CarnegieScience

The Newsletter of the Carnegie Institution for Science

SUMMER 2017

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

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CARNEGIE SCIENCE

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Democratizing Science Through Plain Language

One of my college professors told a story of trying to teach a complex idea about neuroscience. His students did not understand: a sea of blank faces. He tried again, using a different approach. Still blank. He tried a third time, with a new metaphor, and smiles spread as he got through. “At that moment,” he said, “I finally understood what I was talking about.” Teaching and sharing ideas with people who do not have your expertise can be revelatory, as your own ideas and perspective change by the work of communication.

The March for Science included (page 7) many people who are not scientists. Some had been patients whose lives had been improved or saved (or started!) due to scientific advances. Some were friends or family of scientists. Others were there to celebrate advantages science and technology have given our country, and other countries, through economic and security impacts. Teachers marched to celebrate the careers their students would one day have, perhaps in fields not yet invented, benefitting from training in logical analysis, symbolic language, and critical thinking.

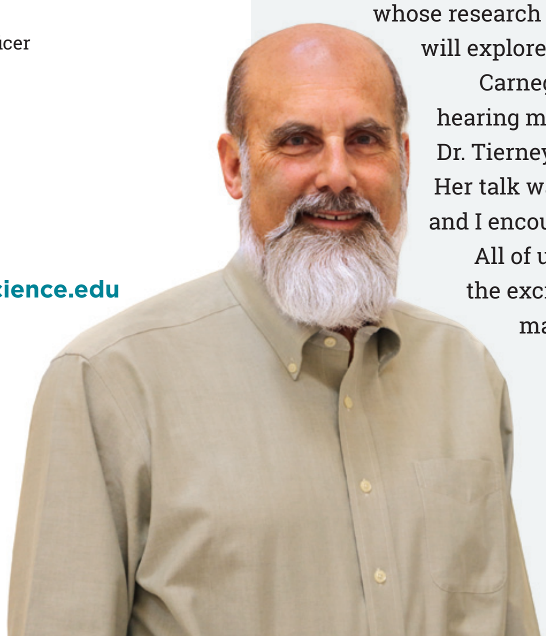
Marching on April 22 was an interdisciplinary project. Many marching Carnegie researchers talked with nonscientists about what we do. It’s fun—it makes you dig down to extract the essentials: why the field is fascinating, what are the questions, how is the work done, and what can be expected to come from it? Above all, what’s amazing? Every one of our fields of Space, Earth, and Life has been and will continue to be a source of wonder. I am trained as a bench biologist. Ever since I was appointed president of Carnegie Science in 2014, I’ve had a steep learning curve in astronomy, earth and planetary science, global ecology, materials science, and high-pressure/high-temperature physics. Continuous learning from our scientists: what a joy.

That joy must be shared. It is vital that we scientists connect to the public who supports us. We must explain science in plain language so everyone understands how discovery research is tied to everyday lives, and how it supports an improved standard of living.

Carnegie has hosted lectures, including the Capital Science Evenings, for over 20 years. They are geared to the general public. We are intensifying this outreach. In one area, we have embarked on a new series called “Science & Society,” with generous support from the Carnegie Corporation of New York. In the first program, Carnegie researchers and colleagues discussed earthquakes, volcanoes, and hurricanes; in the second, researchers whose research ranges from subcellular biology to planets around distant stars will explore the origins of life.

Carnegie trustees, directors, and guests recently had the pleasure of hearing marine biologist, science educator, filmmaker, and TED lecturer Dr. Tierney Thys discuss the challenges and joys of communicating science. Her talk was inspirational. It is time to redouble our efforts in this regard, and I encourage you to take up this important mantle.

All of us at Carnegie reach out to friends, family, and the public to explain the excitement and promise of what we do. On days when we succeed, maybe, we will finally understand what we are talking about.



Matthew Scott, *President*

TRUSTEE NEWS

Trustees Elect Pamela Matson and David Thompson to the Board

The Carnegie board of trustees unanimously elected Pamela Matson and David Thompson to join the board at the May Board of Trustees meeting. Pamela Matson was appointed the Chester Naramore Dean of the School of Earth, Energy & Environmental Sciences at Stanford University in December 2002. She will step down from that position December 31, but will continue as the Richard and Rhoda Goldman Professor of Environmental Studies and a senior fellow of the Woods Institute for the Environment. Matson is world renowned for her work in biogeochemical cycling and biosphere-atmosphere interactions in tropical forests and agricultural systems. Her objective is to identify economically and environmentally sustainable practices.

David Thompson is president and chief executive officer of Orbital ATK, a multi-billion-dollar global aerospace and defense technologies company that employs some 12,500 employees. Thompson cofounded that company's predecessor, Orbital Sciences Corporation, in 1982 and served as the company's chairman, president, and chief executive officer. Orbital Sciences developed and deployed small- and medium-class space and rocket systems for scientific, defense, and commercial customers. In 2013, it successfully completed a supply run to the International Space Station as part of a NASA contract.

Former Carnegie president and trustee Maxine Singer, in addition to Gary Ernst, were voted as trustees emeriti at the same meeting. ■

Sandra Faber

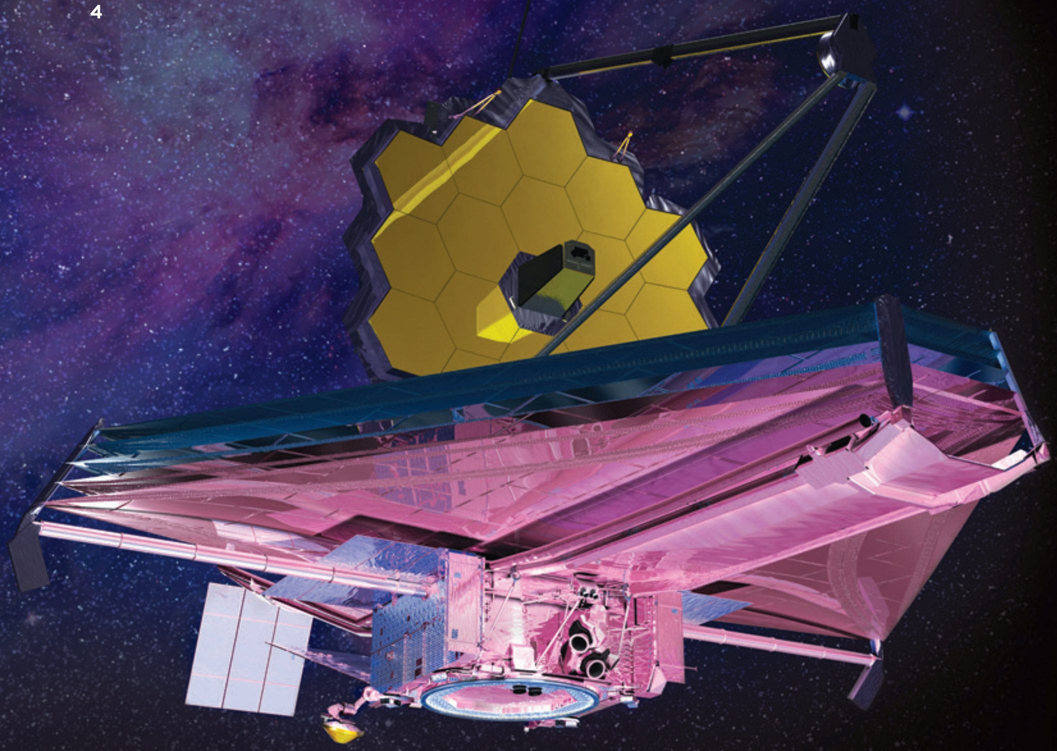
Carnegie Trustee Sandra Faber Awarded Gruber Prize

Former Carnegie fellow and current trustee, astronomer Sandra Faber has been awarded the 2017 Gruber Foundation Cosmology Prize. She was awarded the lifetime achievement award for "her groundbreaking studies of the structure, dynamics, and evolution of galaxies." Her work provided an impetus to study dark matter, the invisible material that makes up most of the mass of the universe. She was additionally lauded for "the recognition that black holes reside at the heart of most large galaxies."

Faber also has a long history of contributing to innovative telescope technology, and she has "aided and inspired the work of astronomers and cosmologists worldwide."

The prize will be awarded this fall and it comes with $500,000 and a gold medal. ■

The Carnegie trustees met at the Broad Branch Road campus for the May meetings and learned about current research at a poster session. ■



The 1994/1995 study, chaired by Carnegie's Alan Dressler, was the "most influential activity that led directly to the development of NASA's premier space observatory of the early 21st century, the James Webb Space Telescope." An artist's rendition of the space-based, infrared telescope is shown left. It is scheduled for launch in late 2018. *Image courtesy NASA*

(Below) Carnegie's Alan Dressler chaired the committee that was awarded the Sagan Award in March. *Image courtesy Tim Neighbors*

Sagan Award Goes to Committee Chaired by Carnegie's Alan Dressler

Over 20 years ago, Carnegie astronomer emeritus Alan Dressler chaired the Association of Universities for Research in Astronomy (AURA) Hubble Space Telescope (HST) and Beyond Committee. This committee was awarded the 2017 Carl Sagan Memorial Award presented at the March meeting of the American Astronautical Society in Greenbelt, Maryland.

In the mid-1990s, the committee was tasked with determining the best goals to pursue beyond the HST's useful life. They determined that the HST should be operated longer than originally scheduled and that NASA should develop a large aperture infrared space telescope and the capacity for space interferometry—a method to measure the interference of different waves for highly accurate results.

The award stated that "the 1994/1995 study and subsequent published report is widely recognized as the original and most influential activity that led directly to the development of NASA's premier space observatory of the early 21st century, the James Webb Space Telescope."

"What is most gratifying to me is that people remember and point to the passionate tone of the HST & Beyond Report, the theme of 'origins,' and the emphasis on 'sharing the journey with the public,'" remarked Dressler. "These were all innovative for such a report, where the traditional presentation was almost exclusively science in its most objective practice."

The Sagan award is given to a person or team "who has demonstrated leadership in research or policies advancing exploration of the Cosmos."

Dressler studies galaxy evolution, the changes in galaxy structure and form, and the pace and nature of star birth. He further remarked, "Our report has had substantial impact on the direction of NASA astrophysics over the last 20 years. I think of it as one of the high points of my career."

"Although Carnegie astronomers are a small group, awards like this one show that our level of influence in the astronomical community is remarkably large."

Carnegie Observatories director John Mulchaey said, "Although Carnegie astronomers are a small group, awards like this one show that our level of influence in the astronomical community is remarkably large. Congratulations to Alan and this group on this prestigious honor." ■

The Association of Universities for Research in Astronomy (AURA), a nonprofit organization, operates the Space Telescope Science Institute under contract for the National Aeronautics and Space Administration.

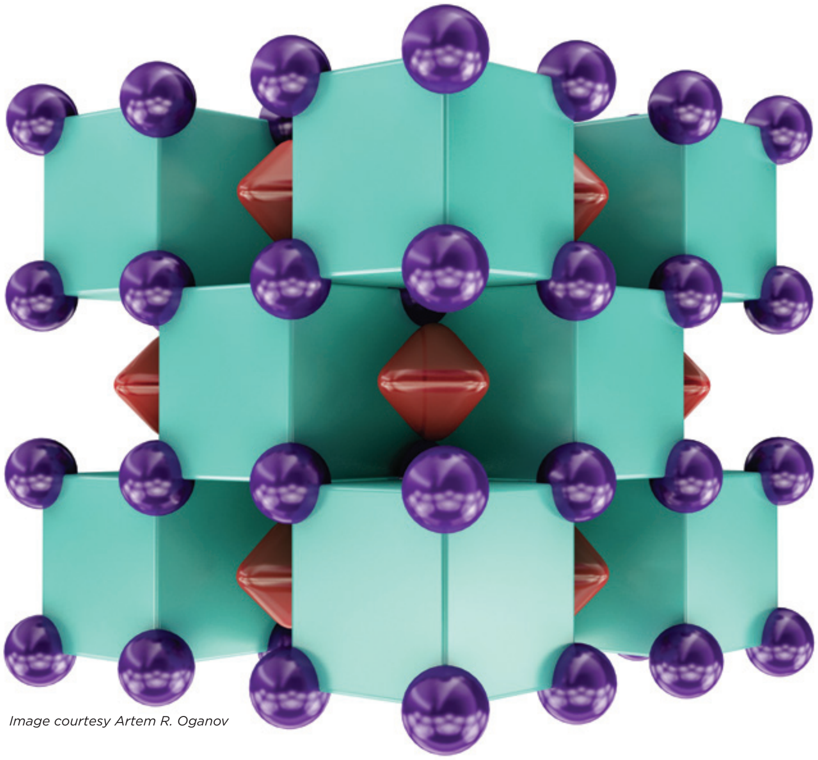


Image courtesy Artem R. Oganov

(Left) The crystal structure of Na_2He resembles a three-dimensional checkerboard. The purple spheres represent sodium atoms, which are inside the green cubes that represent helium atoms. The dark red regions inside voids of the structure show areas where localized electron pairs reside.

Carnegie's Alexander Goncharov

Peculiar Helium Chemistry

"The compound that we discovered is very peculiar: helium atoms do not actually form any chemical bonds, yet their presence fundamentally changes chemical interactions..."

Helium is the second most-abundant element (after hydrogen) in the universe, but it doesn't play well with others. It is a member of a family of seven elements called the noble gases, which are chemically aloof and don't easily form compounds with other elements. Under normal conditions, helium, widely believed to be the most inert element, has no stable compounds.

An international research team led by Skoltech's Artem R. Oganov (a professor at Stony Brook University and head of Computational Materials Discovery Laboratory at Moscow Institute of Physics and Technology) has predicted two stable helium compounds—Na_2He and Na_2HeO. The scientists experimentally confirmed and theoretically explained the stability of Na_2He. This work could hold clues about the chemistry occurring inside gas giant planets and possibly even stars. *Nature Chemistry* published the work.

The authors of the study used a predicting tool of crystal structure, the first-principles evolutionary algorithm called USPEX. First principles begins with assumptions about fundamental properties of a substance of interest. Using this approach the team conducted a systematic search for stable helium compounds. They predicted the existence of Na_2He.

Alexander Goncharov and his colleagues Elissaios Stavrou and Sergey Lobanov successfully synthesized the compound in a diamond anvil cell at Carnegie. The compound appeared at pressures of about 1.1 million times Earth's atmospheric pressure and is predicted to be stable to at least 10 million times that pressure.

"The compound that we discovered is very peculiar: helium atoms do not actually form any chemical bonds, yet their presence fundamentally changes chemical interactions between sodium atoms, forces electrons to localize inside cubic voids of the structure, and makes this material insulating," says Xiao Dong, the first author of this work, who was a visiting student in Oganov's laboratory when this work was done.

Na_2He is what's called an electride, which is a special type of an ionic salt-like crystal. It has a positively charged sublattice of sodium ions and another negatively charged sublattice formed of localized electron pairs. Because electrons are strongly localized, this material is an insulator; it cannot conduct the free-flowing electrons of an electric current.

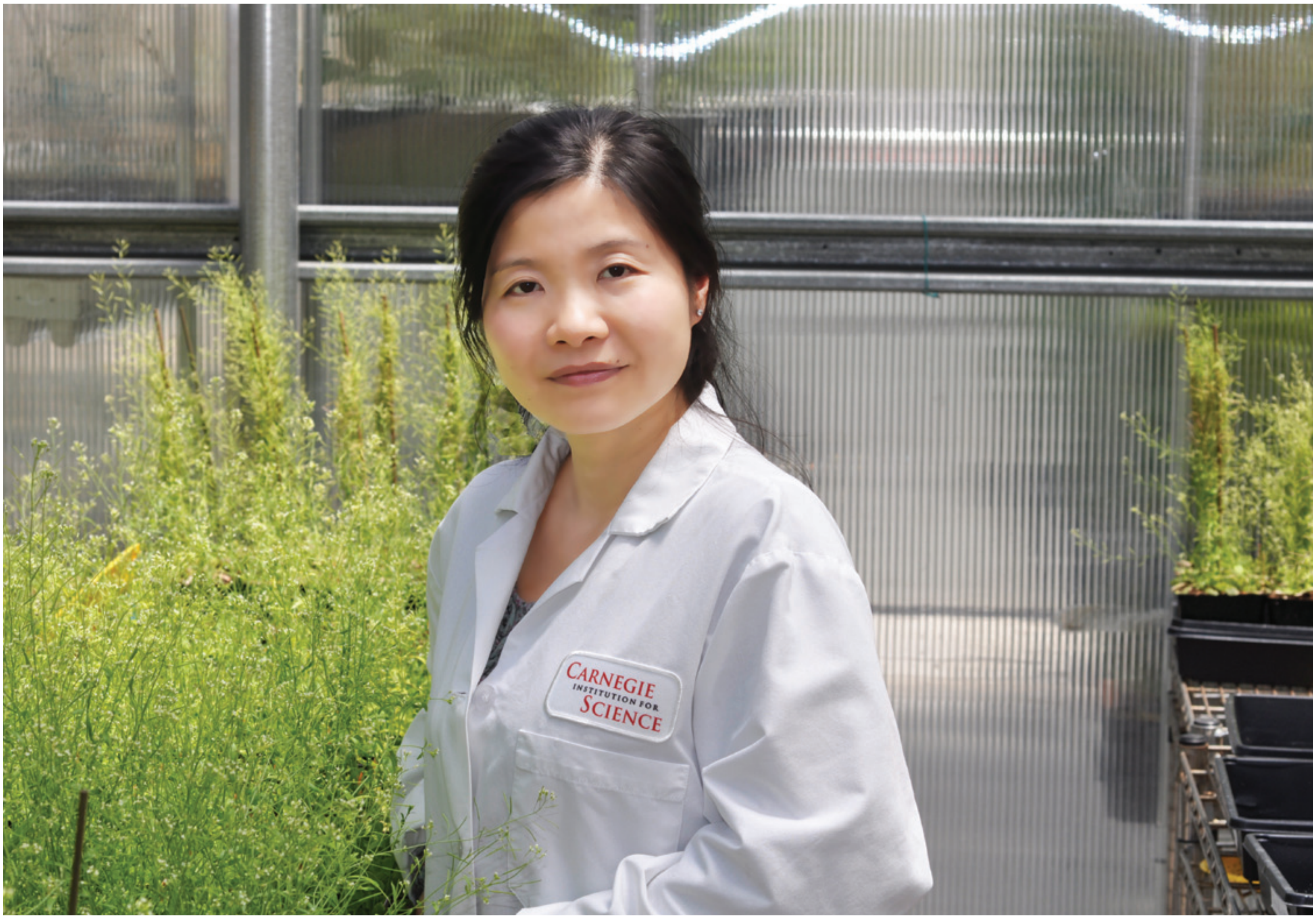
The other predicted helium compound, Na_2HeO, was found to be stable in the pressure range from 0.15 to 1.1 million atmospheres. It is also an ionic crystal with a structure similar to that of Na_2He. However, in place of electron pairs, it has negatively charged oxygen in the form of O^{2-}.

"This study shows how new surprising phenomena can be discovered by the combination of powerful theoretical methods and state-of-the-art experiments. It shows that very weird chemical phenomena and compounds can emerge at extreme conditions, and the role of such phenomena inside planets needs to be explored," says Oganov. ■

SUPPORT AND FACILITIES

The China Scholarship Council, the NSAF, the U.S. National Science Foundation (NSF), DARPA, the Russian Science Foundation, the Foreign Talents Introduction and Academic Exchange Program, the National Science Foundation of China, the Program for New Century Excellent Talents in University, the European Community's Seventh Framework Programme, the U.S. Department of Energy (DOE), the National Natural Science Foundation of China, and the Chinese Academy of Sciences supported this work.

Calculations were performed at the Tianhe II supercomputer in Guangzhou and the supercomputer of the Center for Functional Nanomaterials, Brookhaven National Laboratory, which is supported by the DOE's Office of Basic Energy Sciences. GeoSoilEnviroCARS is supported by NSF's Earth Sciences and DOE's Geosciences. The DOE Office of Basic Energy Sciences supported the use of the Advanced Photon Source. PETRA III at DESY is a member of the Helmholtz Association (HGF).



Plant Biology's Jia-Ying Zhu

Plant Biology's Jia-Ying Zhu Receives Sixth Postdoctoral Innovation and Excellence (PIE) Award

Plant Biology postdoctoral research associate since 2012, Jia-Ying Zhu, was awarded the sixth PIE award for her creativity, productivity, and being a great team player in research and "also an active and caring member of the Carnegie Department of Plant Biology (DPB) community."

The Postdoctoral Innovation and Excellence Awards are made through nominations from the department directors and are chosen by the Office of the President. They recognize exemplary accomplishments in science, education, and community service and come with a prize of $1,000. Awardees are guests of honor at a departmental gathering with celebratory pies.

As a member of the Wang lab, Jia-Ying has made many innovative contributions to our understanding of the molecular mechanisms that control plant growth according to hormonal, nutritional, and environmental conditions. She has conducted several studies that elegantly answer the long-standing question of how multiple hormonal and environmental signals co-regulate cell elongation and growth in response to light and temperature.

In addition to her exceptional science, Jia-Ying is always willing to go above and beyond the call of duty to help her colleagues and to mentor students. She is a member of the Carnegie Institution Postdoc Association Council, and she joins in the planning and organization of postdoc social activities, the department retreat, and holiday parties. She was also a volunteer for *Fascination of Plants Day* at Plant Biology.

Carnegie President Matthew Scott remarked, "Jia-Ying is not only an exemplary member of Plant Biology; she represents a level of excellence and community service that Carnegie postdoctoral researchers have become known for. We congratulate her on her accomplishments." ■

After a group shot on the steps of the Carnegie administration building (above left), guests made their way to the National Mall to listen to March for Science speakers and show their support.

Carnegie Scientists March *for* Science!

Despite a drizzly start to the early morning, the breakfast hosted by Carnegie for the March for Science event on April 22 in Washington, D.C., had a strong turnout. Carnegie, an official supporter for the march, hosted the 7 a.m. breakfast for Carnegie researchers and other staff and guests from the Geophysical Laboratory, Terrestrial Magnetism, and Embryology. Numerous others from out of the region also attended.

Scientific Programs & Outreach Manager, Dione (Dee) Rossiter, planned and executed the weekend's events. In addition to eating breakfast, participants had a lot of fun creating posters for the march.

Images courtesy Mike Colella

Poster-making supplies encouraged creativity as participants expressed their opinions about the importance of science. Carnegie President Matt Scott (image above, on right) admires Larry Nittler's poster hat (left).

Scientific Programs & Outreach Manager Dee Rossiter organized the weekend's March for Science events. She holds Science Deputy Margaret Moerchen's daughter.

PLANTS HELP OFFSET CLIMATE CHANGE, BUT NOT ENOUGH

Plants are currently removing more CO_2 from the air than they did 200 years ago, according to new work from Carnegie's Joe Berry, through a study led by J. Elliott Campbell of the University of California, Merced. The team's findings, published in *Nature*, affirm estimates used in models from the Intergovernmental Panel on Climate Change (IPCC).

Plants take up carbon dioxide as part of photosynthesis—the series of cellular reactions that transform the Sun's energy into chemical energy for food. This new research constructs a new history of global changes in photosynthetic activity.

Just as plants in glass greenhouses grow faster and more profusely when provided with elevated levels of CO_2, plants in natural ecosystems have been expected to grow faster as the concentration of CO_2 in the global atmosphere increases. At the global scale, this effect could offer some stability to the climate system by countering increased human emissions of CO_2.

The magnitude of this effect is currently under debate. Could it be as large at the global scale as it is in small-scale greenhouse experiments? Or are other factors limiting the global system's response to increased greenhouse gas emissions? A long-term record, similar to what we have for CO_2 and temperature, is needed to address this large uncertainty in climate change projections.

The concentration of the atmospheric trace gas carbonyl sulfide is influenced by Earth's photosynthetic activity, as shown by this artist's conceptual rendition. Its variation over centuries is preserved in Antarctic snow and ice, which provides insight into the response of key processes to climate and environmental change. The results of the study show that global photosynthesis was stable for hundreds of years before the industrial revolution, but then grew rapidly throughout the 20th century.
Image courtesy University of California, Merced

"We've done something new here," Campbell said. "Reliable measurements of photosynthesis are typically made at the leaf-level. But you can't get the big picture that way, and we need to know what the Earth as a whole is doing and how it has responded through time."

The team made use of previous work showing that the concentration of the atmospheric trace gas carbonyl sulfide can be used to infer the level of global photosynthesis. They constructed a history of its concentration using air trapped in Antarctic ice and snowpack for centuries, infrared spectra of the atmosphere taken by astronomers since the 1970s, and data from a National Oceanic and Atmospheric Administration greenhouse gas sampling network, which began monitoring carbonyl sulfide in the late 1990s.

The results show that global photosynthesis was stable for hundreds of years before the industrial revolution, but then grew rapidly throughout the 20th century. The recent increases in photosynthesis correlate with the increases in atmospheric carbon dioxide due to fossil fuel burning.

Joe Berry, Acting Director of Global Ecology

"The phenomenon of plants pulling carbon dioxide out of the air has been included in climate change models for many years," Berry explained, "but it has always been difficult to know whether the strength of this effect is being modeled in a realistic way. Our new results affirm that the range of models used in the last IPCC assessment did, in fact, include realistic estimates of the sensitivity of global photosynthesis to CO_2."

"It may be tempting to interpret these results as evidence that Earth's dynamics are responding in a way that will naturally stabilize CO_2 concentrations and climate," Berry added. "But the real message is that the increase in photosynthesis has not been large enough to compensate for the burning of fossil fuels. Nature's brakes are not up to the job. So now it's up to us to figure out how to reduce the CO_2 concentration in the atmosphere." ■

COAUTHORS AND SUPPORT
The paper's other coauthors are Ulli Seibt of UCLA; Steve Smith of the Pacific Northwest National Laboratory; Steve Montzka of National Oceanic and Atmospheric Administration (NOAA); Thomas Launois, Sauveur Belviso, and Laurent Bopp of Laboratoire des Sciences du Climat et de l'Environnement; and Marko Laine of the Finnish Meteorological Institute. The U.S. Department of Energy, NOAA, and the Academy of Finland supported this work.

Carnegie Wins Grant for Prominent Geophysicist's Archives

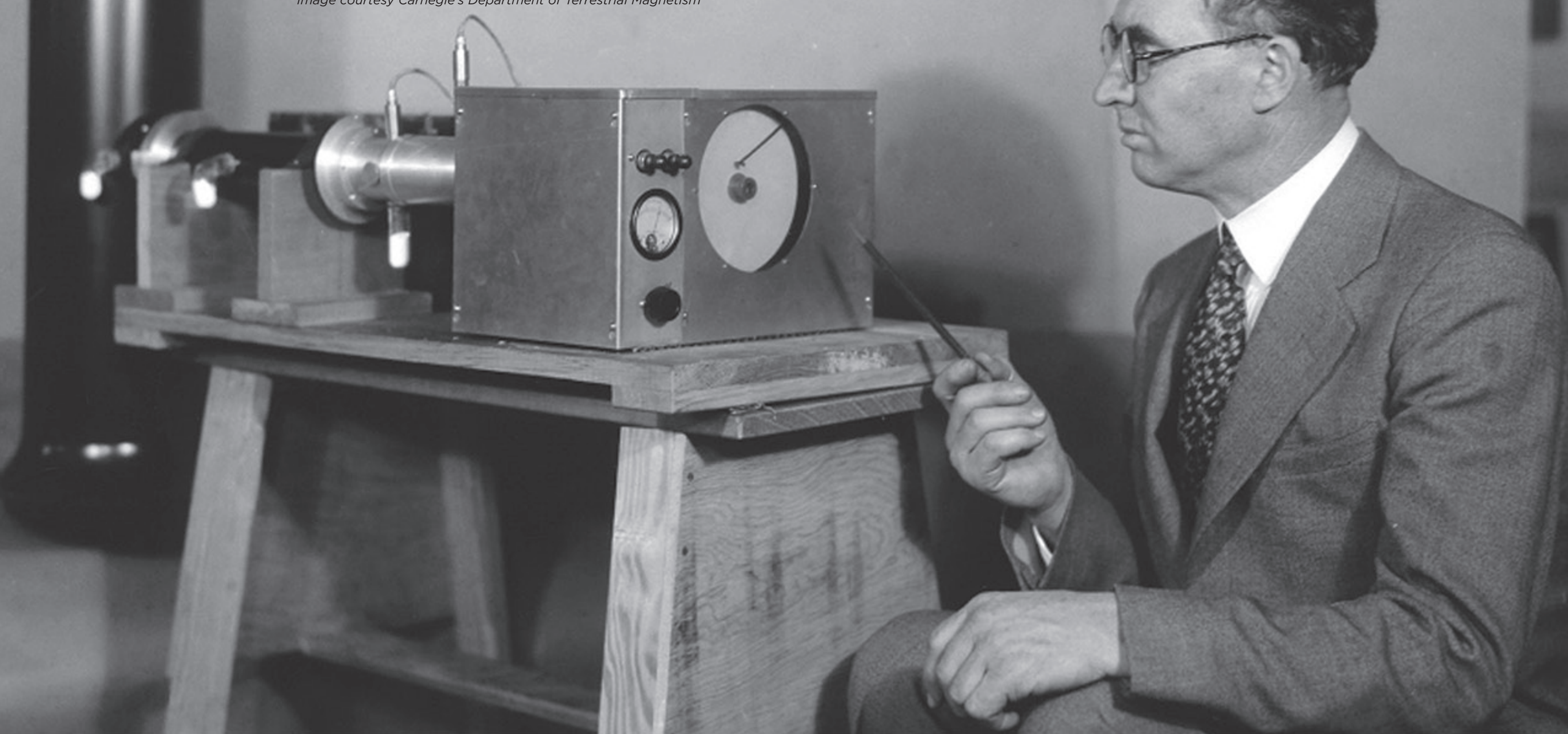
The American Institute of Physics' Center for History of Physics awarded Carnegie a $10,000 grant to organize, preserve, and make available the archives of scientist Oliver H. Gish. A website will showcase the work.

Gish was a prominent figure in American geophysics in the early 20th century and an authority on atmospheric and terrestrial electricity. He was a staff scientist at Carnegie's Department of Terrestrial Magnetism between 1922 and 1948. He also worked in academia, industry, and government research. His papers are in the department's archives.

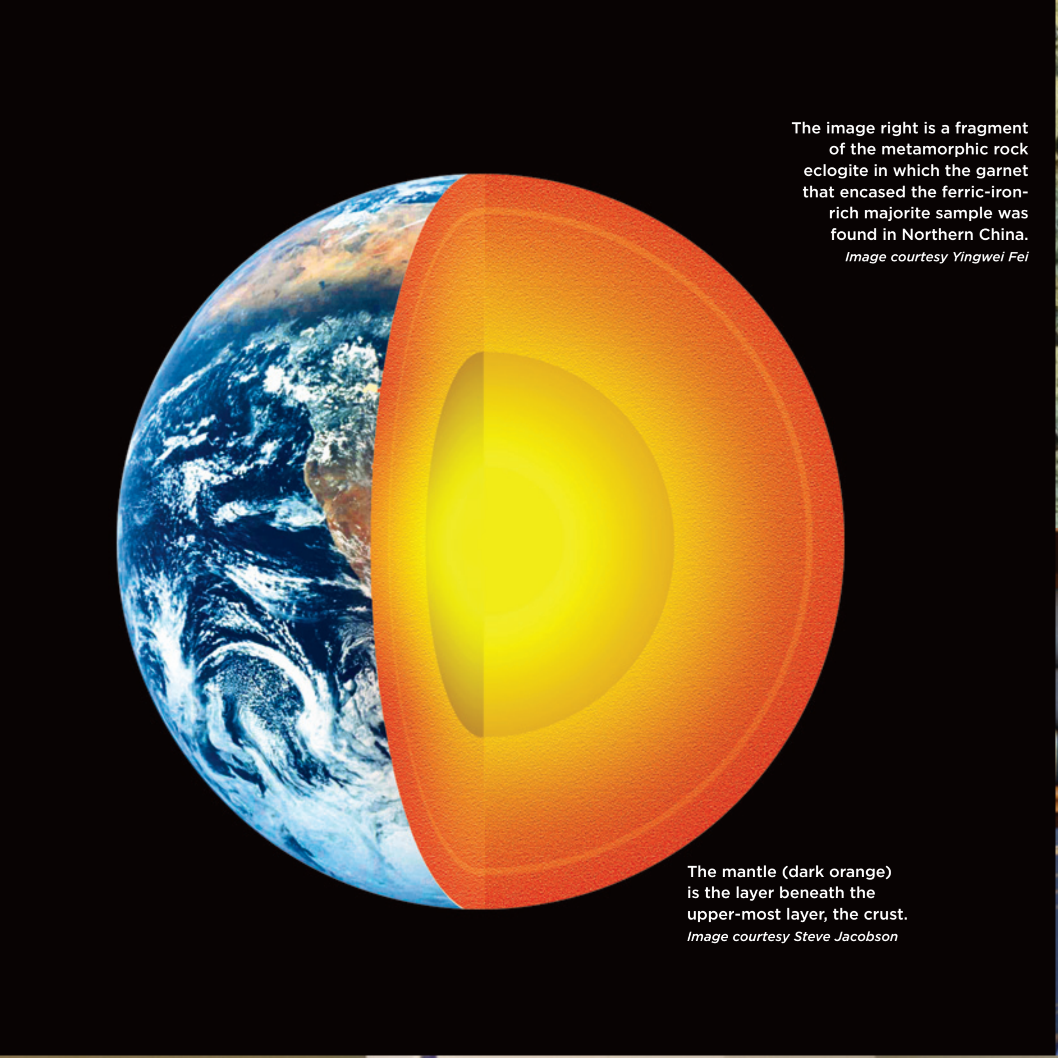
Gish conducted some of the first cosmic ray research in the United States during World War I. At Carnegie, he designed and built instruments for the *Explorer II* manned balloon flight into the stratosphere in 1935. In the 1940s, Gish and collaborator George R. Wait led a pioneering, joint Carnegie–U.S. Air Force investigation of the electrical fields in thunderstorms using instruments mounted on B-29 bombers. He also contributed to our understanding of magnetic storms and the daily variation of the geomagnetic field.

Gish died in 1987 at the age of 103. His extensive files were donated to the department in 2015 by his granddaughters, Nancy R. Crow and Dorothy C. Crow-Willard. ■

Explorer II is ready for launch.
Image courtesy Library of Congress

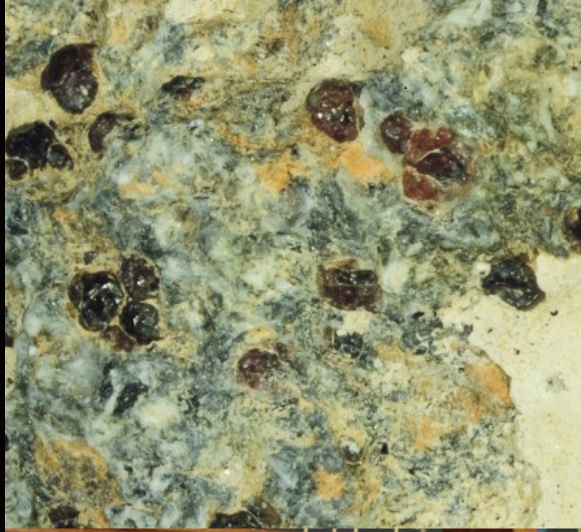


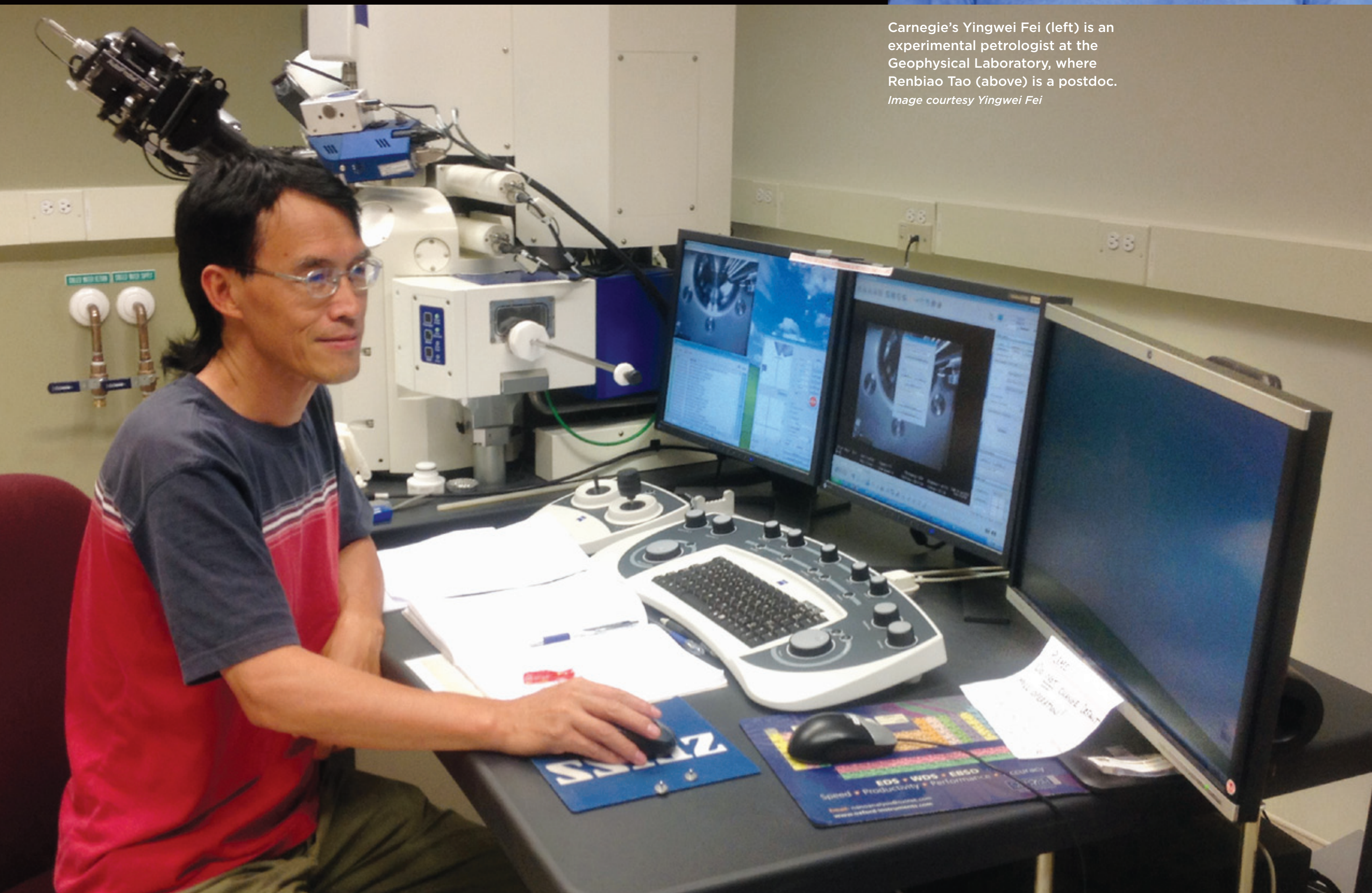
Oliver H. Gish sits with his electrical conductivity apparatus for the *Explorer II* manned balloon flight into the stratosphere in 1935.
Image courtesy Carnegie's Department of Terrestrial Magnetism



The image right is a fragment of the metamorphic rock eclogite in which the garnet that encased the ferric-iron-rich majorite sample was found in Northern China.
Image courtesy Yingwei Fei

The mantle (dark orange) is the layer beneath the upper-most layer, the crust.
Image courtesy Steve Jacobson





Carnegie's Yingwei Fei (left) is an experimental petrologist at the Geophysical Laboratory, where Renbiao Tao (above) is a postdoc.
Image courtesy Yingwei Fei

Nesting Doll Minerals and Earth's Mantle

Minerals from Earth's deep mantle can give scientists glimpses into the dynamic processes deep inside of the Earth and into the history of the planet's mantle layer. A team led by Carnegie's Yingwei Fei and Cheng Xu, a field geologist from Peking University, has discovered that a rare sample of the mineral majorite, a type of garnet, originated at least 235 miles (378 kilometers) below Earth's surface. *Science Advances* published their findings.

Majorite forms only at depths greater than 100 miles (160 kilometers). Fascinatingly, the majorite sample Fei's team found in Northern China was *encased* inside a regular garnet—like a mineralogical nesting doll. It was brought to surface as an eclogite xenolith—a rock fragment inside another rock—in the North China Craton, one of the oldest cratonic blocks in the world. Cratons are the ancient, stable interior parts of continent crust. What's more, the majorite was rich in ferric iron, an oxidized form of iron, which is highly unusual for the mineral. These uncommon factors enticed the team to investigate this sample's origins.

The team used several different kinds of analytical techniques to determine the chemistry and structure of the sample. To determine the exact depth of its origin, Carnegie's postdoc Renbiao Tao conducted high-pressure experiments that mimicked the formation conditions of natural majorite. The team pinpointed its origin to a depth of nearly 250 miles (400 kilometers), at the bottom of the soft part of the upper mantle, called the asthenosphere, which drives plate tectonics.

It is extremely unusual that a high-pressure majorite could survive transportation from such a depth. Adding to the strange circumstances is the fact that it was later encased by a garnet that formed at a much shallower depth of about 125 miles (200 kilometers). The nesting-doll sample's existence required two separate geological events to explain, and these events created a time capsule that the researchers could use to better understand the Earth's deep history.

"This two-stage formation process offers us important clues about the mantle's evolutionary stage at the time when the majorite was first formed," Fei explained.

The sample's location and depth of origin indicate that it is a relic from the end of an era of supercontinent assembly that took place about 1.8 billion years ago. Called Columbia, this supercontinent's formation built mountain ranges that persist today.

"More research is needed to understand how the majorite became so oxidized, or rich in ferric iron, and what this information can tell us about mantle chemistry. We are going back to the site this summer to dig deeper trenches and hope to find fresh rocks that contain more clues to the deep mantle," Fei added. ■

SUPPORT
The National Natural Science Foundation of China, the Carnegie Institution for Science, and the U.S. National Science Foundation supported this research.

An expanse of the Hudson region is shown at bottom. The photo, left, shows ancient crust, such as that found along the eastern shores of Hudson Bay.
Images courtesy Jonathan O'Neil and Rick Carlson

(Inset) Carnegie's Director of Terrestrial Magnetism, Rick Carlson, collects samples of Earth rocks in the field and then brings them back to the lab for analysis to determine how our planet evolved.
Image courtesy Matthew Scott

Earth's First Recycling: The Crust!

Rock samples from northeastern Canada retain chemical signals that help explain what Earth's crust was like more than 4 billion years ago. The new work is from Carnegie's Rick Carlson and Jonathan O'Neil of the University of Ottawa and was published in *Science*.

There is much about Earth's ancient crust that scientists don't understand, because most of the planet's original crust isn't around any longer to be studied directly. It has either sunk back into the interior from the movements of Earth's tectonic plates, or it has been transformed into new, younger rocks.

"Finding remnants of this ancient crust has proven difficult, but a new approach offers the ability to detect the presence of truly ancient crust that has been reworked into 'merely' really old rocks," Carlson said.

This study examined variations in the abundance of an isotope of the element neodymium, which is created by the radioactive decay of a different element, samarium.

Isotopes are versions of an element with the same number of protons but different numbers of neutrons, causing each isotope to have a different mass. The isotope of samarium with a mass of 146 is unstable and decays to the isotope of neodymium with a mass of 142. It does this by emitting an alpha particle—which is composed of two neutrons and two protons from its nucleus.

Samarium-146 is a radioactive isotope that has a half-life—the time it takes to decrease by half—of only 103 million years. Although it sounds like a long time, in geological terms it is quite short. While samarium-146 was present when Earth formed, it became extinct early in Earth's history. We know of its existence from very ancient rocks, especially meteorites and samples from Mars and the Moon.

Variations in the relative abundance of neodymium-142 compared to other, non-samarium derived isotopes of neodymium reflect chemical processes that changed the ratio of samarium to neodymium in the rock while samarium-146 was still present. That was before about 4 billion years ago.

Carlson and O'Neil studied 2.7-billion-year-old granitic rocks that make up much of the eastern shore of Hudson Bay. The abundance of neodymium-142 in these granites indicates that they were derived from the re-melting of much older rocks—rocks that were more than 4.2 billion years old. These ancient rocks were compositionally similar to the abundant magnesium-rich rock type known as basalt, volcanic rock that makes up the present day oceanic crust as well as large volcanoes such as in Hawaii and Iceland.

In more recent times, basaltic oceanic crust survived at Earth's surface for less than 200 million years before it sunk back into Earth's interior from plate tectonics. The new results, however, suggest that basaltic crust, which may have formed not long after Earth's formation, survived at Earth's surface for at least 1.5 billion years before later being re-melted into rocks that form much of the northernmost Superior craton. This formation extends roughly from the Hudson Bay in Quebec to Lake Huron in Ontario.

"Whether this result implies that plate tectonics was not at work during the earliest part of Earth history can now be investigated using our tool of studying neodymium-142 variation to track the role of truly ancient crust in building up younger, but still old, sections of Earth's continental crust," Carlson explained. ■

SUPPORT
A Natural Sciences and Engineering Research Council of Canada Discovery grant supported this project.

This image shows the live liver of a translucent, larval zebrafish. It was taken using confocal microscopy, which allows for clear images of the internal organs of the animal. Carnegie's Vanessa Quinlivan fed a fluorescently tagged fatty acid to a larval zebrafish and then photographed its liver at 400x magnification. The round dots of varying sizes are lipid droplets, which contain the fat triglyceride. These triglycerides were constructed using the fluorescent fat. Fluorescence also shows up in the gallbladder (GB) and developing kidney (K).
Image courtesy the Farber lab

WATCHING FAT METABOLISM IN LIVE FISH

We all know that too much fat is bad for us.

But the process of studying what happens to lipids—oils, fatty acids, cholesterol, and triglycerides— after eating has been technologically difficult and expensive to accomplish until now.

Studying how our bodies metabolize lipids is vital for understanding cardiovascular disease, diabetes, and other health problems, plus it can reveal basic cellular functions.

New work from Carnegie's Steve Farber and graduate student Vanessa Quinlivan debuts a method using fluorescent tagging to visualize and measure lipids in real time as they are metabolized by living fish. *Journal of Lipid Research* published their work.

"Lipids play a vital role in cellular function, because they form the membranes surrounding each cell and many of the structures inside of it," Quinlivan said. "They are also part of the crucial makeup of hormones such as estrogen and testosterone, which transmit messages between cells."

Unlike proteins, the recipes for different lipid-containing molecules are not precisely encoded by DNA sequences. A cell may receive a genetic signal to build a lipid for a certain cellular purpose, but the exact type may not be indicated with a high degree of specificity.

Instead, lipid molecules are built from an array of building blocks whose combinations can change depending on the type of food we eat. However, lipid compositions vary between cells and cellular structures within the same organism, so diet isn't the only factor determining which lipids are manufactured.

"Understanding the balancing act in what makes up our bodies' lipids—between what we're eating and genetic guidance—is very important to cell biologists," Farber explained. "There is growing evidence that these differences can affect wide arrays of cellular processes."

Omega-3 fatty acids, for instance, are lipid building blocks in foods like salmon and walnuts and are known to be especially good for the heart and liver health. There is evidence that when people eat omega-3 fatty acids the cellular membranes into which they are incorporated are less likely to overreact to signals from the immune system than membranes comprised of other kinds of lipids. This has an anti-inflammatory effect that could prevent heart or liver disease.

Farber and Quinlivan's method allowed them to delve into these kinds of connections. They tag different kinds of lipids, feed them to live zebrafish, and then watch what the fish did with them. Using fluorescent tags, the team could watch the fats, under the microscope, as they were broken down and reassembled into new molecules in different organs. Further experiments allowed them to learn into what types of molecules the broken-down fat components were incorporated.

"Being able to do microscopy and biochemistry in the same experiment made it easier to understand the biological meaning of our results," Quinlivan said. "We hope our method will allow us to make further breakthroughs in lipid biochemistry going forward."

The other members of the team were Meredith Wilson of Carnegie and Josef Ruzicka of Thermo Fisher Scientific. ■

Carnegie's Steve Farber carried a sign about the importance of zebrafish for cardiovascular disease research at the March for Science in April.
Image courtesy Mike Colella

SUPPORT
The National Institute on Alcohol Abuse and Alcoholism, the National Institute of Diabetes and Digestive and Kidney Diseases, and the National Institute of General Medicine grant of the Zebrafish Functional Genomics Consortium supported this work.

How Grasses Cope with Climate Change

A team of plant biologists and ecologists from Carnegie and Stanford University has uncovered the factor behind an important innovation that makes grasses—both native and crop—among the most common and widespread plants on the planet. Their findings, published by *Science*, may lead to plants that perform better in warmer and drier conditions.

All land plants take in carbon dioxide (CO_2) from the atmosphere and exhale oxygen and water vapor. The carbon dioxide is made into sugars by photosynthesis, which turns the Sun's energy into food. But it also is a major driver of global climate cycles.

A plant needs to balance its ability to take in CO_2 with the potential to lose water. To achieve this balance it uses tiny, cellular valve-like pores on its leaves called stomata (after the Greek word for mouths). In grasses, these valves are particularly well-tuned; they can open wide to maximize CO_2 uptake and shut quickly when the surrounding conditions might lead to increased water loss.

Because grass crops such as corn, wheat, and rice are a major food source, the Carnegie-Stanford group wanted to know why the stomata in these particular plants work so much better than stomata in other plants. Most plants stomata are made up of just two so-called guard cells. But grasses have an additional pair of cells on either side, called subsidiary cells, which enable the guard cells to open and close especially quickly.

Additionally, while the guard cells of many plants are kidney shaped, grass guard cells are an unusual dumbbell shape. The subsidiary cells alongside these dumbbell-like cells provide a mechanical boost to open wide.

In this study, led by Dominique Bergmann, an adjunct staff member at Carnegie's Department of Plant Biology and Professor at Stanford University, the researchers used a relative of wheat called *Brachypodium* to demonstrate that all grass stomata with the four-cell configuration, are indeed more responsive to changing environmental conditions, and have a wider range of apertures for pore opening and closing.

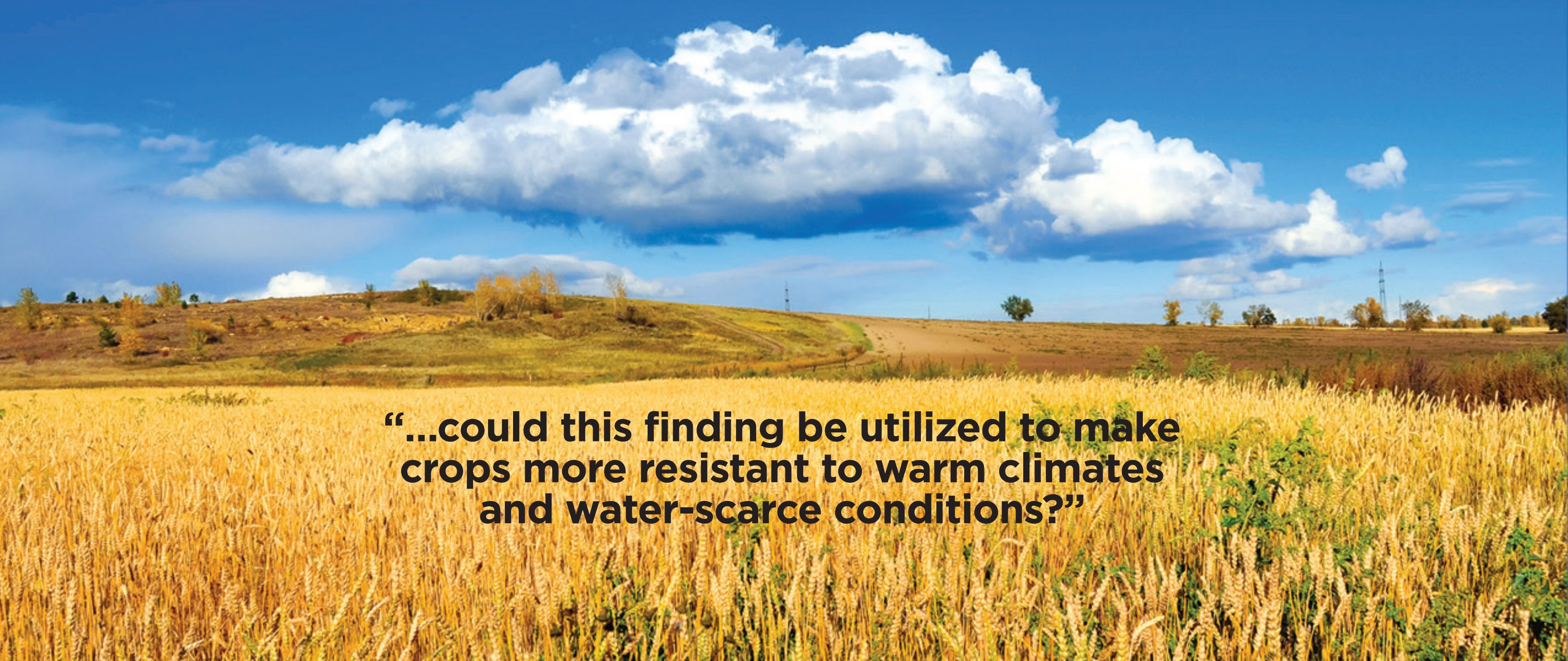
This past spring Dominique Bergmann, a professor at Stanford University and an adjunct staff member at Carnegie, was elected to the National Academy of Sciences.
Image courtesy Dominique Bergmann

Furthermore, the team—including lead author Michael Raissig of Stanford and Carnegie Global Ecology's Acting Director Joseph Berry—used sophisticated research techniques to identify a specific gene that enables *Brachypodium* to form the lateral subsidiary cells. The gene, called *BdMUTE,* encodes a protein (MUTE) that is considered a master regulator of cell behavior by turning other genes on and off to give cells their unique properties. Without this master regulator, *Brachypodium* stomata resemble the more primitive two-celled stomata found in other plants. The research team showed that grasses with these two-celled stomata perform poorly.

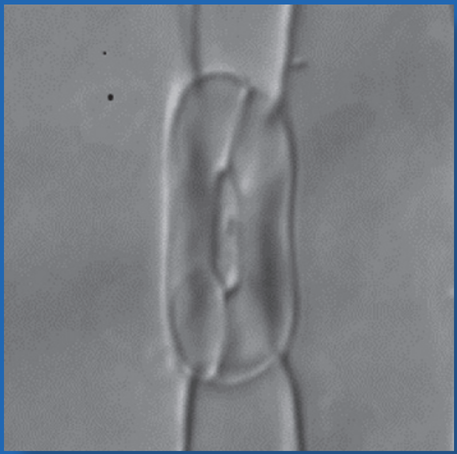
MUTE isn't a brand new protein found only in the grasses. Rather, it is a slightly modified version of protein that, a decade ago, was shown to have a different role in making two-celled stomata in the laboratory broadleaf plant *Arabidopsis*. When an *Arabidopsis* cell is exposed to this version of the MUTE protein, it gets the message that it should commit itself to making guard cells. In *Brachypodium*, however, the protein moves out of the guard cell precursors into the neighbor cells and then induces these neighbors to become subsidiary cells in the four-celled complex.

"Could the mobility of the grass version of MUTE be the key to this master regulator's ability to set up these physiologically improved, four-celled grass stomata?" Raissig asked.

"And could this finding be utilized to make crops more resistant to warm climates and water-scarce conditions?" added Bergmann. ■



"…could this finding be utilized to make crops more resistant to warm climates and water-scarce conditions?"



The upper image shows the four-celled stomata found in grasses, featuring two dumbbell-shaped guard cells surrounded by two subsidiary cells. Scientists attribute the tremendous success of grasses to this valve structure, which is capable of more-sensitive and precise responsiveness to the environment and likely enhances the plant's performance, particularly in high temperatures or drought conditions.

The lower image shows mutant grass that's lacking the *BdMUTE* gene, which is responsible for the four-celled stomatal architecture normally found in grasses. In this mutant, a two-celled stomatal valve develops instead, which is much less efficient.

Images courtesy Dominique Bergmann and Michael Raissig

CO-AUTHORS AND SUPPORT

Other coauthors on the study were Juliana Matos, Ximena Anleu Gil, Emily Abrash, Akhila Bettadapur, and Hannah Allison of Stanford; Ari Kornfeld and Grayson Badgley of Carnegie's Department of Global Ecology; and John Vogel of the Department of Energy's Joint Genome Institute.

The Swiss National Science Foundation and the Gordon and Betty Moore Foundation supported this work through a grant to Life Science Research Foundation; the U.S. National Science Foundation also supported this work. Dominique Bergmann is a Gordon and Betty Moore Foundation investigator of the Howard Hughes Medical Institute.

Leopoldo Infante Appointed Director of Carnegie's Las Campanas Observatory

Leopoldo Infante will direct Carnegie's Las Campanas Observatories effective July 31, 2017. Running the observatory is a complex job with the operation of numerous telescopes, living and dining facilities, and the infrastructure to support all the activities in the remote location high in the Chilean Andes. Las Campanas will also be the site of the Giant Magellan Telescope.

Images courtesy Pontifica Universidad Católica de Chile and Yuri Beletsky

The Carnegie Observatories announced the appointment of Professor Leopoldo Infante of Pontifica Universidad Católica (PUC) de Chile to direct the Las Campanas Observatories (LCO) in Chile. His first day is July 31, 2017, succeeding Carnegie astronomer Mark Phillips, who stepped in as interim director when director Miguel Roth retired in 2014.

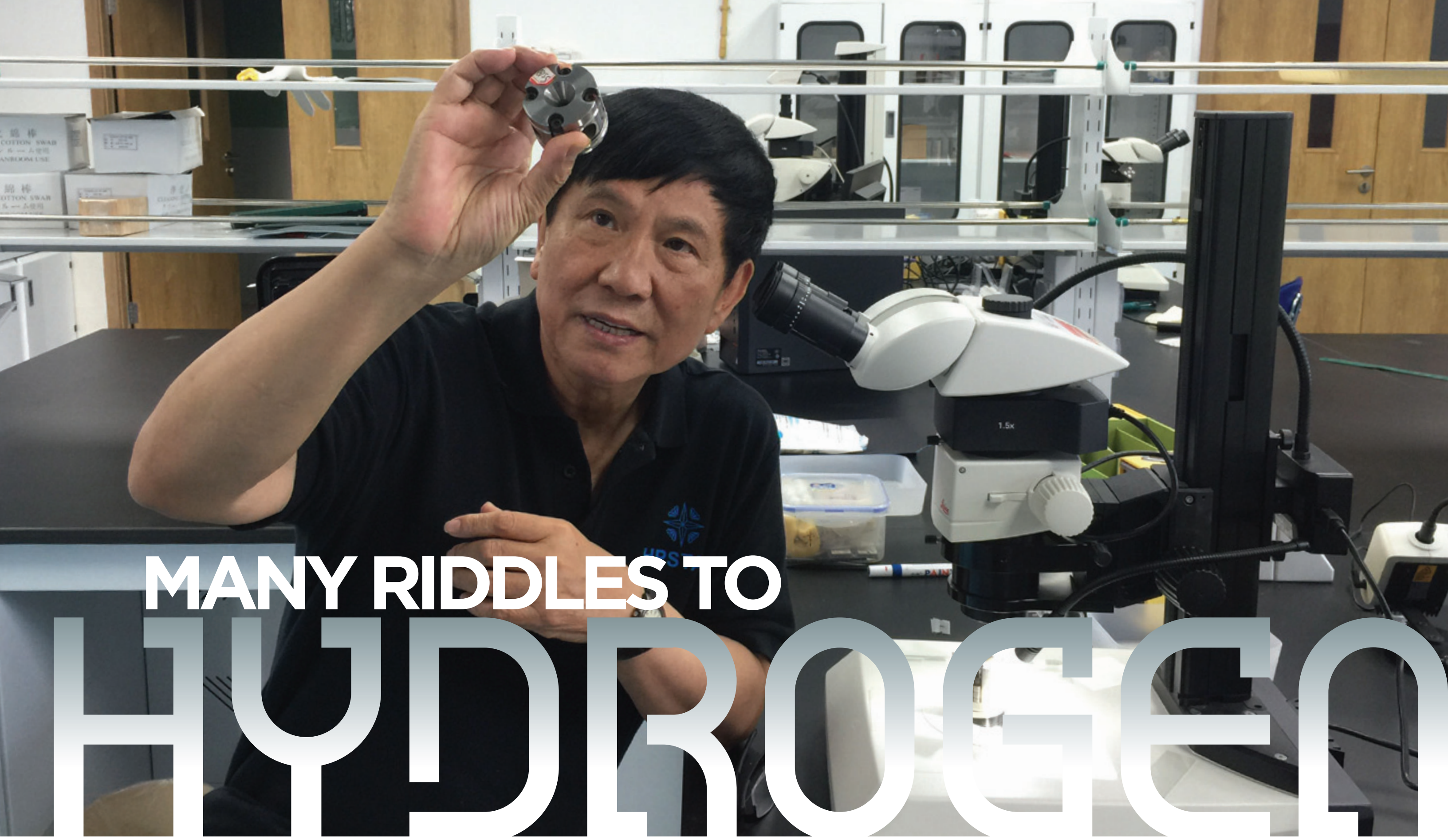
Since 2009, Infante has been the founder and director of the Centre for Astro-Engineering at the Chilean university. He joined PUC as an assistant professor in 1990 and has been a full professor since 2006. He was one of the creators of PUC's Department of Astronomy and Astrophysics, and served as its director from 2000 to 2006. He also established the Chilean Astronomical Society (SOCHIAS) and served as its president from 2009 to 2010.

Director of the Carnegie Observatories John Mulchaey remarked, "We could not be happier that Leopoldo will direct Las Campanas. His in-depth knowledge of leading complex organizations, his scientific accomplishments, outreach and service to the astronomical community worldwide make him an ideal selection for this post."

Infante received his B.S. in physics at PUC. He then acquired a M.S. and Ph.D. in physics and astronomy from the University of Victoria in Canada. Infante has been visiting professor at Princeton University and The Johns Hopkins University. He has also held research positions at the European Southern Observatory, University of Bonn in Germany, and the Vatican Observatory, among others. In addition, he has significant international teaching experience.

Infante reflected on his new position, "The notions 'to encourage the broadest and most liberal manner' of discovery, with complete freedom that embodies Carnegie Science, made me think that I want to be part of that and contribute to the discovery of the universe by running the best astronomical facilities."

Infante has published over 370 papers, which have been cited more than 10,800 times. He has earned numerous awards and belongs to the Chilean Astronomical Society, the American Astronomical Society, the American Institute of Physics, and the International Astronomical Union. ■



MANY RIDDLES TO HYDROGEN

Carnegie's Dave Mao has been a pioneer in high-pressure, high-temperature research for decades. *Image courtesy Dave Mao*

Hydrogen is the simplest and most-abundant element in the universe, so studying it can teach scientists about the essence of matter and what is happening in Earth's interior, among other things. There are many, many secrets to this first element, including how best to force it into a superconductive, metallic state with no electrical resistance and how it behaves in the deep Earth.

ARGON IS NO "DOPE" FOR METALLIC HYDROGEN

Superconductivity is a state where there is zero electrical resistance and electrons flow freely. But these conditions can only be reached at super low temperatures, which is unrealistic for practical applications at the moment.

"Although theoretically ideal for energy transfer or storage, metallic hydrogen is extremely challenging to produce experimentally," said Ho-kwang "Dave" Mao, who led a team in researching the effect of the noble gas argon on pressurized hydrogen. Noble gases are those that have very low chemical reactivity.

It has long been proposed that introducing impurities into a sample of molecular hydrogen, H_2, could help ease the transition to a metallic state. So Mao and team studied the intermolecular interactions of hydrogen that's weakly-bound, or doped, with argon, $Ar(H_2)_2$, under extreme pressures. The idea is that the impurity could change the nature of the bonds between the hydrogen molecules, reducing the pressure necessary to induce the nonmetal-to-metal transition. Previous research had indicated that $Ar(H_2)_2$ might be a good candidate.

Surprisingly, they discovered that the addition of argon did not facilitate the molecular changes needed to initiate a metallic state in hydrogen. *Proceedings of the National Academy of Sciences* published their findings.

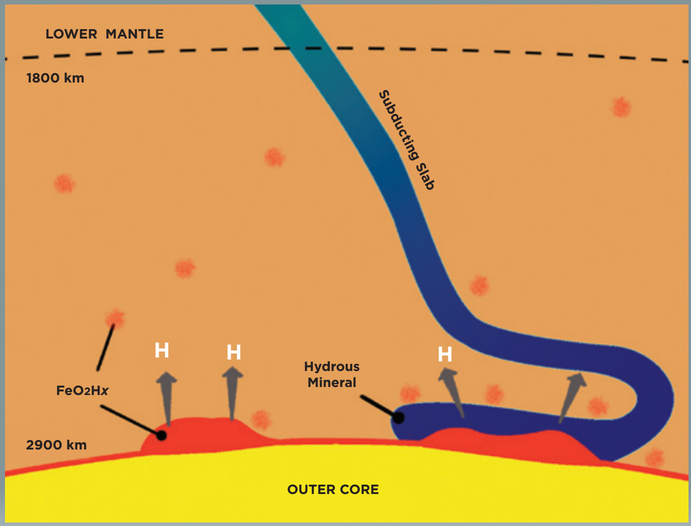
The team brought the argon-doped hydrogen up to 3.5 million times normal atmospheric pressure—or 358 gigapascals—inside a diamond anvil cell and observed its structural changes using advanced spectroscopic tools.

What they found was that hydrogen stayed in its molecular form even up to the highest pressures, indicating that argon is not the facilitator many had hoped for.

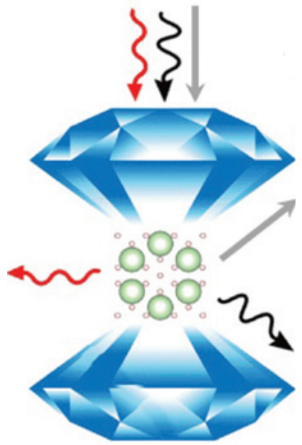
"Counter to predictions, the addition of argon did not create a kind of 'chemical pressure' on the hydrogen, pushing its molecules closer together. Rather, it had the opposite effect," said lead author Cheng Ji.

The study's other coauthors are Carnegie's Alexander Goncharov, Dmitry Popov, Bing Li, Junyue Wang, Yue Meng, Jesse Smith, and Wenge Yang; Vivekanand Shukla, Naresh Jena, and Rajeev Ahuja of Uppsala University; and Vitali Prakpenka of the University of Chicago.

SUPPORT The U.S. National Science Foundation, the U.S. Department of Energy, the Chinese Academy of Sciences Visiting Professorship for Senior International Scientists and Recruitment of Foreign Experts, the European Erasmus Fellowship program, and the Swedish Research Council supported this work.



This diagram shows the hydrogen cycling in the deep Earth under mantle conditions.
Image courtesy Qingyang Hu



STUDYING DOPED HYDROGEN

This is an illustration of hydrogen doped with argon—$Ar(H_2)_2$—in a diamond anvil cell. The arrows represent different ways that spectroscopic tools study the effect of extreme pressures on the crystal and molecular structures of the compound. The red arrow represents Raman spectroscopy, which measures vibrational, rotational, and other characteristics that can be signatures of specific molecules. The black arrow represents synchrotron X-ray diffraction. X-ray diffraction is the use of high-energy X-rays to determine structure at minute scales. The gray arrow represents optical absorption spectroscopy, which can reveal the presence and amount of trace substances.

Image courtesy Cheng Ji

HYDROGEN THE HOUDINI

In Earth's interior, water (H_2O) plays an important role in rock physics, but geoscientists rarely treat water in its constituent forms, that is, as hydrogen plus oxygen. Other work from a team led by Dave Mao has identified that hydrogen can escape from the water under conditions found in Earth's lower mantle leading to a new paradigm in lower-mantle chemistry. *Proceedings of the National Academy of Sciences* published these results.

In the atmosphere, hydrogen is a colorless, transparent gas. It bonds with oxygen to form water, which fuels the surface biosphere. Deep in the rocky world, so-called hydrous minerals enriched with water mainly exist in subduction slabs—tectonic plates that sink into the interior. These slabs are relatively colder than the mantle into which they descend. At ambient condition, the chemistry of water is so stable that it is the major hydrogen carrier in surface water.

For a long time, it was thought that the cycling of hydrogen in the Earth's solid crust and mantle would be equivalent to the cycling of water.

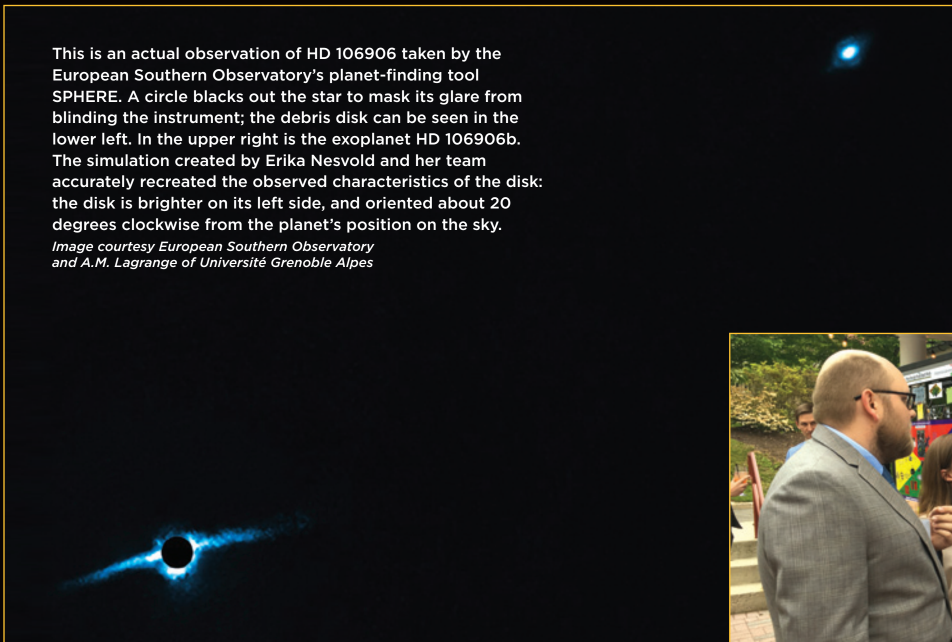
"The stability of water in hydrous mineral might break at the lower mantle," said Mao. Using advanced X-ray diffraction to characterize the material, the team, including Carnegie's Liuxiang Yang and Yue Meng, alumni Qingyang Hu and Duck Young Kim, and collaborators Jin Liu and Wendy Mao of Stanford University, discovered that hydrogen was freed from hydrous minerals in its elemental form.

The team subjected a typical hydrous mineral—goethite—to lower mantle pressure and temperature conditions (about 720,000 atmospheres, and 3140°F or ~2,000 K) and was able to identify released hydrogen. The hydrogen loss closely correlated with the temperature heating and duration.

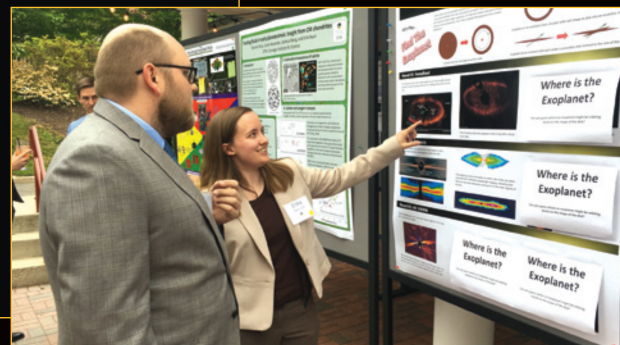
"Oxygen and hydrogen cycles are separated above the Earth's core," said Qingyang Hu, the lead author. "Hydrogen is not freezing; instead, it is freed from rocks."

The team's results have led to a paradigm change in the planetary science of lower-mantle chemistry. The released hydrogen can directly penetrate the liquid outer core, which is considered to have a substantial amount of hydrogen. Free hydrogen can also rise upwards, partially recovering its loss from the subduction of hydrous minerals, and closing up the hydrogen cycling to the Earth's surface. ■

SUPPORT HPCAT operations are supported by the Department of Energy (DOE)-National Nuclear Security Administration (NNSA) under Award DE-NA0001974 and by the DOE-Basic Energy Sciences (BES) under Award DE-FG02-99ER45775, with partial instrumentation funding by the National Science Foundation (NSF). The 13BM-C operation is supported by Consortium for Materials Properties Research in Earth Sciences (COMPRES) through the Partnership for Extreme Crystallography project, under NSF Cooperative Agreement EAR 11-57758. Jin Liu, Qingyang Hu, and Wendy Mao acknowledge support from the NSF Geophysics Program (EAR 1446969). A portion of simulation was conducted on the SR10000-K1/52 supercomputing facilities of the Institute for Materials Research, Tohoku University. NSF Grants EAR-1345112 and EAR-1447438 support Qingyang Hu and Ho-kwang Mao. NSAF (Grant U1530402) supports the Center for High Pressure Science and Technology Advanced Research.



This is an actual observation of HD 106906 taken by the European Southern Observatory's planet-finding tool SPHERE. A circle blacks out the star to mask its glare from blinding the instrument; the debris disk can be seen in the lower left. In the upper right is the exoplanet HD 106906b. The simulation created by Erika Nesvold and her team accurately recreated the observed characteristics of the disk: the disk is brighter on its left side, and oriented about 20 degrees clockwise from the planet's position on the sky.
Image courtesy European Southern Observatory and A.M. Lagrange of Université Grenoble Alpes



Erika Nesvold has been a Terrestrial Magnetism postdoctoral fellow since 2015. She was a graduate researcher at NASA Goddard Space Flight Center from 2010 to 2015.
Images courtesy Erika Nesvold

Roller Derby Planetary Disks

When planets first begin to form, a rotating ring of rocky and icy material collides around the young central star like a celestial roller derby. Analogs to our own Solar System's Kuiper Belt, these distant disks of leftover debris can be detected and studied to help understand the processes that create planetary systems.

Determining how the gravity of existing planets influences a disk's architecture is one important area of study. Most of this research focuses on how planets that exist inside the debris disk define its shape, which is one of the few disk characteristics that can be directly observed from Earth. New work led by Carnegie's Erika Nesvold looks at how a disk is affected by a planet that exists beyond its outermost edge. She demonstrates that the disk's shape can indicate whether the planet formed beyond the disk or initially existed inside of the disk and moved outward. *The Astrophysical Journal Letters* published the work.

The star HD 106906 is perfect for studying this phenomenon. It has one giant planet, about 11 times the mass of Jupiter, orbiting very far away from its host star, at least 650 times the distance between the Earth and our own Sun. Planet HD 106906b orbits outside of the star's debris disk, which is about 10 times closer to the star.

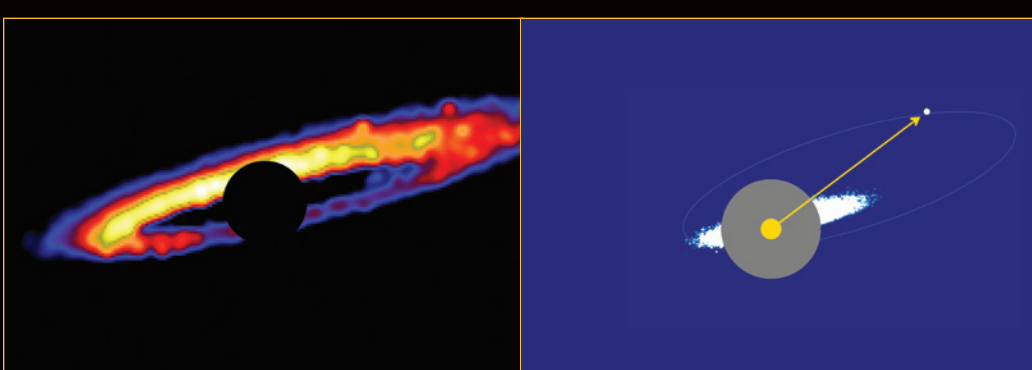
Nesvold and her colleagues, Smadar Naoz and Michael Fitzgerald of UCLA, modeled the HD 106906 system to better understand how an outside planet affects the structure of a debris disk.

"We were able to create the known shape of HD 106906's debris disk without adding another planet into the system, as some had suggested was necessary to achieve the observed architecture," Nesvold said.

The single, distant giant planet's gravity affected the debris in just the right way to produce the system's flat, noncircular ring and to account for the disk's observed shape and features.

What's more, Nesvold's model helped her and the team better understand the orbit and likely formation history of the planet HD 106906b. The team's results indicate that, counter to some predictions, it's likely that the planet formed outside of the disk. If the planet had formed inside the disk and moved outward, the disk would have taken on a different shape than the one that astronomers can see in the system.

"Other debris disks that are shaped by the influence of distant giant planets are probably likely," Nesvold added. "My modeling tool can help recreate and visualize how the various features of these disks came to be and improve our understanding of planetary system evolution overall." ■

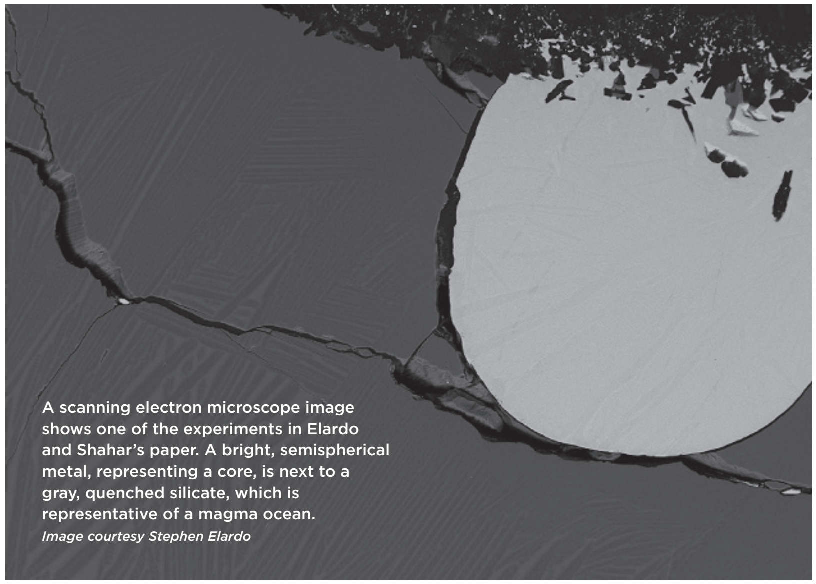


These two images show the HD 106906 stellar system created by Erika Nesvold and her team's simulation. The left panel shows a zoomed-in image of the ring of leftover rocky and icy planet-forming material that is rotating around the star. (The black circle masks the star.) The different hues represent gradients of brightness in the disk material: yellow is the brightest, and blue the dimmest. The right panel shows a farther-out view of the simulated system. The yellow circle represents the star; the arrow points to the exoplanet HD 106906b. Nesvold's team demonstrated that the exoplanet is shaping the structure of the debris disk, shown by the white and blue dots encircling the star.
Images courtesy Erika Nesvold

"Flavors"of Iron Unlock Mysteries of Planetary Interiors

Scientists can't take samples of the planet's core. But they can study iron chemistry to help understand the differences between differentiation events—when the material inside formed interior layers—on Earth, other planets and asteroids.

New work from Carnegie's Stephen Elardo and Anat Shahar shows that interactions between iron and nickel under the extreme pressures and temperatures similar to a planetary interior can help scientists understand the period in our Solar System's youth when planets were forming and their cores were created. *Nature Geoscience* published their findings.


A scanning electron microscope image shows one of the experiments in Elardo and Shahar's paper. A bright, semispherical metal, representing a core, is next to a gray, quenched silicate, which is representative of a magma ocean.
Image courtesy Stephen Elardo

Earth and other rocky planets formed as the matter surrounding our young Sun slowly accreted. At some point in Earth's earliest years, its core formed through differentiation—when the denser materials, like iron, sunk inward toward the center, resulting in an iron core and a silicate upper mantle and crust.

One key to researching Earth's differentiation period is studying variations in iron isotopes. Every element contains a unique and fixed number of protons, but the number of neutrons in an atom can vary. Each variation is a different isotope. Analysis of these differences in samples of ancient rocks and minerals from the Earth, Moon, other planets, and planetary bodies sheds light on their history.

As a result of the difference in neutron numbers, isotopes have slightly different masses. These slight differences mean that some isotopes are preferred by certain reactions, which results in an imbalance in the ratio of each isotope in the end products.

One outstanding mystery on this front has been the significant variation between iron isotope ratios found in samples of hardened lava that erupted from Earth's upper mantle and samples from primitive meteorites, asteroids, the Moon, and Mars. Other researchers had suggested these variations were caused by the Moon-forming giant impact or by chemical variations in the solar nebula.

Elardo and Shahar used laboratory tools to mimic the conditions found deep inside the Earth and other planets to determine why iron isotopic ratios can vary under different planetary formation conditions.

They found that nickel is the key to unlocking the mystery.

Under the conditions under which the Moon, Mars, and the asteroid Vesta's cores were formed, preferential interactions with nickel retain high concentrations of lighter iron isotopes in the mantle. However, under the hotter and higher-pressure conditions expected during Earth's core formation process, this nickel effect disappears, which can help explain the differences between lavas from Earth and other planetary bodies and the similarity between Earth's mantle and primitive meteorites.

"There's still a lot to learn about the geochemical evolution of planets," Elardo said. "But laboratory experiments allow us to probe to depths we can't reach and understand how planetary interiors formed and changed through time." ■



Anat Shahar (left) has been a staff scientist at Carnegie's Geophysical Laboratory since 2009. Steve Elardo is a postdoctoral fellow in the lab.
Images courtesy Anat Shahar and Steve Elardo

SUPPORT
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Hazen's Mineral Evolution Gets Permanent Exhibition!

In the mid-2000s Carnegie's Bob Hazen wondered why only 12 minerals existed before the Solar System formed over 4 billion years ago but now there are about 5,000. In 2008 he discovered that there was a connection between new mineral formation and changing environmental conditions during our planet's evolution—the emergence of life was intimately tied to mineral evolution and plate tectonics. This April Hazen spoke at an event opening an exhibition at the Natural History Museum, Vienna, about this work. ■

Carnegie's Bob Hazen attended the event showcasing the permanent exhibition about mineral evolution.
Image courtesy Bob Hazen

Images courtesy NHM Wien, Alice Schumacher