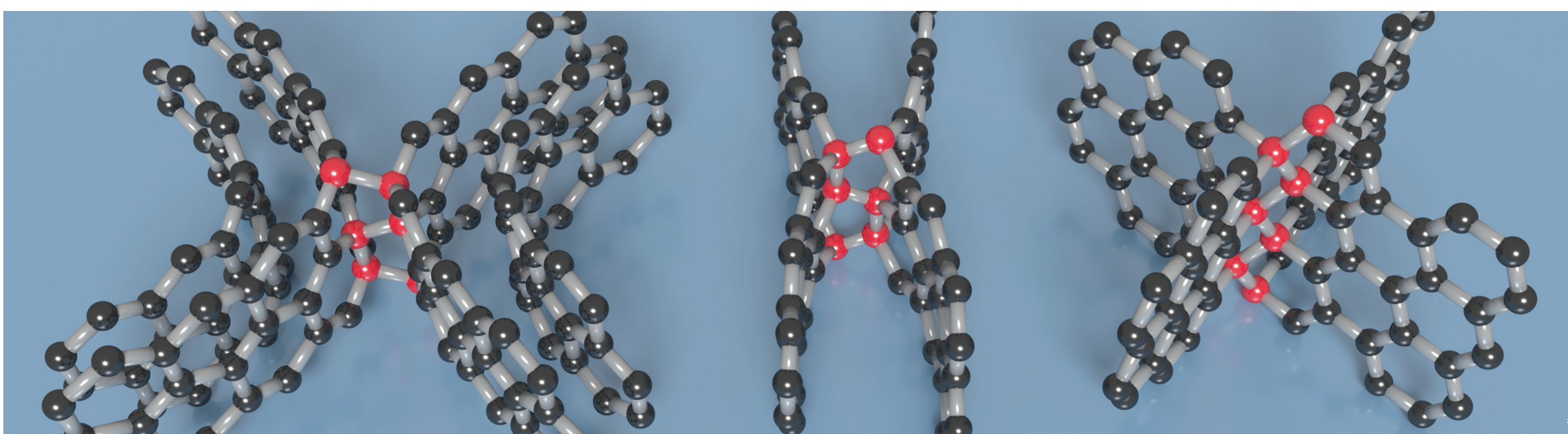
CarnegieScience

The Newsletter of the Carnegie Institution for Science

FALL 2017

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

On the Inside



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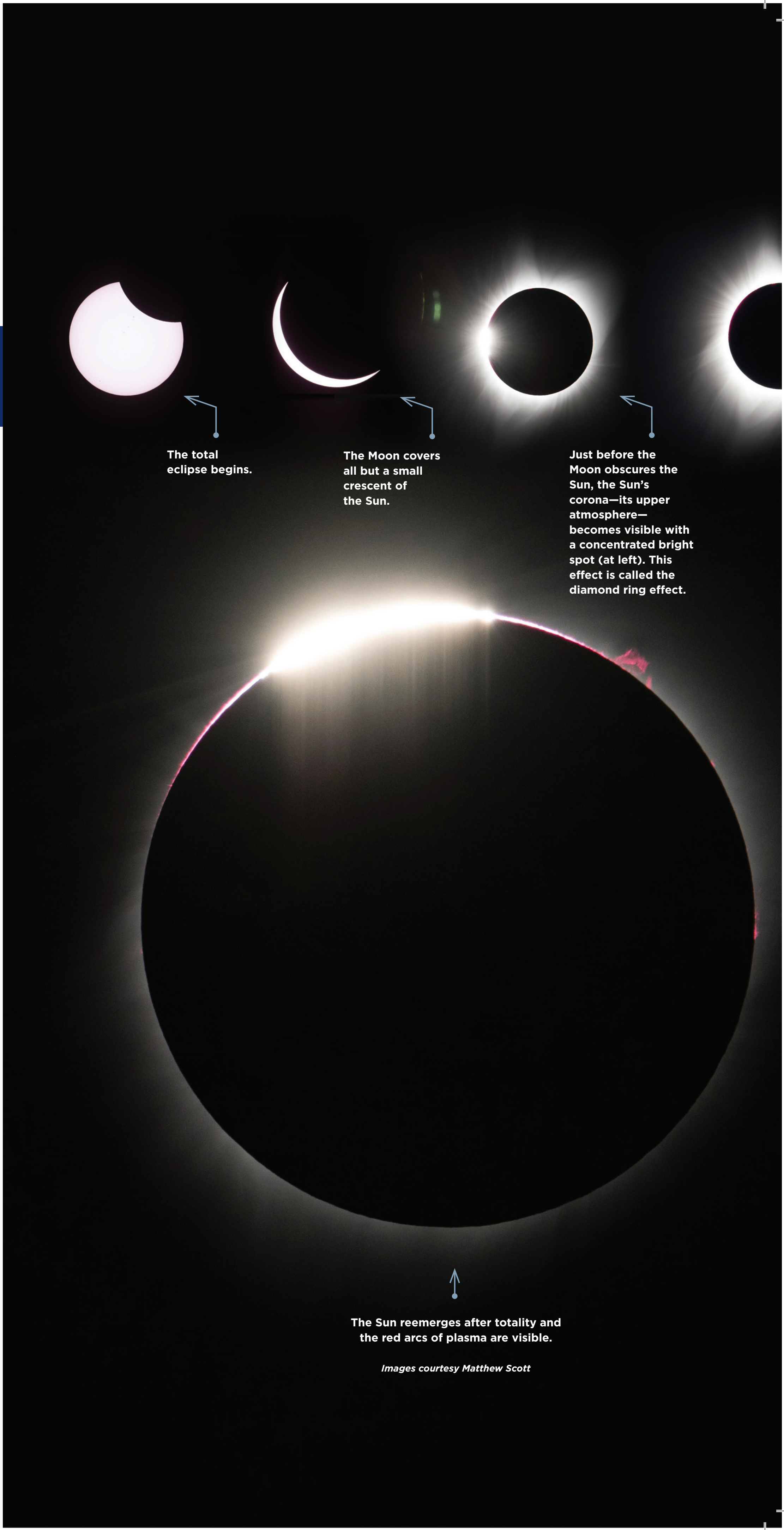
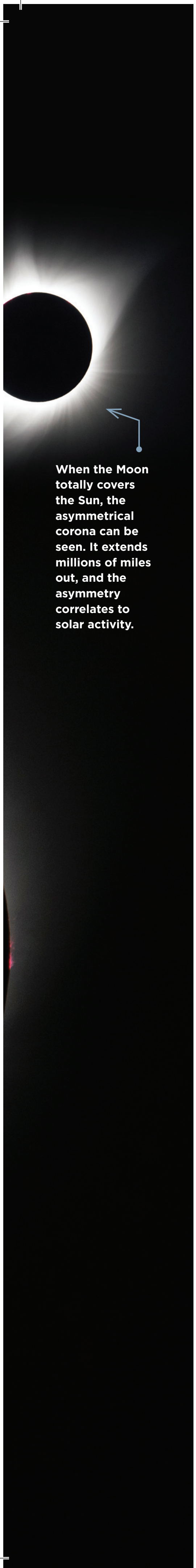


Images courtesy Matthew Scott

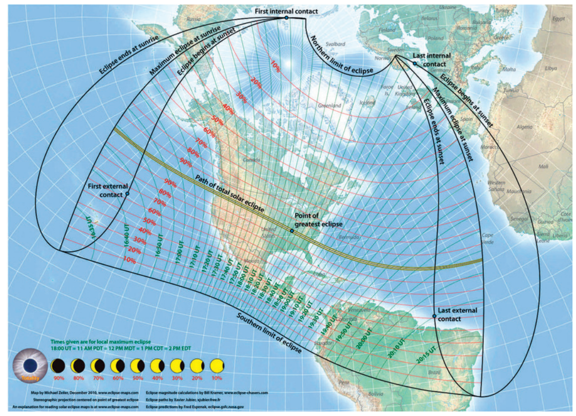
MILLIONS ENCHANTED WITH THE GREAT AMERICAN ECLIPSE



When the Moon totally covers the Sun, the asymmetrical corona can be seen. It extends millions of miles out, and the asymmetry correlates to solar activity.

This past August, people from Oregon to South Carolina had, what was for most of us, a once-in-a-lifetime experience witnessing the total eclipse of the Sun; other regions of the country witnessed a spectacular partial eclipse. I was heartened to see that millions of Americans of all ages and walks of life became increasingly excited as the spectacle approached.

The same scientific process of observation, analysis, deduction, and prediction that allowed us to know precisely when and where the eclipse would happen has been used to make predictions about the influence of climate change upon storm intensities. In the past weeks, the predictive power and value of science has been brought home once again in both arenas.



This map shows how much of the eclipse appeared throughout the U.S.
Image courtesy Michael Zeller, www.eclipse-maps.com

The eclipse raised the interest of many about the physics and mechanics of the Sun-Moon-Earth system, and how the Moon casts an umbral shadow in totality zones and partial shadows in flanking regions.

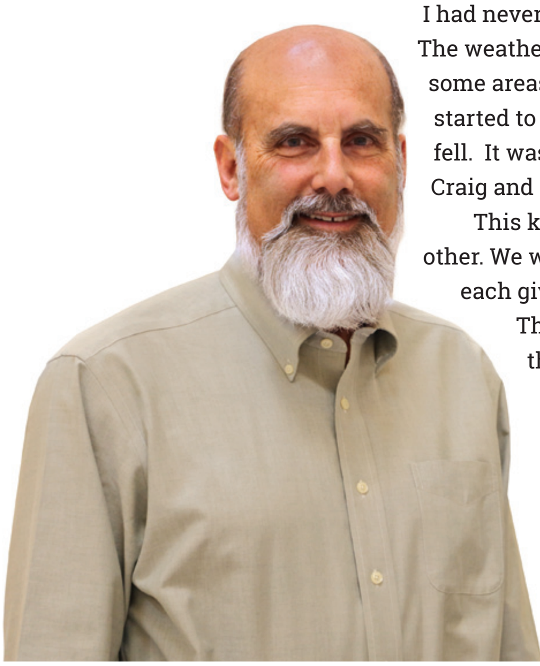
Staff at our Broad Branch Road campus celebrated by viewing the partial eclipse using eclipse glasses, a telescope, pinhole and colander projectors, and they monitored a live feed from a totality region. They listened to an eclipse playlist created by the Giant Magellan Telescope Organization.

As part of the surge in eclipse tourism, a number of Carnegie astronomers gathered at a school in Mackay, Idaho—located in the totality—to participate in engagement activities with teachers. Other Carnegie astronomers attended an event in western Montana.

Carnegie trustee Craig Barrett and his wife Barbara invited several friends of Carnegie and Carnegie scientists to their Triple Creek Ranch in Montana's Bitterroot Mountain Range for the awe-inspiring event. I cohosted the trip with John Mulchaey, director of The Observatories, and accompanying Carnegie scientists infused the experience with the science behind the nature.

During the days leading up to the eclipse, guests enjoyed ranch activities, learned about the local ecology, and discovered fascinating information about local geology from Terrestrial Magnetism director Rick Carlson.

Carnegie's Scott Sheppard oversaw a "star party." Guests observed constellations and Saturn through a telescope. Juna Kollmeier gave an astronomy talk to help guests understand how the eclipse fits into the larger cosmos. These and other learning opportunities helped forge new friendships and gave guests a greater understanding of just how unique Carnegie Science is.



I had never seen a full eclipse and found it more impressive than I had expected. The weather was perfect that day, though forest fire smoke dimmed the sky in some areas. I do not think any of us will forget the eerie feeling as the birds started to sing night songs and the temperature suddenly plunged as darkness fell. It was truly an amazing, magical time—thanks to the warm and engaging Craig and Barbara Barrett, our consummate hosts.

This kind of immersion science instills the wonder of exploration like no other. We will offer other immersion occasions to our friends and supporters, each giving real-time experiences with different areas of Carnegie Science. The trips will showcase our extraordinary investigators, inspire with the thrill of discovery, and grow our circle of Carnegie friends.

Matthew Scott, *President*

Marjorie Burger and Theo van de Sande

RECEIVE 2017

Service to Science Awards

Carnegie president Matthew Scott announced the recipients of the 2017 Service to Science Awards in July. The awardees are Marjorie Burger, senior financial analyst in Administration, and Theo van de Sande, operations manager at the Departments of Plant Biology and Global Ecology.

The Service to Science Award was created to recognize outstanding and/or unique contributions to science by employees who work in administration, support, and technical positions at Carnegie Science. Any individual employed by or officially affiliated with Carnegie may nominate an eligible employee for this award. The selection panel consisted of P Street administrators and was led by Loronda Lee, associate director of Human Resources.

Marjorie Burger

Senior Financial Analyst

Administration

Marj joined Carnegie in 2002 as a financial accountant and was promoted to financial manager/controller in 2007 when Carnegie was expanding and changes were occurring in the regulatory environment because of the financial crisis.

Marj's dedication, work ethic, and in-depth knowledge of accounting, grants, and Carnegie's inner workings allowed her to develop a strong bond with the business managers in the departments and the respect of everyone at P Street. She is also well known and respected by many members of the Board, particularly members of the Audit Committee due to the stability she provided during challenging times and for her effort ensuring Carnegie had years of clean audits.

Marj stepped in as the interim director of Administration and Finance for several months in 2011. She then accepted the role of senior financial analyst in 2013. However, she was twice asked to step back as the interim controller, which is a testament to her professional ethics and dedication to Carnegie.

Theo van de Sande

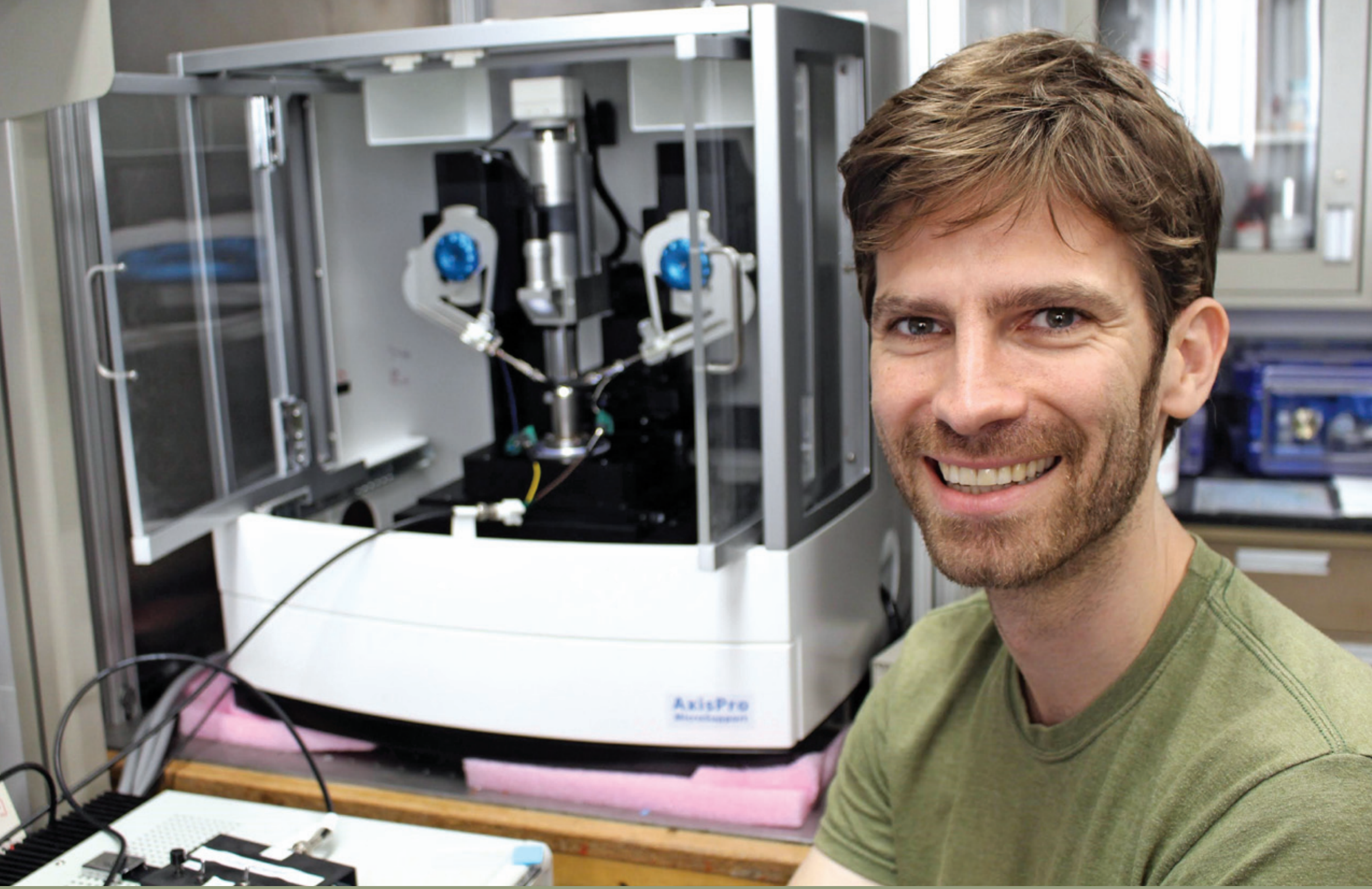
Operations Manager

Departments of Plant Biology and Global Ecology

Theo has been at Carnegie four years and has exhibited outstanding leadership qualities. His detailed and conscious care of Carnegie scientists and the facilities for the Departments of Plant Biology and Global Ecology have gained the appreciation of all of his colleagues.

Theo elegantly overcomes many challenges with the management and upkeep of multiple buildings on campus, while remaining particularly considerate of the occupants. Theo exhibited his professionalism when the specifications for a new HVAC system came in 20% heavier than the prior unit. This situation required new calculations and possible structural upgrades and threatened the deadline and budget. Theo worked tenaciously with the vendor to expedite the timeline.

Impressively, within the framework of the HVAC replacement, Theo had to synchronize the scheduling of roofing crews, oversee installation of cooling towers and upgrades to the climate controls in the greenhouses, and support the Stanford work crew who began construction on a new bike path bordering Carnegie. His project management skills also led to the timely completion of the Mass Spectrometry room. ■



Geophysical Laboratory's Zachary Geballe received the seventh Postdoctoral Innovation and Excellence Award.
Image courtesy Michelle Scholtes

Geophysical Laboratory's Zachary Geballe Receives Seventh Postdoctoral Innovation and Excellence Award

The Geophysical Laboratory's postdoctoral associate Zachary Geballe has been honored with Carnegie's seventh Postdoctoral Innovation and Excellence (PIE) Award. These prizes are made through nominations from the departments and are chosen by the Office of the President. Geballe, in Viktor Struzhkin's lab, was awarded the prize for his scientific innovations and community service to the Broad Branch Road (BBR) campus.

Geballe works on developing methods to measure the heat capacities of metals and silicates at high pressures. This work applies to developing new materials and studying the deep interiors of planets.

He developed a pioneering technique to measure heat in a diamond anvil cell (DAC) by using a method called the alternating current 3rd harmonic method. *Journal of Applied Physics* published the work in two recent papers. Additionally, Geballe devised new, sophisticated sample-loading procedures into the DAC with micromanipulator equipment. The new approach has changed the way the group loads very small samples for high-pressure experiments.

The nomination stated that "Zack is much more than just a very skillful and dedicated experimentalist, he is also the leader of our weekly Bread and Cheese seminar with research updates from our own scientists and discussions of high-impact papers from other groups around the world."

Additionally, Geballe was a founding organizer of postdoc-led poster sessions at BBR, which featured the work of nearly all the researchers and sparked new collaborations, approaches, and teamwork.

Carnegie president Matthew Scott remarked, "This cycle of nominations was particularly strong and it was a difficult choice. Zack's exceptionally creative approaches to scientific innovation and his extraordinary volunteer efforts have made a significant contribution to the sense of community at BBR, making him the high caliber of researcher and colleague envisioned for the PIE awards to recognize. I congratulate him on his accomplishments." ■

New Directors for Embryology and the Geophysical Laboratory

Carnegie president Matthew Scott announced the appointments of two new Carnegie department directors this past July. Yixian Zheng has been selected to direct Carnegie's Department of Embryology in Baltimore, Maryland. She has been acting director since February 1, 2016. Experimental petrologist Michael Walter, head of the School of Earth Sciences at the University of Bristol, will direct the Geophysical Laboratory beginning April 1, 2018.

Yixian Zheng

The Zheng lab has a long-standing interest in cell division and the cytoskeleton—the lattice arrangement of rods and fibers and motors that gives shape to cells and allows movement of cell components to specific locations. Yixian Zheng's research is concentrated in the mechanism of cell division; the mechanism of genome organization in development, homeostasis, and aging; and the influence of cell structural development on cell fates.

Her lab uses a wide range of tools and systems, including genetics in model organisms, cell culture, biochemistry, proteomics—the analysis of proteins—and genomics—the study of entire collections of genes.

Zheng has been a staff member at Embryology since 1996. She was a Howard Hughes Medical Institute Investigator from 2000 to 2012. She received a B.S. in Biology from Sichuan University, Sichuan, China, and a Ph.D. in Molecular Genetics at Ohio State University.

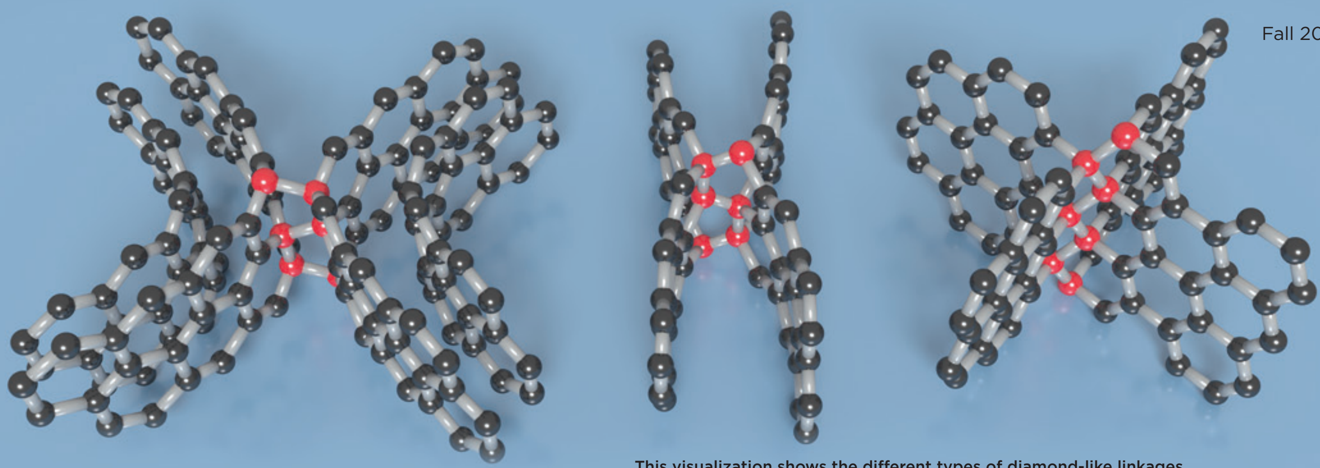
From 1992 to 1996 she was a postdoctoral fellow at the University of California, San Francisco, working with Bruce Alberts and Tim Mitchison. She has received numerous honors including a Pew Scholar Award and the Women in Cell Biology Award.

Michael Walter

Michael Walter's recent research has focused on the period early in Earth's history, shortly after the planet accreted from the cloud of gas and dust surrounding our young Sun, when the mantle and the core first separated into distinct layers. Current topics of investigation also include the structure and properties of various compounds under the extreme pressures and temperatures found deep inside the planet, and information about the pressure, temperature, and chemical conditions of the mantle that can be gleaned from mineral impurities preserved inside diamonds.

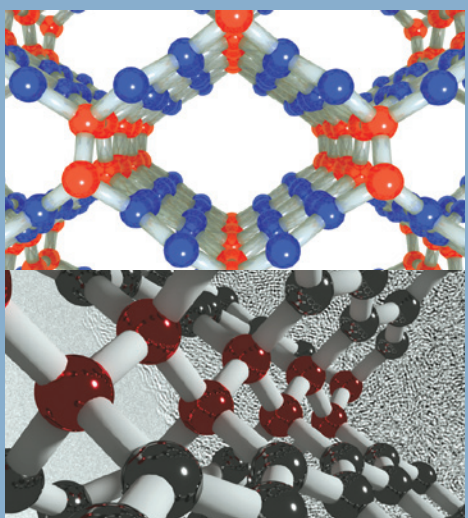
His scientific background makes him an ideal fit to oversee the diverse scientific research at the Geophysical Laboratory where investigators explore fundamental physics and chemistry at high pressures and temperatures, materials science, astrobiology, mineralogy, geochemistry, planetary differentiation, and Solar System formation. Walter is a member of the interdisciplinary Deep Carbon Observatory program, the secretariat of which is based at the department.

Walter has been at the University of Bristol since 2004 and began a five-year term as head of the School of Earth Sciences in 2013. He received his B.S. in geology and Earth science from the University of Nebraska, Omaha, and his Ph.D. in the same from the University of Texas, Dallas. Early in his career, Walter was a postdoctoral fellow at the Geophysical Laboratory. ■



This visualization shows the different types of diamond-like linkages (red spheres) formed at curved surfaces or between the layers of graphene (black spheres) in this new compressed glassy carbon.

Images courtesy Timothy Strobel



The top view is through the channels of a mixed interpenetrating graphene network in compressed glassy carbon. Graphene-like sheets (blue spheres) are cross-linked at diamond-like nodes (red spheres).

The bottom visualization of ultrastrong, hard, and elastic compressed glassy carbon shows its structure overlaid on an electron microscope image of the material.

Images courtesy Timothy Strobel

CARBON:

Hard as Rock, But Like Rubber?

A team including several Carnegie scientists has developed a form of ultrastrong, lightweight carbon that is elastic and can conduct electricity. A material with such unique properties could serve a wide variety of applications from aerospace engineering to military armor.

Carbon is an element of seemingly infinite possibilities. This is because the configuration of its electrons allows for numerous self-bonding combinations that give rise to a range of materials with varying characteristics. For example, transparent, superhard diamonds, and opaque graphite, used in pencils and as industrial lubricant, are both made of carbon.

In this international collaboration between Yanshan University and Carnegie, which included Carnegie's Zhisheng Zhao, Timothy Strobel, Yoshio Kono, Jinfu Shu, Ho-kwang "Dave" Mao, Yingwei Fei, and Guoyin Shen, scientists pressurized and heated a structurally disordered form of carbon called glassy carbon. The glassy carbon starting material was brought to about 250,000 times normal atmospheric pressure and heated to approximately 1800°F to create the new strong and elastic carbon. *Science Advances* published their findings.

Scientists had previously tried subjecting glassy carbon to high pressures at both room temperature (called cold compression) and extremely high temperatures. But the cold-synthesized material could not maintain its structure when brought back to ambient pressure and, under the extremely hot conditions, nanocrystalline diamonds formed.

The newly created carbon is comprised of both graphite-like and diamond-like bonding motifs, which gives rise to the unique combination of properties. Under the high-pressure synthesis conditions, disordered layers within the glassy carbon buckle, merge, and connect in various ways. This process creates an overall structure that lacks a long-range spatial order but has a short-range spatial organization on the nanometer scale.

"Light materials with high strength and robust elasticity like this are very desirable for applications where weight savings are of the utmost importance, even more than material cost," explained Zhisheng Zhao, a former Carnegie fellow who is now a Yanshan University professor. "What's more, we believe that this synthesis method could be honed to create other extraordinary forms of carbon and entirely different classes of materials." ■

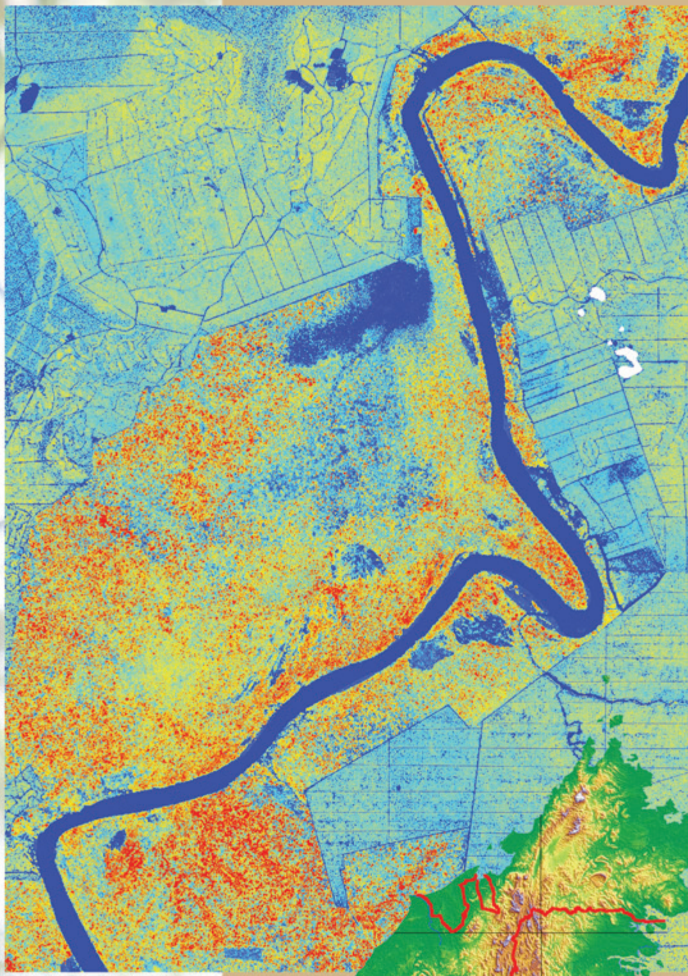
From left: lead author Zhisheng Zhao, Carnegie's Tim Strobel, and Bo Xu, a professor at Yanshan University, who is also an author on the paper.

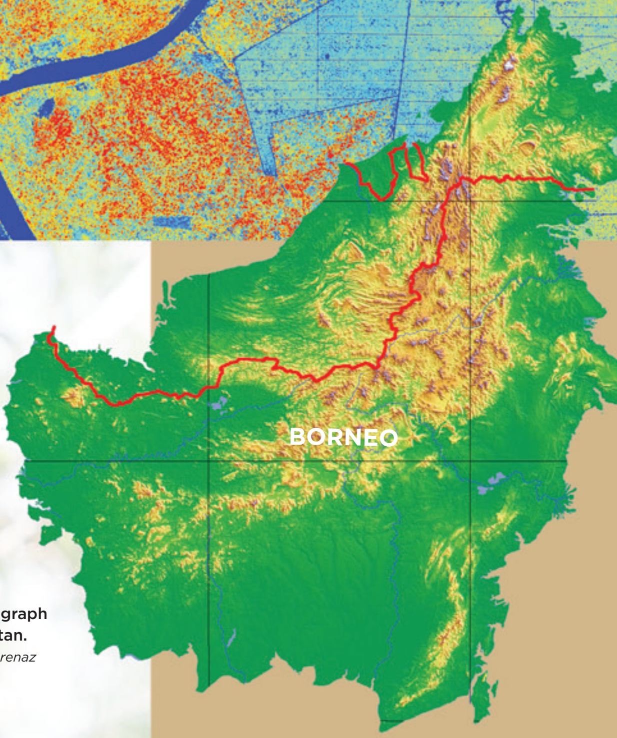
Image courtesy Michelle Scholtes

COAUTHORS AND SUPPORT:
The other members of the team are Meng Hu, Julong He, Wentao Hu, Dongli Yu, Hao Sun, Lingyu Liu, Zihe Li, Mengdong Ma, Jian Yu Huang, Zhongyuan Liu, Bo Xu, Yongjun Tian of the State Key Laboratory of Metastable Materials Science and Technology; Yanbin Wang of the University of Chicago; and Stephen J. Juhl of Penn State University.

The National Natural Science Foundation of China, a grant for Distinguished Young Scholars of Hebei Province of China, the Postgraduate Innovation Project of Hebei Province of China, the Defense Advanced Research Projects Agency, EFree—funded by the U.S. Department of Energy (DOE), Office of Science, and the National Science Foundation (NSF) supported this work. HPCAT is supported by DOE-NNSA and DOE-BES with partial instrument support from NSF. APS is supported by DOE-BES.

(Left) This is a photograph of a Bornean orangutan.
Image courtesy Marc Ancrenaz





(Top) This image taken by the Carnegie Airborne Observatory's Light Detection and Ranging (LiDAR) sensor shows forest canopy height as an indicator of forest quality. Areas with red are taller, mature trees. Areas in blues and yellows are forest that's been degraded by logging. Beyond the forest are oil palm plantations.
Image courtesy the Carnegie Airborne Observatory team

(Bottom) Borneo, shown in this map, is home to the endangered Bornean orangutans.
Image courtesy Wiki commons

ORANGUTANS FLAG CONSERVATION TARGETS

Critically endangered Bornean orangutans, who live in forests impacted by human commerce, seek areas of denser canopies, taller trees, and zones with trees of uniform height, according to new research from Carnegie's Andrew Davies and Greg Asner. *Proceedings of the National Academy of Sciences* published their work.

Despite intense conservation efforts, these orangutan populations continue to decline. Additional habitat management strategies, which account for orangutan behavior in forests affected by human activity, are needed to ensure the species' survival.

Davies and Asner, with Malaysian partners, looked at which human-impacted forest areas are most crucial to preventing orangutan extinction. Their research focused in the Lower Kinabatangan region of Sabah, Malaysia, on the island of Borneo. This area consists of forest patches that have been highly degraded by timber extraction, in a landscape of palm oil plantations and human settlements.

Carnegie's Andrew Davies (top) and Greg Asner (bottom) discovered that the orangutans' habitat was key to understanding how they move through and use disturbed forests in Borneo.
Images courtesy Greg Asner

Davies and Asner used the fixed-wing Carnegie Airborne Observatory's (CAO) Light Detection and Ranging (LiDAR) sensor. It uses reflected laser light to image vegetation in 3-D. They combined it with three years of highly detailed field observations of orangutans by coauthors Marc Ancrenaz of HUTAN/Borneo Futures, a core project partner, and Felicity Oram.

"Our combination of field and airborne data on orangutans and their habitat was key to understanding how they move through and use disturbed forests in Borneo," said first author Davies, a postdoc at Carnegie's Department of Global Ecology. "Similar approaches will be needed to determine the minimum habitat requirements of other endangered species in human-modified landscapes."

They found that orangutans prefer certain canopy characteristics within human-disturbed forests. Thus, some human-impacted forest segments are more important than others for orangutan conservation.

Orangutans require strong branches to move laterally through the canopy. They can descend and cross large canopy gaps on the ground, but this wastes energy and exposes them to predators. This could explain their preference for enclosed canopies, tall trees, and areas with uniform tree height in disturbed forests.

The researchers anticipated that areas with a lot of vertical complexity would be preferred to assist the orangutans with climbing. But this was not the case; observations indicated that lateral movement was a greater need.

"In the course of a year, we took the CAO aircraft and team to northern Borneo, mapped its habitats in 3-D, combined the data with Marc's orangutan observations, and made a critically important scientific discovery that directly bears on the conservation of one of the world's most iconic ape species," said project leader Asner.

Like many large vertebrates, orangutans play a critical role in maintaining healthy ecosystem function. That's why it is so important that they be protected.

"Considering that most of the critically endangered orangutans' habitat is disturbed by human activities, understanding the habitat elements required to ensure orangutan survival in degraded forests is key for their long-term survival," added Ancrenaz.

The results of this orangutan study contribute to a larger Bornean biodiversity mapping mission co-led by Carnegie and the South East Asia Rainforest Research Partnership (SEARRP).

The research group, along with government and nongovernment organization partners in Sabah, is in the process of generating ecological maps, ranging from forest carbon stocks to plant and animal biodiversity. The forthcoming maps have been hailed as key input to an upcoming decision by the Sabah Forestry Department about what area should next be designated as protected.

"This orangutan study is another critical piece of information we are assembling to support the Sabah government to determine where to save the most species in this super-biodiverse region of the world," Asner added. ■

SUPPORT:
Grants from the UN Development Programme, Avatar Alliance Foundation, Roundtable on Sustainable Palm Oil (RSPO), World Wildlife Fund, the Morgan Family Foundation, and the Rainforest Trust supported this study.

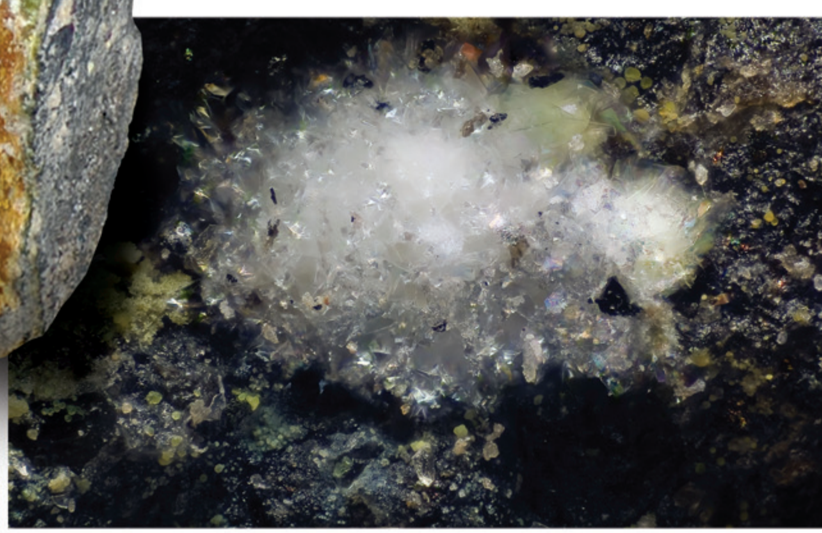
HUTAN-KOCP's long-term supporters are Arcus Foundation; zoos of Zooparc de Beauval, la Palmyre, Chester, Woodland Park, Houston, Cleveland, Columbus, Phoenix, Saint Louis, Basel, Apenheul, Hogle, Oregon Metroparks; AZA Great Ape TAG, Australian Orangutan Project; Synchronicity Earth; U.S. Fish and Wildlife Service; World Land Trust; Waterloo Foundation; and other partners.

The Avatar Alliance Foundation, the John D. and Catherine T. MacArthur Foundation, the David and Lucile Packard Foundation, and William R. Hearst III currently support the Carnegie Airborne Observatory.

BIG DATA Find New Minerals, New Deposits

Applying big data analysis to mineralogy can predict missing minerals as well as where to find new deposits, according to a groundbreaking study. In a paper published by *American Mineralogist*, and covered widely by the media, scientists report the first application to mineralogy of network theory, which is used to analyze the spread of disease, terrorist networks, and Facebook connections.

The results pioneer a potential way to reveal mineral diversity and distribution worldwide, their evolution, new trends, and new mineral deposits. The paper has 12 authors, led by Shaunna Morrison of the Deep Carbon Observatory (DCO), headquartered at Carnegie, and DCO executive director Robert Hazen.



(Above) Parisite-(La) is one of the new carbon-bearing minerals that was predicted before it was found.
Image courtesy rruff.info, donated by Luiz Menezes

(Right) This Abellaite was found in the Eureka mine in Spain.
Image courtesy J. Soldevilla

"The quest for new mineral deposits is incessant, but until recently mineral discovery has been more a matter of luck than scientific prediction," said Morrison. "All that may change thanks to big data."

Humans have collected voluminous information on Earth's more than 5,200 known mineral species. Each has a unique chemical composition and atomic structure.

Millions of mineral specimens from hundreds of thousands of locations around the world have been described and catalogued into databases, which record information on chemical compositions, locations, and physical properties, including hardness, color, atomic structure, and more.

Earth scientists have access to big data resources for analysis. But until recently, they didn't have the modeling and visualization tools to capitalize on these information stockpiles.

Capitalizing on Data Stockpiles

"Big data are a big thing," says Hazen. "You hear about it in all kinds of fields—medicine, commerce, even the U.S. National Security Agency to analyze phone records—but until recently no one had applied big data methods to mineralogy and petrology. I think this is going to expand the rate of mineral discovery in ways that we can't even imagine now."

Network analysis enables Earth scientists to represent data from multiple variables on thousands of minerals sampled from hundreds of thousands of locations within a single graph. These visualizations can reveal patterns that might be hidden within a spreadsheet and provide an intimate picture of which minerals coexist and what geological, physical, chemical, and biological characteristics are necessary for their appearance.

From those insights, it's relatively simple to predict what minerals are missing from scientific lists and where to go to find new deposits.

Hazen remarked, "Network analysis can provide visual clues to mineralogists regarding where to go and what to look for. This is a brand-new idea and I think it will open up an entirely new direction in mineralogy."

The technique has already been used to predict 145 missing carbon-bearing minerals and where to find them, leading to creation of DCO's Carbon Mineral Challenge. Ten have been found so far.

The estimate came from a statistical analysis of carbon-bearing minerals known today and then extrapolating how many scientists should be looking for.

Abellaite and parisite-(La) are examples of new-to-science carbon-bearing minerals predicted before they were found, thanks in part to big data analysis.

"We have used the same kinds of techniques to predict that at least 1,500 minerals of all kinds are 'missing,' to predict what some of them are, and where to find them," Hazen said.

Making Predictions

Morrison followed, "These new approaches to data-driven discovery allow us to predict both minerals unknown to science today and the location of new deposits. Additionally, understanding how minerals have changed through geologic time, coupled with our knowledge of biology, is leading to new insights regarding the coevolution of the geosphere and biosphere."

In a test case, the researchers explored minerals containing copper, which is critical to modern society (e.g., pipes, wires) and in biological evolution. The element is extremely sensitive to oxygen, so the nature of copper in a mineral offers a clue to the level of oxygen in the atmosphere during mineral formation.

The investigators also performed network analysis of common minerals in igneous rocks, which formed from a molten state. The big data analysis recreated "Bowen's reaction series," based on painstaking experiments in the early 1900s, which shows how a sequence of characteristic minerals appears as the magma cools. The analysis showed the same sequence of minerals.

The researchers hope that these techniques will lead to an understanding and appreciation of previously unrecognized mineral relationships in varied mineral deposits.

Growing Mineralogy and Petrology

Mineral networks will also serve as effective visual tools for learning about mineralogy and petrology, the science concerned with the origin, composition, structure, properties, and classification of rocks and minerals.

Researchers could use these tools to explain how Earth's minerals have changed over time and to incorporate data from biomarker molecules to show how cells and minerals interact.

And ore geologists hope to use mineral network analysis to lead to valuable new deposits and predict the locations of unknown mineral deposits.

Morrison also hopes to use network analysis to reveal the geologic history of other planets. She is a member of the NASA Mars Curiosity Rover team identifying Martian minerals through X-ray diffraction data sent back to Earth. By applying these tools to analyze sedimentary environments on Earth, she believes scientists may also start answering similar questions about Mars. ■

SUPPORT:
The W.M. Keck Foundation's Deep-Time Data Infrastructure project supported this work, with additional support by the Deep Carbon Observatory, the Alfred P. Sloan Foundation, a private foundation, the Carnegie Institution for Science, and NASA NNX11AP82A, Mars Science Laboratory Investigations.

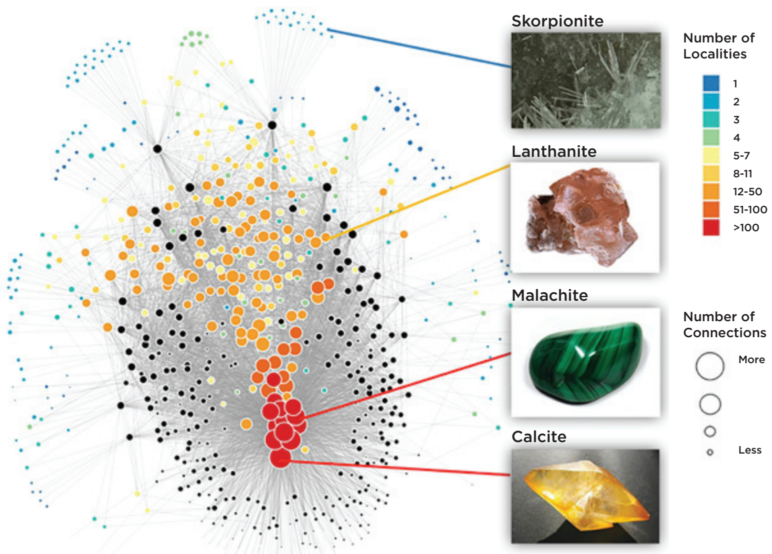


Image courtesy Keck DTDI Project

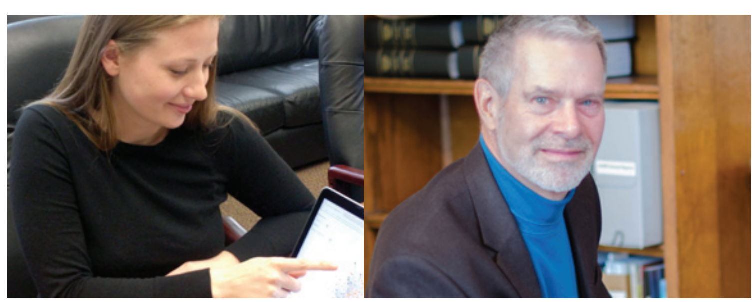
BIG DATA **NETWORK**

This network diagram for 403 carbon minerals reveals previously hidden patterns in their diversity and distribution. Each colored circle represents a different carbon mineral. The size and color of the circles indicates how common or rare each mineral is on Earth.

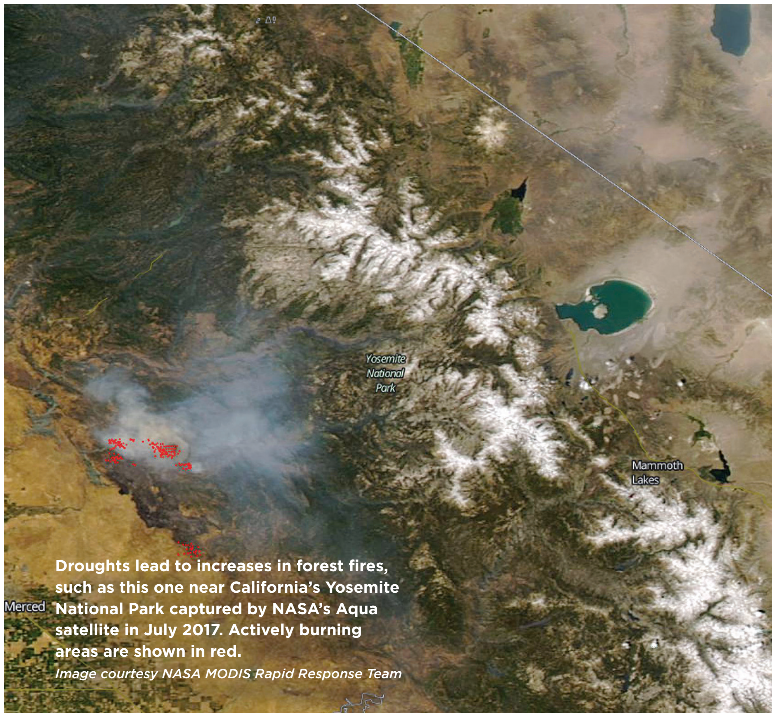
Calcite, the commonest carbon-bearing mineral, occurs at tens of thousands of localities. Malachite is a beautiful green ornamental copper carbonate mineral that is known from thousands of localities. Lanthanite is a carbonate of rare Earth elements reported from only 14 places. The exceedingly rare calcium-zinc carbonate mineral skorpionite is known from only one locality in Namibia.

The black circles represent more than 300 different regional localities at which these minerals are found. The sizes of the circles indicate how many carbon-bearing minerals are found at each location, and the lines link mineral species and their localities.

The distribution of minerals and localities follows a distinctive pattern with a few very common minerals and many more rare species, a distribution that has led to the prediction that more than 1,500 mineral species occur on Earth but have yet to be discovered and described. The hunt is now on for these "missing" minerals.



Shaunna Morrison (left) of the Deep Carbon Observatory (DCO), headquartered at Carnegie, led the study. Bob Hazen (right) is the executive director of the DCO.
Left image courtesy Anirudh Prabhu, right Bob Hazen



Droughts lead to increases in forest fires, such as this one near California's Yosemite National Park captured by NASA's Aqua satellite in July 2017. Actively burning areas are shown in red.
Image courtesy NASA MODIS Rapid Response Team

These are drought-affected aspen trees in Colorado. The paper's authors argue that assessments of drought recovery need to account for the restoration of normal plant function, not just the amount of precipitation.
Image courtesy William and Leander Anderegg

New Normal: Incomplete Drought Recovery

Carnegie's Anna Michalak (left) and Yuanyuan Fang (right) were among the researchers on the drought study.
Images courtesy Robin Kempster and Yuanyuan Fang

The amount of time it takes for an ecosystem to recover from a drought is an important measure of a drought's severity. During the 20th century, the total area of land affected by drought increased, and longer recovery times became more common, according to new research published by *Nature* by a group of scientists including Carnegie's Anna Michalak and Yuanyuan Fang.

Scientists predict that more severe droughts will occur with greater frequency in the 21st century, so understanding how ecosystems return to normal again will be crucial to preparing for the future. However, the factors that influence drought recovery have been largely unknown until now.

"Research has usually focused on the amount of rain and other precipitation that ends the deficit of water that causes a drought, but assessments of drought recovery need to account for the restoration of normal plant function," explained Michalak.

The team—including three other alumni of Carnegie Global Ecology research groups, William Anderegg (University of Utah), Adam Wolf (Arable Labs Inc.), and Deborah Huntzinger (Northern Arizona University)—used measures of photosynthetic activity to assess drought recovery. Quantifying how long it took for plant productivity to return to normal gave the researchers a better understanding of the longevity of a drought's effects.

"If another drought arrives before trees and other plants have recovered from the last one, the ecosystem can reach a 'tipping point' where the plants' ability to function normally is permanently affected," Fang said.

The conditions most strongly contributing to drought recovery time were precipitation and temperature, they found. Unsurprisingly, better conditions shortened recovery. Temperature extremes, both hot and cold, lengthened it.

Recovery took the longest in the tropics, particularly the Amazon and Indonesia, and in the far north, especially Alaska and the far east of Russia.

Other factors influencing drought recovery included pre-drought photosynthetic activity, carbon dioxide concentrations, and biodiversity.

The team found that drought impacts increased over the 20th century. Given anticipated 21st century changes in temperature and projected increases in drought frequency and severity due to climate change, their findings suggest that recovery times will be slower in the future. A chronic state of incomplete drought recovery may be the new normal for the remainder of the 21st century and the risk of reaching "tipping points" that result in widespread tree deaths may be greater going forward. ■

COAUTHORS AND SUPPORT:
Other members of the team include lead author Christopher Schwalm of Woods Hole Research Center; Joshua Fisher of the Jet Propulsion Laboratory; Franco Biondi of the University of Nevada, Reno; George Koch and Kiona Ogle of Northern Arizona University; Marcy Litvak of the University of New Mexico; John Shaw of the U.S. Forest Service; Kevin Schaefer of the National Snow and Ice Data Center; Robert Cook and Yaxing Wei of Oak Ridge National Laboratory, Daniel Hayes of the University of Maine, Maoyi Huang of the Pacific Northwest National Laboratory; Atul Jain of the University of Illinois; and Hanquin Tian of Auburn University.

The National Science Foundation and NASA supported this research. Data management support for preparing, documenting, and distributing model driver and output data was performed by the Modeling and Synthesis, Thematic Data Center at Oak Ridge National Laboratory, with funding through NASA.

(Left) This artist's impression shows a quasar and neighboring merging galaxy. The galaxies observed by the team are so distant that no detailed images are possible. However, this combination of images of nearby counterparts gives an impression of how they might look. This image was created by the Max Planck Institute for Astronomy using material from the NASA/ESA Hubble Space Telescope.

(Right) Eduardo Bañados is the Carnegie-Princeton fellow at the Observatories and a coauthor of this research.

Super Star-Churning Galaxy Found

A team of astronomers, including Carnegie's Eduardo Bañados, has discovered a new kind of galaxy which, although extremely old—it formed less than a billion years after the Big Bang, creates stars more than a hundred times faster than our own Milky Way. *Nature* published their findings.

Roberto Decarli of the Max Planck Institute for Astronomy led the team. Their discovery could help solve a cosmic puzzle—a mysterious population of surprisingly massive galaxies from when the universe was only about 10 percent of its current age.

After first observing these galaxies a few years ago, astronomers proposed that they must have been created from hyperproductive precursor galaxies, which is the only way so many stars could have formed so quickly. But astronomers had never seen anything that fit the bill for these precursors until now.

This newly discovered population could solve the mystery of how these extremely large galaxies came to have hundreds of billions of stars in them when they formed only 1.5 billion years after the Big Bang.

The team made this discovery by accident when investigating quasars, which are supermassive black holes that sit at the center of enormous galaxies, accreting matter. They were trying to study star formation in the galaxies that host these quasars.

"But what we found, in four separate cases, were neighboring galaxies that were forming stars at a furious pace, producing a hundred solar masses' worth of new stars per year," Decarli explained.

"Very likely it is not a coincidence to find these productive galaxies close to bright quasars. Quasars are thought to form in regions of the universe where the large-scale density of matter is much higher than average. Those same conditions should also be conducive to galaxies forming new stars at a greatly increased rate," added Fabian Walter, also of Max Planck.

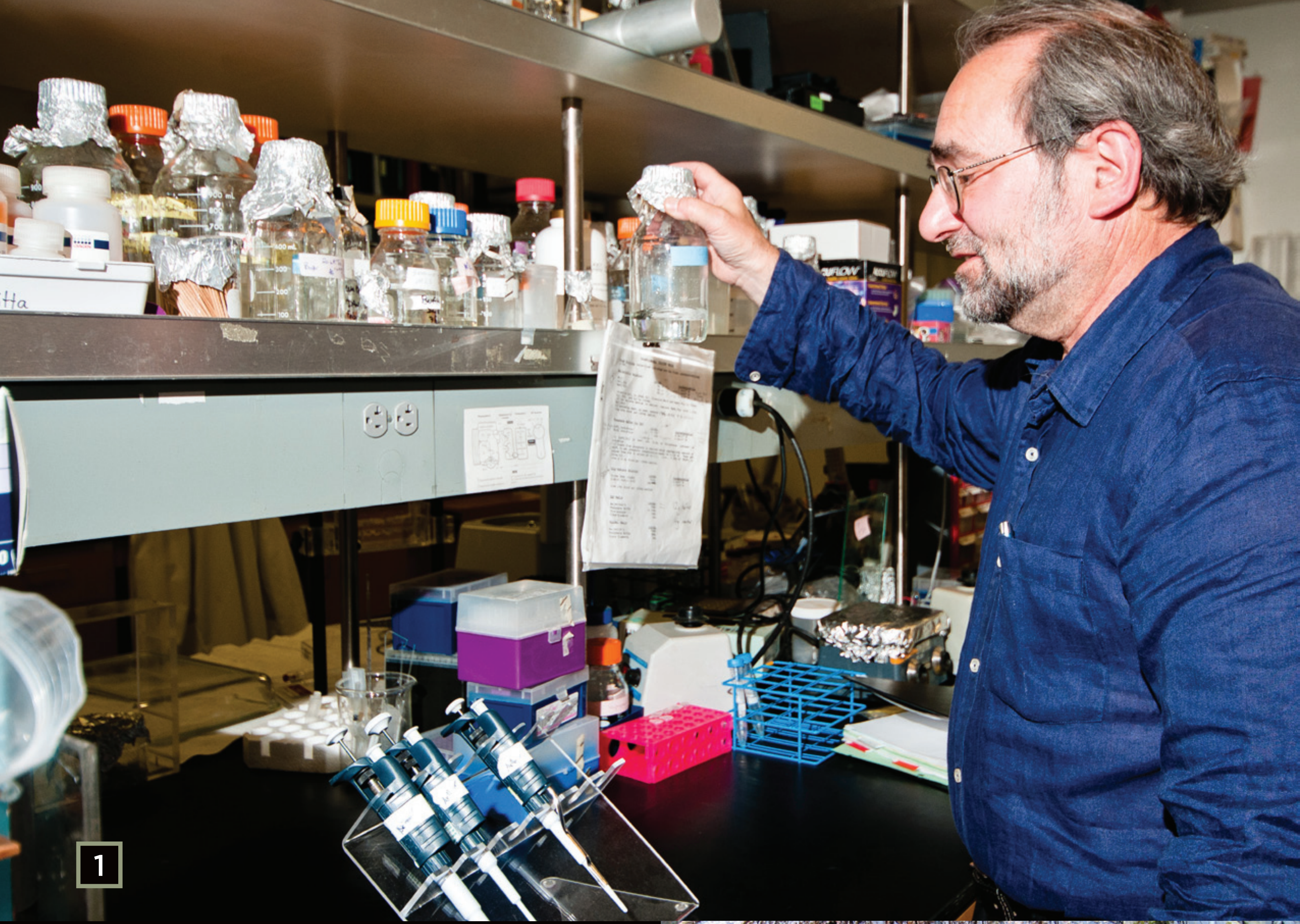
"Whether the fast-growing galaxies we discovered are indeed precursors of the massive galaxies first seen a few years back will require more work to see how common they actually are," Bañados explained.

Decarli's team already has follow-up investigations planned.

The team also found what appears to be the earliest known example of two galaxies undergoing a merger, which is another major mechanism of galaxy growth. The new observations provide the first direct evidence that such mergers have been taking place even at the earliest stages of galaxy evolution, less than a billion years after the Big Bang. ■

COAUTHORS AND SUPPORT:
Other members of the research team are Bram Venemans, Emanuele Farina, Chiara Mazzucchelli, and Hans-Walter Rix of the Max Planck Institute for Astronomy; Frank Bertoldi of the University of Bonn; Chris Carilli of the National Radio Astronomy Observatory and Cambridge University; Xiaohui Fan of the University of Arizona; Dominik Riechers of Cornell University; Michael A. Strauss of Princeton University; Ran Wang of Peking University); and Y. Yang of the Korea Astronomy and Space Science Institute.

The researchers were supported by the DFG priority programme 1573 "The physics of the interstellar medium," European Research Council grant COSMIC-DAWN, the National Science Foundation of China, the National Key Program for Science and Technology Research and Development, and a Carnegie-Princeton fellowship. The discoveries were made at ALMA Observatory, which is a partnership of the European Southern Observatory, the National Science Foundation, and the National Institutes of Natural Sciences, together with Canada's National Research Council, Taiwan's National Science Council and Academia Sinica Institute of Astronomy and Astrophysics, and the Korea Astronomy and Space Science Institute, in cooperation with Chile.



1. The Grossman lab has a wide range of projects: identifying new functions associated with photosynthetic processes, understanding mechanisms of coral bleaching, analyzing algae in various environments and conditions, studying the *Chlamydomonas* genome, and establishing methods for examining photosynthesis and acclimation processes, among other topics.
Image courtesy Robin Kempster

2. *Porphyra umbilicalis,* shown in this photo, was taken at low tide at Sand Beach, Acadia National Park, Maine.
Image courtesy Susan Brawley, Department of Energy

3. *Porphyra* is included in salads in Japan. It is called nori and is used to wrap sushi.
Image courtesy Japanese Cooking

4. Seaweed is used to make a Welsh favorite, laverbread, shown here. The sea product is mixed with oatmeal and molded into patties.
Image courtesy Galloway Wild Foods

The Promise of ALGAE

Algae dominate the oceans, covering nearly three-quarters of our planet. They produce half of the oxygen that we breathe. And yet fewer than 10 percent of the algae have been formally described in the scientific literature, as noted in a new review coauthored by Carnegie's Arthur Grossman.

Algae are everywhere. They form crust on desert surfaces and massive blooms in lakes and oceans. They range from tiny single-celled organisms to giant kelp.

Algae are also crucial to humans. People have eaten seaweed (macroalgae) for millennia. But they can also be a health hazard when toxic blooms suffocate lakes and coastlines.

Despite the pervasiveness and importance of algae, there is much that scientists don't know due to limited support and the need to develop methodologies for probing the different algal groups at the molecular level.

The term algae is used informally to embrace a large variety of photosynthetic organisms that belong to a number of different taxa. To effectively reveal the mysteries of each requires creating research processes for each.

Lately, some molecular techniques have allowed scientists to unravel major genetic processes that have shaped algal evolution. This improved knowledge has implications beyond basic scientific discovery. For example, algae might be used to produce biofuels or synthesize therapeutic compounds or plastics. Plus, with an improved understanding of algal metabolism, scientists can better develop strategies to exploit algae to produce materials—cellular factories, in a sense.

Many studies show that algae can also adapt to changing environmental conditions. But what are the limits, and how will the effect of climate change on the world's oceans impact algae and the oxygen that we derive from them?

"In the process of reviewing the state of algal research, we feel that we are on the cusp of a revolution in understanding this group of organisms, their importance in shaping ecosystems worldwide, and the ways in which they can be used to enrich mankind," said Grossman.

What Makes Red Algae So Different?

Along the lines of developing a better understanding of algae, Grossman and colleagues sequenced and analyzed the complete genome of the red algae *Porphyra umbilicalis*. This provides a better understanding of its evolution and the ways in which these organisms cope with their brutal intertidal habitat.

Porphyra and its ancestors have thrived for millions of years in the harsh habitat of the intertidal zone—exposed to fluctuating temperatures, high ultraviolet radiation, severe salt stress, and dryness.

Red algae comprise some of the oldest nonbacterial photosynthetic organisms on Earth, and they are one of the most ancient of all multicellular lineages. Some red algae play a major role in building coral reefs. They are also fundamentally integrated into human culture: *Porphyra,* included in salads, is called nori in Japan, where it is used to wrap sushi; it is called laver in Wales, where it is a traditional and nutritious ingredient.

Despite *Porphyra's* ecological, evolutionary, and commercial importance, there has been relatively little known about its molecular genetics and physiology.

The team's analysis showed that *Porphyra* and other red algae have minimal structural elements that make up their internal cellular cytoskeletons compared to other types of multicellular organisms. This may explain why the multicellular red algae tend to be small in stature.

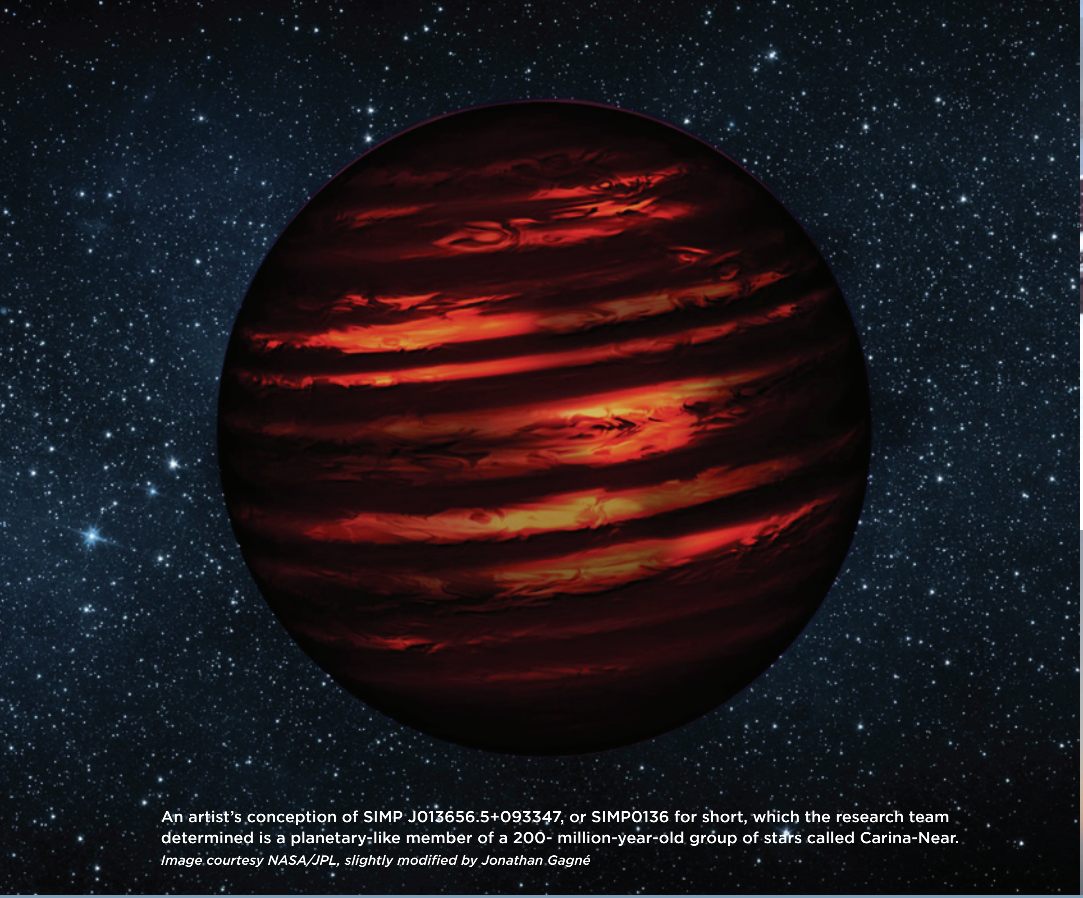
The team also found genes for cellular processes that help *Porphyra* and its ancestors survive under extreme duress—including sunscreen-like compounds that protect from ultraviolet radiation and compounds that allow them to withstand drying conditions. Additionally, they found proteins that improve the potentially toxic consequences of absorbing strong sunlight. The extremely resilient, flexible walls of *Porphyra* cells allow them to dramatically change volume as they lose water when baked by the Sun and dried by the winds and to withstand the forces of beating waves.

"The information we gleaned from the *Porphyra* genome shows us just how different red algae are," Grossman explained. "But it is also interesting to note that organisms evolutionarily related to the red algae have had profound impacts on human health and marine ecosystems."

For example, one group of organisms that evolved from the red algae, the apicomplexans, is nonphotosynthetic and includes parasites that cause malaria. Another algal group that evolved from the red algae, the dinoflagellates, not only is responsible for toxic red tides but also provides nutrients that sustain corals, which serve as the foundation of ecologically important reefs.

Grossman remarked, "As we learn more about the different algal groups and their evolutionary histories, we are learning more about the biotic pillars that continue to be a major foundation for sustaining and shaping life on our planet." *Proceedings of the National Academy of Sciences* published the findings. ■

COAUTHORS AND SUPPORT: Other coauthors on the review are Juliet Brodie of the Natural History Museum in London, Cheong Xin Chan of the University of Queensland, Oliver De Clerck of Ghent University, J. Mark Cock and Susan Coelho of Sorbonne Université, Claire Gachon of the Scottish Marine Institute, Thomas Mock of the University of East Anglia, John Raven of the University of Dundee and the University of Western Australia, Alison Smith of Cambridge University, Hwan Su Yoon of Sungkyunkwan University, and Debashish Bhattacharya of Rutgers University.



An artist's conception of SIMP J013656.5+093347, or SIMP0136 for short, which the research team determined is a planetary-like member of a 200- million-year-old group of stars called Carina-Near.
Image courtesy NASA/JPL, slightly modified by Jonathan Gagné

(Top) Jonathan Gagné has been a NASA Sagan Fellow at Carnegie since 2015.
Image courtesy Jonathan Gagné

(Bottom) Jackie Faherty was a Hubble Fellow at Terrestrial Magnetism from 2013 to 2016 before joining the American Museum of Natural History.
Image courtesy Jackie Faherty

Brown Dwarf Actually a Planetary-mass Object

Sometimes celestial objects called brown dwarfs are actually a planet, or planet-like anyway. A team led by Carnegie's Jonathan Gagné, including researchers from the Institute for Research on Exoplanets (iREx) at the Université de Montréal, the American Museum of Natural History (AMNH), and the University of California, San Diego, discovered that what was thought to be one of the closest brown dwarfs to our Sun is in fact a planetary-mass object. *The Astrophysical Journal Letters* published their results.

Brown dwarfs are smaller than stars but bigger than giant planets. They are too small to sustain hydrogen fusion that fuels stars. So after formation, brown dwarfs slowly cool down and contract, usually ending after a few hundred million years, with continuous cooling.

"This means that the temperatures of brown dwarfs can range from as hot as stars to as cool as planets, depending on how old they are," said Jackie Faherty, former Carnegie postdoctoral fellow, now with AMNH, and a coauthor.

The team determined that a well-studied object known as SIMP J013656.5+093347, SIMP0136 for short, is a member of a planetary-like, 200-million-year-old group of stars called Carina-Near.

Groups of similarly aged stars moving together through space are considered prime regions to search for free-floating planetary-like objects, because they provide the only means of dating these cold and isolated worlds. Knowing the age and temperature of such free floaters are necessary to determine the mass.

Gagné and the team demonstrated that at about 13 times the mass of Jupiter, SIMP0136 is at the boundary between brown dwarf-like properties, with the short-lived burning of deuterium in the core, and planet-like properties.

These free-floaters are valuable because they are very similar to gas giant exoplanets orbiting other stars in the Milky Way. But it is easier to study their atmospheres versus distant exoplanets, because dim light emitted by exoplanets is overwhelmed by the brightness of their host stars that blinds the instruments used to characterize exoplanet atmospheres.

"The implication that the well-known SIMP0136 is actually more planet-like than we previously thought will help us to better understand the atmospheres of giant planets and how they evolve," Gagné said.

They may be easier to study in great detail, but free-floating worlds are still extremely hard to discover without a lot of telescope time observing, because they can be located anywhere in the sky and they are hard to distinguish from brown dwarfs or very small stars. So only a handful of free-floating planetary-like objects have been identified so far.

Étienne Artigau, coauthor and leader of the original SIMP0136 discovery, added, "This newest addition to the very select club of free-floating planetary-like objects is particularly remarkable, because we had already detected fast-evolving weather patterns on the surface of SIMP0136, back when we thought it was a brown dwarf."

In a field where analyzing exoplanet atmospheres is of the utmost interest, having already seen evidence of weather patterns on an easier-to-observe free-floating object away from the brightness of its host star is an exciting realization. ■

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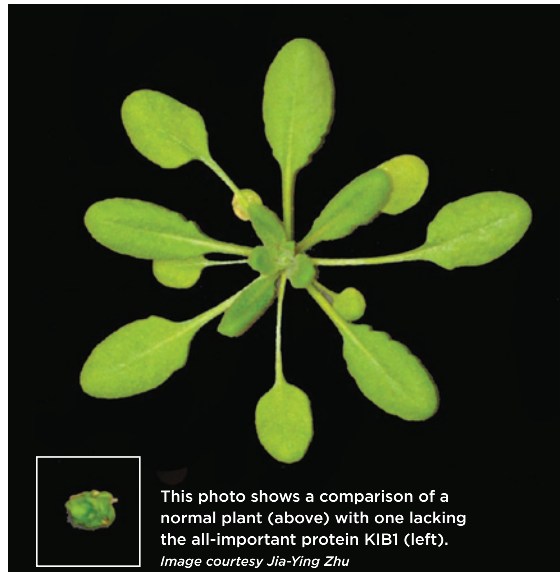


This photo shows a comparison of a normal plant (above) with one lacking the all-important protein KIB1 (left).
Image courtesy Jia-Ying Zhu

Since plants don't walk around, their growth must be highly regulated; they use the surrounding resources as advantageously as possible. A complex system of hormones guides this growth and maximizes plants' ability to take advantage of their environment. One mastermind class of hormones is called brassinosteroids.

Zhi-Yong Wang's lab has spent years homing in on the chemical cascade by which brassinosteroids activate and deactivate different proteins in a plant cell. Gaining a complete understanding of how such master hormones work could help scientists find targets for engineering high-yield crops and fighting world hunger.

Brassinosteroids can turn on or off more than 2,000 plant genes. They are crucial to normal plant growth—including stem architecture, flowering, and the development of pores called stomata, which allow plants to "breathe"—as well as reacting to environmental stresses. Plants that are engineered to lack the ability to make brassinosteroids have defects throughout their life cycle, including dwarfism, late flowering, and sterility.

Like all hormones, brassinosteroids control a chain reaction of cellular proteins—a signaling pathway—with each protein reacting on the next to either activate or inhibit an activity to maximize the plant's growth and survival.

New research from Carnegie's Jia-Ying Zhu and Wang identified one missing link in the brassinosteroid signaling chain. They found that this link, called K1B1, is an essential part of brassinosteroids' effectiveness as a master-regulator.

Mutant plants lacking KIB1 were insensitive to the presence of brassinosteroids and exhibited abnormal growth patterns.

"Elucidating hormone signaling pathways is like putting together a puzzle," Zhu said. "We uncover one piece at a time, working toward a full picture." ■

Zhi-Yong Wang's lab studies the brassinosteroid class of master hormones, which controls many aspects of plant growth and development. Postdoctoral fellow Jia-Ying Zhu (right) was lead author on this study. Understanding the hormone could help scientists find targets for engineering better crops.
Images courtesy Robin Kempster and Jia-Ying Zhu

SUPPORT:
The National Institutes of Health supported this work.

THE BUSINESS SIDE OF CARNEGIE SCIENCE

Scientific discovery does not happen in a vacuum. There is a vast support network of technicians, machinists, information technology personnel, and of course the business offices that allow Carnegie researchers to pursue research agendas of their own designs.

There have recently been four retirements from the business side and several new faces have arrived. This group is responsible for supervising the flow of money, managing procurement, coordinating benefits, working with federal agencies and auditors, managing Carnegie's endowment, keeping information technology upgraded and maintained, providing infrastructure for labs, greenhouses, animal facilities, and much, much more.

Despite the wide geographic distribution of the six research departments on both coasts with headquarters in Washington, D.C., the business team is a cohesive unit through the formation in 2006 of what is now called the Administration Working Group.

The working group is comprised of senior administrative staff from headquarters and the departments. The group reports to the chief operating officer (Tim Doyle) and is coordinated and organized by two cochairs, one person from the P Street administration and one from the departments. The group helps strengthen administrative, financial, and technology applications to support Carnegie's scientific mission. They participate in training related to regulatory requirements, Carnegie policies and procedures, and nonprofit best practices.

The group meets monthly via teleconference and annually in person. Attendance is mandatory and minutes of the meetings are sent to the president and department directors and are reported to the board of trustees. ■

Four Members of the Business Staff Recently Retired:

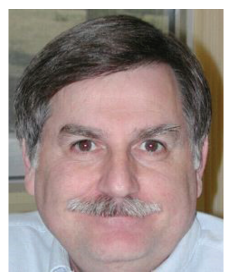
(Left) Current members of the Administration Working Group met at the Broad Branch Road Campus in the spring. Front row (from left): Lara Budeit (Executive Assistant to the Chief Operating Officer), Tony DiGiorgio (Associate Director, Information Technology), Jessica Moore (Director of Finance), Jessie Chen (Assistant Business Manager, Plant Biology/Global Ecology), Carol McMullen (Human Resources and Administration Manager, Plant Biology/Global Ecology). Second row (from left): Loronda Lee (Associate Director, Human Resources), Ben Aderson (General Counsel), Marj Burger (Senior Financial Analyst), Sonya Bajwa (Business Manager, Embryology), Kristi Macklin (Business Manager, Observatories). Back row (from left): Trong Nguyen (Assistant Controller, Geophysical Laboratory), Harminder Singh (Headquarters Controller), Tim Doyle (Chief Operating Officer), Wan Kim (Business Manager, Terrestrial Magnetism), Jeff Lightfield (Controller, Geophysical Laboratory).
Image courtesy Anat Shahar

Kathi Bump of Plant Biology and Global Ecology, Marj Burger from P Street Administration, Vgee Ramiah of the Observatories, and Terry Stahl of Terrestrial Magnetism. Collectively they had over 80 years of Carnegie business experience, led by Stahl who retired after spending 39 years at DTM and five years at Carnegie headquarters.

Kathi Bump started with Plant Biology in 1995 as an administrative assistant. She held various positions there until 2006, when she was named the business manager of Plant Biology and Global Ecology, which share space on the Stanford University campus. Bump was honored with the Service to Science award in 2012. Her level of dedication is legendary; she handled issues ranging from accounting, inventory, facilities, the care of students and visitors, and even the proper functioning of the soda machine.

Marj Burger joined the P Street Administration as a financial accountant in 2002 and was promoted to controller in 2007. In 2011 she stepped in as the interim director of administration and finance, and in 2013 she became senior financial analyst. Over the many years she worked at P Street Burger developed a strong bond with the department business managers and the respect of all of her peers within administration. She was honored with this year's Service to Science Award (see page 4).

Vgee Ramiah led the Observatories business office beginning in 2007. She was responsible for all financial and human resources management in Pasadena, and she had financial oversight of the Las Campanas Observatory in Chile. That was a big job, with budgeting and reporting to the Magellan Council. Through her hard work and dedication, Ramiah ensured that the Observatories exceeded fiduciary and regulatory reporting requirements while helping to support the scientific mission. As demanding as this role was, she always found time to share her knowledge and lead special projects. She made a point to get to know everyone, and all the staff is truly appreciative of all her many contributions.



Terry Stahl had been the business manager at the Department of Terrestrial Magnetism since 1978. He was the recipient of the 2011 Service to Science Award. His role as a business manager changed significantly over the years as the department grew. With just one assistant over most of his tenure, Stahl efficiently and effectively managed an increasingly complex workload, tackling ever-increasing requirements for federal grants while providing outstanding service to staff members and postdoctoral researchers. He managed multidepartmental, multiinstitutional cooperative agreements with Carnegie's participation in the NASA Astrobiology Institute and the multimillion-dollar NASA contract for the MESSENGER Mission to Mercury. ■

Science Writers Tour Broad Branch Road Campus

The Broad Branch Road Campus hosted almost two dozen science writers from the D. C. Science Writers Association on June 17, 2017. The writers learned how researchers conduct their science by visiting different instrument facilities. Postdocs and staff researchers conducted demonstrations in the electron microscopy lab, the high-pressure facility, and the stable isotope lab. The writers also learned how new Solar System objects are found, how mass spectrometers and ion probes work to analyze and age date Earth and space rocks, and the performance and deployment of modern seismometers. The group at left includes scientists, participants, and organizers. ■
Image courtesy Michelle Scholtes

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SEPTEMBER 28, 2017 / 6:30 P.M.

Dr. James E. Rothman
How Vesicles in our Cells Allow Communication in the Body and the Brain
Nobel Laureate in Physiology or Medicine, Sterling Professor and Chair, Department of Cell Biology, Yale University School of Medicine

Registration opens August 28, 2017
#VESICLES

OCTOBER 25, 2017 / 6:30 P.M.

Drs. Giada Arney and Shawn Domagal-Goldman
Pale Rainbow Dots: The Search for Other Earths
Astrobiologists, NASA Goddard Space Flight Center

Registration opens September 25, 2017
#OTHEREARTHS


DECEMBER 13, 2017 / 6:30 P.M.

Dr. Ayanna Howard
Pediatric Robotics: A Journey from Lab Innovations to Social Impact
Professor, Linda J. and Mark C. Smith Endowed Chair, School of Electrical & Computer Engineering, Georgia Institute of Technology, Chief Technology Officer, Zyrobotics

Registration opens November 13, 2017
#PEDIATRICROBOTICS

JANUARY 16, 2018 / 6:30 P.M.

Drs. Peter and Rosemary Grant
40 years of Evolution of Darwin's Finches
Professors emeriti, Princeton University

Registration opens December 16, 2017
#DARWINSFINCHES