples of ST12-germanium that the team created were large enough that they could be studied using a variety of spectroscopic techniques to confirm its long-debated characteristics.

Like the most common, diamond-cubic form of germanium, they found that ST12 is a semiconductor with a so-called indirect band gap. Metallic substances conduct electrical current easily, whereas insulating materials conduct no current at all. Semiconducting materials exhibit mid-range electrical conductivity. When semiconducting materials are subjected to an input of a specific energy, bound electrons can be moved to higher-energy, conducting states. The specific energy required to make this jump to the conducting state is defined as the "band gap." While direct band gap materials can effectively absorb and emit light, indirect band gap materials cannot.

"Our team was able to quantify ST12's optical band gap—where visible light energy can be absorbed by the material—as well as its electrical and thermal properties, which will help define its potential for practical applications," Strobel said. "Our findings indicate that due to the size of its band gap, ST12-germanium may be a better material for infrared detection and imaging technology than the diamond-cubic form of the element already being used for these purposes."

The other Carnegie members of the team were Carnegie's Duck Young Kim and Emma Bullock, as well as Wentao Hu of Yanshan University. ■

The above illustration of ST12-germanium shows the complex tetragonal structure with tetrahedral bonding.
Image courtesy Haidong Zhang

Left: Tim Strobel's lab concentrates on the synthesis and characterization of new materials, particularly those useful to energy and other advanced applications.

Some 100,000 students have participated in the BioEYES outreach effort. Additionally, some 1,300 teachers in six states and two countries (the U.S. and Australia) have been trained to teach the course.
Images courtesy BioEYES

BioEYES

Boosts Science Understanding and Positive Attitudes

A first-of-its-kind study on almost 20,000 K-12 underrepresented public school students shows that Project BioEYES, based at Carnegie's Department of Embryology, is effective at increasing students' science knowledge and positive attitudes about science. Younger students had the greatest attitude changes. The study covered five years and tested students before and after the one-week BioEYES program. *PLOS Biology* published the research.

BioEYES (www.bioeyes.org) uses live zebrafish to teach basic scientific principles, animal development, and genetics. The zebrafish embryo is clear, making it ideal for observations. Each BioEYES center reflects a partnership between local educators, school districts, and cutting-edge scientific laboratories like that of Carnegie scientist Steve Farber, cofounder of the program.

This program empowers students to approach science as a professional scientist would. BioEYES provides scientific equipment and teaches concepts that are relevant to students' lives. In this case, inner-city students learn about the biology of the inheritance of skin color.

Over a week, students collect zebrafish embryos and watch them develop from a single cell to a swimming larva complete with a beating heart and a distinct pigmentation pattern. Elementary students learn about human and fish anatomy, habitats, cells, and DNA. Older students identify the observable traits of their zebrafish offspring or delve into the genetic makeup of parents by studying their offspring. At week's end, students analyze these data and discuss their results.

For the five-year study (2010-2015), the BioEYES team assessed students and teachers before and after a weeklong experiment. They asked knowledge-based questions and questions about their attitudes toward science and scientific careers. All grade levels showed significant positive gains in learning. Seven of the eight knowledge questions had significant positive gains for elementary students.

Interestingly, for all grade levels BioEYES increased students' ability to imagine themselves as scientists. The largest effect on attitudes occurred at the elementary school level—six out of eleven statements showed significant positive changes. Among all grade levels, the strongest attitude shift was in the statement, "I know what it's like to be a scientist."

The second largest attitude change observed in elementary and high school grades, and the third largest in middle school, was an increase in agreement with the statement, "Science is becoming more popular than it used to be."

Farber remarked, "We think educators can leverage this finding in a big way. We know how important popularity is to the social lives of kids. So if the science experience is fun, engaging, and popular, more underserved students could be attracted to the Science, Technology, Engineering, and Math (STEM) fields. It turns out that our efforts in training teachers have made a huge impact," Farber continued. "We see that the program increases their confidence to create innovative and engaging science lessons, which affects many more students beyond BioEYES." ■

PARTNERS:
BioEYES is a joint effort between the Carnegie Institution for Science and the Johns Hopkins University School of Education. Additional centers are located at the University of Pennsylvania, the University of Utah, and Monash University in Melbourne, Australia. The program is funded by grants and gifts with help from the Carnegie Institution's endowment. A complete list of sponsors can be found at the project's website www.bioeyes.org/index.php.

How Fast to ADAPT TO CLIMATE

Carnegie's Ken Caldeira in the field
Image courtesy Ken Caldeira

What would we do differently if sea level were to rise one foot per decade, versus one foot per century? Until now, most policy and research has focused on adapting to specific amounts of climate change and not on how fast that climate change might happen.

CHANGE?

Environmental Research Letters published this research in its October 4, 2016, issue.

Using sea level rise as a case study, researchers at Carnegie's Department of Global Ecology have developed a quantitative model that considers different rates of sea level rise, in addition to economic factors, and shows how consideration of rates of change affect optimal adaptation strategies. If the sea level rises slowly, it could still make sense to build near the shoreline, but if the sea level rises quickly, then a buffer zone along the shoreline might make more sense.

Nearly all of the literature on the damage from climate change and adaptation focuses on amounts of change. But the world is more likely to get progressively warmer, with sea level rise getting progressively higher.

"It is a very different thing to adapt to a sea level that is three feet higher if you think that sea level will rise no farther after that, than to adapt to a sea level rise that is three feet higher with the expectation that the seas will keep rising," remarked Soheil Shayegh, a former Carnegie postdoc and lead author of the study.

The researchers analyzed how the rate of sea level rise affects economic decision making in coastal areas in four scenarios. In the first scenario, there is no adaptation, and people build on land that will be flooded. In the second scenario, people consider some future, specific amount of sea level rise and create a no-build buffer zone prohibiting development along the coast. In the third scenario, people adapt to ongoing rates of change and consider whether buildings are likely to be flooded during their economically productive lifetime. In the last scenario, people try to adapt by protecting themselves with dikes or seawalls.

The researchers calculated the return on investment for each scenario using the discount rate—a measure that investors use to value future income. A high discount rate means investors don't value the future cost as much as if it has a low discount rate.

It makes more sense to build near the coast if buildings don't last very long, because investors are focused on short-term return, and sea level is rising slowly. Durable buildings, low discount rates, and rapid rates of sea level rise would point to building farther from the shoreline. A buffer zone, based on a single amount of sea level rise, fails to make productive use of valuable coastal land. While the dike approach provides only a temporary hold, it could make sense if the dikes could be made cheaply enough.

While the researchers focused on sea level rise, they believe rates of climate change and sea level rise should be taken into account in areas of adaptation of agriculture, buildings, and other sectors. Their study represents a first step in understanding practical approaches to adaptation and that more research is needed to understand and manage the response of both human and natural systems to increased rates of change.

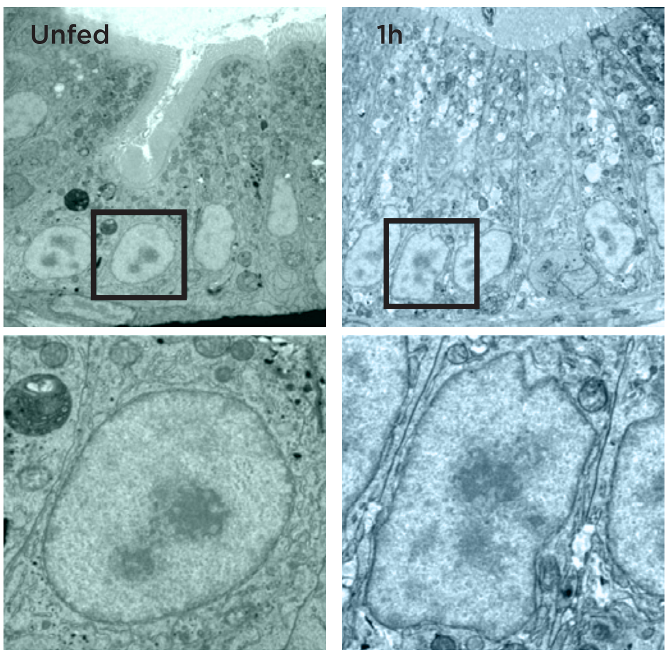
Carnegie's Ken Caldeira said, "Future research on adaptation strategy needs to consider how economic incentives interact with real political systems, so that we might produce better outcomes. Future adaptation strategy needs to think about what the best use of land is, and don't try to fit everything into a 'one size fits all' policy." ■

Top: Humans in coastal areas will have to adapt to rising sea levels from climate change. Researchers at Carnegie's Department of Global Ecology developed a quantitative model that considers different rates of sea level rise, in addition to economic factors, and that shows how consideration of rates of change affect optimal adaptation strategies. The photo shows One Tree Island off Australia.

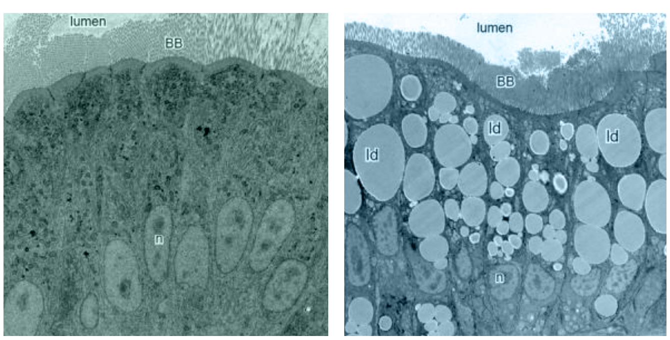
Images courtesy Ken Caldeira

PARTNERS:
A combination of the Fund for Innovative Climate and Energy Research and the Carnegie Institution for Science endowment supported this work.

Gut Cells "Remodel" with Fatty Meal



This is a comparison between an enterocyte cell before (left column) and after (right column) a fatty meal. Specialized enterocytes line the insides of our intestines and grab and absorb nutrients from food as it is digested, including the lipid molecules from fatty foods.



The research team found that fatty food consumption causes the cells that line our intestines to do some interior remodeling. One such shape shift occurs in the nucleus, where the cell's DNA is stored. The team demonstrated that the nucleus takes on a rapid and reversible ruffled appearance (right) after fatty food is consumed.

Images courtesy Steve Farber and Erin Zeituni

SUPPORT:
The National Institute of Diabetes and Digestive and Kidney Diseases, National Institute of General Medicine, and the Zebrafish Functional Genomics Consortium supported this work.

Carnegie's Steve Farber

New work by Carnegie's Steven Farber, with help from Yixian Zheng's lab, sheds light on how form follows function for intestinal cells responding to high-fat foods that are rich in cholesterol and triglycerides. *Journal of Biological Chemistry* published their findings.

Specialized cells called enterocytes line the insides of our intestines. The intestinal surface is like a toothbrush, with lots of grooves and protrusions allowing the cells to grab and absorb nutrients from food, including the lipid molecules from fatty foods. The cells absorb, process, and package these lipids for distribution. They are very important, since lipids are necessary for many of the body's functions, including nutrient absorption and hormone production.

"When we eat fatty foods, our body's response is coordinated between our digestive organs, our nervous system, and the microbes living in our gut," explained Farber. "Our research used zebrafish to focus on one aspect of this system—how intestinal enterocytes respond to a high-fat meal."

It turns out that fatty foods cause enterocyte cells to do some interior remodeling. Different cellular functions are carried out by highly specialized structures called organelles. In enterocytes, several of these organelles undergo shape changes in response to an influx of fats from rich foods. One such shape shift occurs in the nucleus, where the cell's DNA is stored. Farber's team demonstrated that the nucleus takes on a rapid and reversible ruffled appearance after fatty foods are consumed.

This is of interest because a cell's genetic material is housed in the nucleus, where different genes get turned on and off in response to external stimuli, such as the presence of lipids from fatty foods.

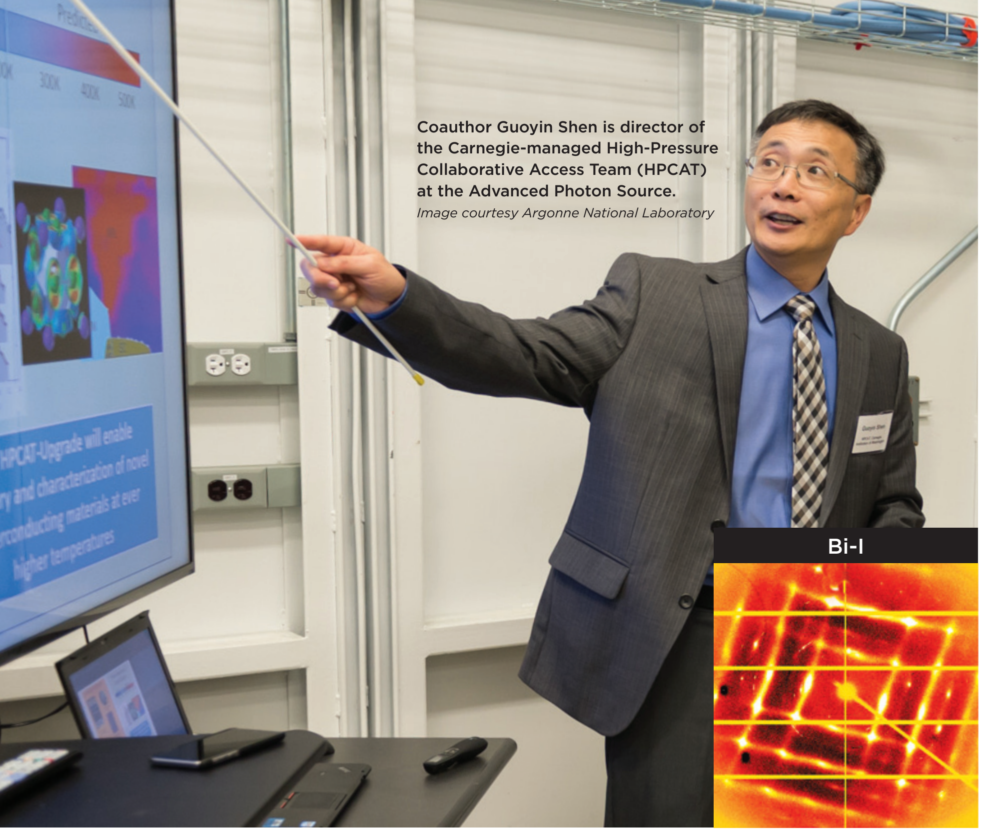
The team examined this issue further and found that the shape shifting in the nucleus coincides with the activation of certain genes that regulate the intestinal cell's ability to package and distribute the lipids to other parts of the body. This activation process occurs within an hour of eating high-fat foods.

"Our working hypothesis is that the whole response to fat in the enterocyte—the remodeling and gene activation—may be coordinated by an organelle called the endoplasmic reticulum," said lead author Erin Zeituni.

The endoplasmic reticulum is an assembly line, where various cellular products are synthesized, stored, and packaged for distribution outside of the cell. It is constructed of a series of interconnected tube-like shapes.

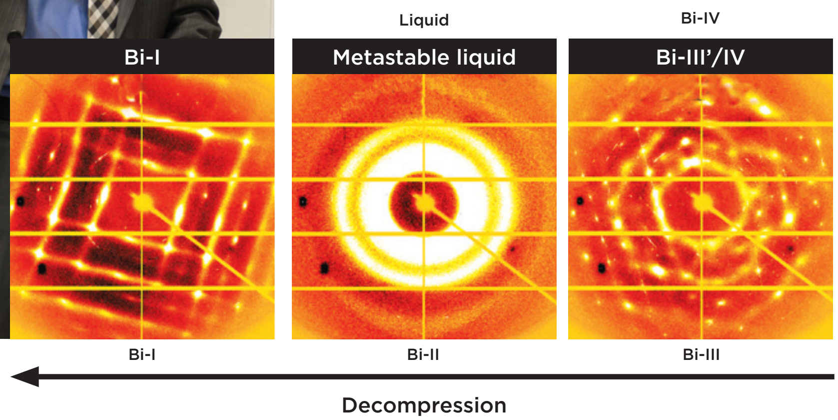
When the team used pharmaceuticals to inhibit one function of the endoplasmic reticulum (the building of so-called lipoprotein particles that will export fats out of the cell), the gene activation process was inhibited for many key genes and nuclear ruffling was altered. This demonstrated that the flux of fat in the endoplasmic reticulum is crucial for initiating the intestinal response to a fatty meal.

"So much of the process by which enterocytes prepare and package fats for distribution to the circulatory and lymphatic system is poorly understood," Farber said. "These findings should help increase our understanding of the basic molecular and cellular biology of intestinal cells." ■



Coauthor Guoyin Shen is director of the Carnegie-managed High-Pressure Collaborative Access Team (HPCAT) at the Advanced Photon Source.
Image courtesy Argonne National Laboratory

When a crystal structure of bismuth (below right) is decompressed from 32,000 atmospheres (3.2 GPa) to 12,000 atmospheres (1.2 GPa) it melts into a liquid at about 23,000 atmospheres (2.3 GPa) (middle). It then recrystallizes at 12,000 atmospheres (left). The so-called metastable liquid produced by this decompression occurs in a pressure-temperature range similar to where the supercooled bismuth is produced. Supercooled liquids are cooled below the freezing point without turning into a solid or a crystal.
Images courtesy Chuanlong Lin and Guoyin Shen



Melting Solid Below the Freezing Point

Phase transitions surround us; liquid water changes to ice when frozen and to steam when boiled, for instance. Carnegie's High-Pressure Collaborative Access Team (HPCAT)* has discovered a new phenomenon of so-called metastability in a liquid phase. A metastable liquid is not quite stable. This state is common in supercooled liquids, which are liquids that cool below the freezing point without turning into a solid or a crystal. These scientists report the first experimental evidence of creating a metastable liquid directly by the opposite approach: melting a high-pressure solid crystal of the metal bismuth via a decompression process below its melting point.

The results, reported in the January 23, 2017, issue of *Nature Communications,* could be important for developing new materials and for understanding the dynamics of planetary interiors, such as earthquakes, because a metastable liquid could act as a lubricant strongly affecting the dynamics of the Earth's interior.

"Phase transitions come in two basic 'flavors,'" explained Carnegie coauthor Guoyin Shen, director of HPCAT at the Advanced Photon Source. "In one type, the chemical bonds do not break as the material goes from one phase to another. But they do alter in orientation and length in an orderly manner. The other, called reconstructive phase transition, is more chaotic, but the most prevalent in nature and the focus of this study. In these transitions, parts of the chemical bonds are broken and the structure changes significantly when it enters a new phase."

Pressure can be used to change the phase of a material in addition to heating and cooling. The scientists put a form of crystalline bismuth in a pressure-inducing diamond anvil cell and subjected it to pressures and decompression ranging from 32,000 times atmospheric pressure (3.2 GPa) to 12,000 atmospheres (1.2 GPa) at a temperature of 420°F (489 K). Under decompression only, at about 23,000 atmospheres, bismuth melts into a liquid. Then at 12,000 atmospheres it recrystallizes.

"The richness in crystalline structure of bismuth is particularly useful for witnessing changes in the structure of a material," remarked lead author Chuanlong Lin.

The researchers imaged the changes using a technique called X-ray diffraction, which uses much higher energy X-rays than those we use for medical imaging and can therefore discern structure at the atomic level. They conducted five different compression/decompression rounds of experiments.

"The bismuth displayed a metastable liquid in the process of solid-solid phase transitions under decompression at about 23,000 to 15,000 atmospheres," Lin said.

The scientists also found that the metastable state can endure for hours below the melting point under static conditions. Interestingly, the metastable liquid produced by decompression occurred in a pressure-temperature range that is similar to where supercooled bismuth is produced

"Because reconstructive phase transitions are the most fundamental type, this research provides a brand new way for understanding how different materials change," Shen said. "It's possible that other materials could display a similar metastable liquid when they undergo reconstructive transitions and that this phenomenon is more prevalent than we thought. The results will no doubt lead to countless surprises in both materials science and planetary science in the coming years." ■

AUTHORS AND SUPPORT:
*Authors on the paper are from Carnegie's Geophysical Laboratory, High-Pressure Collaborative Access Team at Argonne National Laboratory: Chuanlong Lin, Jesse Smith, Stanislav Sinogeikin, Yoshio Kono, Changyong Park, Curtis Kenney-Benson, and Guoyin Shen. The work was performed at the Carnegie Institution for Science and Argonne National Laboratory and is supported by the Department of Energy (DOE)/BES X-ray Scattering Program. HPCAT operation is supported by DOE-NNSA. The Advanced Photon Source is a DOE Office of Science User Facility operated by Argonne National Laboratory under contract no. DE-AC02-06CH11357.

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For details see https:/carnegiescience.edu/events

TUESDAY, MARCH 7, 2017 **6:30PM**
Dr. Pierre Cox - ALMA: In Search of Our Cosmic Origins
Director Atacama Large Millimeter/submillimeter Array (ALMA)
Registration opens February 7 / **#COSMICORIGINS**

THURSDAY, APRIL 6, 2017 **6:30PM**
Dr. Elaine Ostrander - Dog Genes Tell Surprising Tales: Understanding the Genetics of Breed Behavior, Shape, and Disease
Chief, Cancer Genetics and Comparative Genomics,
National Human Genome Institute, National Institutes of Health
Registration opens March 6 / **#DOGGENETICS**

MONDAY, MAY 8, 2017 **6:30PM**
Dr. George Church - Engineering Human Genomes & Environments
Professor, Genetics, Harvard Medical School,
Health Sciences & Technology, Harvard-MIT
Registration opens April 8 / **#GENEDRIVE**

WEDNESDAY, MAY 31, 2017 **6:30PM**
Dr. Diana Roman - When the Volcano Stirs
Staff Scientist, Department of Terrestrial Magnetism, Carnegie Institution for Science
Registration opens May 1 / **#VOLCANOES**

THURSDAY, JUNE 22, 2017 **6:30PM**
Dr. Kwabena Boahen - Neuromorphic Computing
Professor, Bioengineering and Electrical Engineering, Stanford University
Registration opens May 22 / **#BRAINCOMPUTERS**