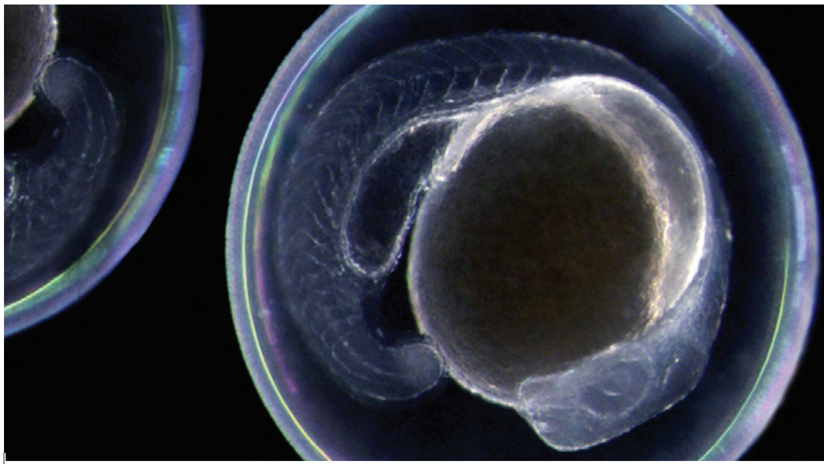
CarnegieScience

The Newsletter of the Carnegie Institution for Science

FALL 2016

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



On the Inside

How Roots Bank Water During Drought 5

Toxic Waters and Climate Change 8

New Path to Superconductivity 17

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Appreciating Our Postdocs!

For the second consecutive year, Carnegie Science celebrated National Postdoc Appreciation Week September 19th through the 23rd. As part of the festivities, I gave a talk at the Broad Branch Road campus, home to Terrestrial Magnetism and the Geophysical Lab. The subject "How to Give a Good Talk: Finding and Keeping a Job" was part of our new initiatives to further nurture our absolutely essential postdoctoral fellows. Each of the departments planned other events as well.

Since the last year's celebration, our first one, we have made substantial progress in promoting, supporting, and encouraging our postdocs in the work that they do to advance Carnegie Science and to advance their own careers.

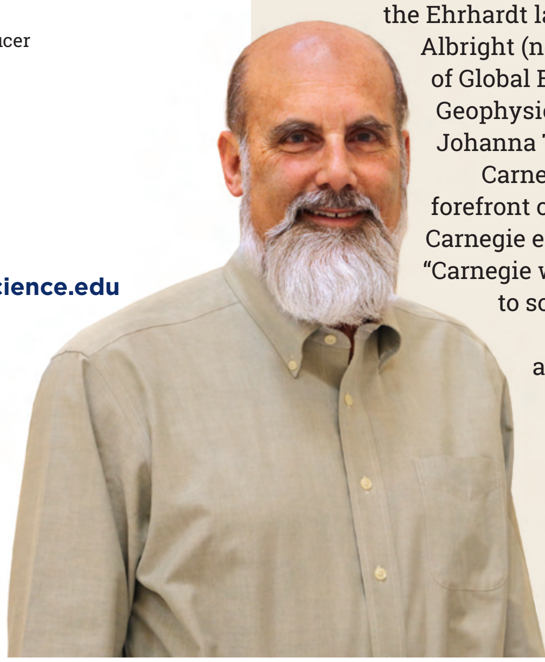
Perhaps the most important milestone is the establishment of the Carnegie Institution Postdoctoral Association, initiated by the postdocs themselves. In the last year, the postdocs in every department have formed a postdoc "chapter." This group provides a forum to develop social and networking opportunities, to work with the administration to optimize the postdoctoral experience, to enhance professional and career development, and more.

To encourage the out-of-the-box science that Carnegie is known for, we also established the Postdoctoral Innovation and Excellence (PIE) Awards. Under this program, one postdoc is honored every quarter for his or her extraordinary accomplishments. These nominations are made through the department directors, and the recipients are chosen by the Office of the President. The award recipient is given a cash prize and is the guest of honor at a departmental gathering where all the postdocs enjoy some celebratory pies! This year we awarded the first four awards to Matt Sieber of Embryology, Rebecca Albright of Global Ecology (now at the California Academy of Sciences), Johanna Teske of Terrestrial Magnetism and now the Observatories, and Zehra Nizami of Embryology. They are all a true testament to Andrew Carnegie's original vision of supporting individuals who pursue particularly imaginative work.

In addition to these recognitions, postdocs are also encouraged to collaborate with senior scientists on another new program we initiated over the last year—the Carnegie Science Venture grants. These are internal awards of up to $100,000 to foster entirely new directions of research by teams that ignore departmental boundaries. Up to six grants may be funded each year. There are a number of postdocs on these teams, including several in Yixian Zheng's lab and one joining the Ehrhardt lab in December. Others include research associates Rebecca Albright (now at the California Academy of Sciences) and Robin Martin of Global Ecology, Zehra Nizami of Embryology, Stephen Elardo of the Geophysical Lab, Sergio Dieterich of Terrestrial Magnetism, and Johanna Teske at the Observatories.

Carnegie postdocs are absolutely critical to keeping us at the forefront of discovery. I hope that these new initiatives further enrich the Carnegie experience for our young scientists. They will carry with them the "Carnegie way" of innovative research when they move on in their careers to some of the most prestigious institutions all over the world.

Join me in thanking all the postdocs for their hard work and dedication!



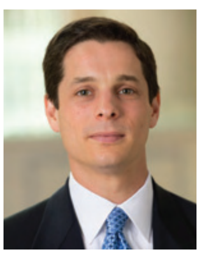
Matthew Scott, *President*

New Chief Development Officer and First General Counsel Join Carnegie

Ann McElwain was appointed the new Chief Development Officer starting July 1, 2016. She came from Dartmouth College where she was Executive Director of Leadership Giving. Benjamin Aderson also joined as Carnegie's first General Counsel on August 15, 2016. He was Managing Director of Legal Affairs at the Pew Research Center.

Ann McElwain

With 17 years of experience, McElwain brings a rich portfolio to Carnegie, including her highly successful fundraising, marketing, and management experience. She has been involved in three capital campaigns, strategic planning, donor relations, alumni relations, volunteer and board management, corporate/foundation relations, staff recruiting and development, and much, much more. Before Dartmouth, she served eight years at the University of Florida as Assistant Vice President of Development. Her undergraduate degree is in economics and she has an M.B.A.



Benjamin Aderson

Aderson brings more than 10 years of experience providing legal counsel to organizations and serving as a corporate secretary. At the Pew Research Center, he oversaw all legal matters, including transactions, compliance, governance, and risk management. Previously, he served as Senior Vice President, Operations, General Counsel, and Secretary at the global technology trade association TechAmerica. He has also worked in Congress, on political campaigns, in private practice, and at the Department of Justice's Antitrust Division. Aderson received a B.A. in political science and in history from the University of Chicago and his J.D. from Northwestern University School of Law. ■

Postdoctoral Astronomers Rachael Beaton & Eduardo Bañados

Receive Prestigious Awards

The Astronomical Society of the Pacific (ASP) awarded Observatories' postdoctoral associate Rachael Beaton the 2016 Robert J. Trumpler Award for a Ph.D. thesis "considered unusually important to astronomy." In addition, the Observatories' Carnegie-Princeton Fellow Eduardo Bañados received the Otto Hahn Medal from Germany's Max Planck Society. It honors young researchers for outstanding scientific achievements.

Beaton studies the structure of galaxies to probe their evolution and formation. In particular, she investigates the outer halos of galaxies because they are billions of years old and the stars can retain a "memory" of how they evolved via merging events. She primarily explores the nearby galaxy M31 using techniques that other astronomers use to study the Milky Way. Beaton's dissertation, honored by the ASP, was titled "Life in the Outer Limits: Insights on Hierarchical Assembly from Stellar Halos in the Local Universe."

Bañados' work explores how and when the first stars, galaxies, black holes, and structure of the universe evolved. He received the Otto Hahn Medal "for groundbreaking studies regarding the characterization of quasars in the very early universe." Quasars are supermassive black holes accreting material in the center of massive galaxies. They are the most luminous objects in the universe and the most distant objects that can currently be studied in detail, providing a snapshot of our infant universe.

Observatories Director John Mulchaey remarked, "We pride ourselves in having one of the best postdoc programs in all of astronomy and astrophysics. The awards given to Rachael and Eduardo for their research demonstrate that we are attracting some of the best and brightest young astronomers to work at the Observatories." ■

Carnegie-Princeton Fellow Eduardo Bañados received the Otto Hahn Medal from Germany's Max Planck Society for his early-career outstanding scientific achievements.

Rachael Beaton received the 2016 Robert J. Trumpler Award from the Astronomical Society of the Pacific for her Ph.D. thesis "considered unusually important to astronomy."

3 NEW VENTURE GRANTS AWARDED

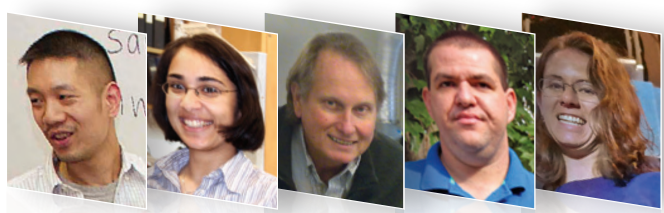
President Matthew Scott and Science Deputy Margaret Moerchen announced three new Carnegie Science Venture Grants in July. The program is designed to support investigations led by Carnegie scientists that ignore conventional boundaries and bring together cross-disciplinary teams providing fresh eyes for new questions. Each grant provides $100,000 support. Up to six adventurous investigations may be funded each year. Awards are distributed twice yearly, in spring and fall following the proposal and review process. The belief is that these projects will grow in unexpected ways with many surprises.

Arthur Grossman Rebecca Albright Ken Caldeira

1 Art Grossman of Plant Biology is teaming up with Global Ecology's Rebecca Albright (now at the California Academy of Sciences), Ken Caldeira, and others to develop a new model for understanding how coral calcification works at the cellular/molecular and community levels. The team will collaborate with the California Academy of Sciences to build a laboratory-based coral model system and focus on the critical larval and metamorphosis period when cells begin to calcify. It has a potential biomedical spin-off—the generation of bone material for grafting.

Yixian Zheng David Ehrhardt

2 Embryology's Yixian Zheng's lab is teaming up with David Ehrhardt's lab at Plant Biology to determine how plants sense temperature and time their flowering. This team will investigate the molecular mechanisms that control how plants sense temperature changes. Temperature changes affect carbon fixation, development, the timing of flowering, and more. The timing of flowering is particularly important with global temperature rise. They will investigate a plant protein, similar to one in animals, to investigate temperature-dependent phase transition to regulate the flowering process.



Frederick Tan Zehra Nizami Alan Boss Sergio Dieterich Johanna Teske

3 Frederick Tan and Zehra Nizami of Embryology are teaming up with Terrestrial Magnetism's Alan Boss, Sergio Dieterich, and Johanna Teske (also with the Observatories) to combine Carnegie's experience in cell, molecular, and computational biology expertise with astronomical and astrophysical observations and programming experience to create C-MOOR: The Carnegie Massive Open Online Research Platform, an internet resource that allows data sets to be accessed and analyzed by citizen scientists. Carnegie researchers are invited to help establish a community website with tutorials, discussion forums, an "Ask a Scientist" query portal, and other engaging features. This platform targets users seeking course credit, scouting, or merit badges as well as those driven by sheer curiosity. ■

This excavated maize seedling shows crown roots beginning to grow from the base of the shoot (red arrowhead).
Image courtesy Jose Sebastian

How Roots Bank Water During Drought

With a growing world population and a changing climate, understanding how agriculturally important plants respond to drought is crucial. New work from a team led by Carnegie's José Dinneny discovered a strategy used by grasses in drought conditions that could potentially be harnessed to improve crop productivity. *Proceedings of the National Academy of Sciences* published their findings.

Plants obtain most of their water through their roots. But there are different kinds of roots in different kinds of plants. The study focused on grasses, a family that includes maize, sorghum, sugarcane, and other commercially important species.

Crown roots are the major conduits by which grasses take up water. They are unique to this plant family and grow from regions of the shoot at the soil surface, called the crown. The crown root system starts to form after the seedling has sprouted and expands throughout its life.

"Crown roots are like the lanes of a highway connecting the suburbs to the city. As the plant grows, new lanes are added to this highway to increase the flux of water and nutrients from the soil to the shoot," explains Jose Sebastian, a postdoctoral fellow and lead author of the study.

Until now, little was known about how drought and low-water conditions affected crown root development compared with other types of roots, and how such changes might influence tolerance to stress.

Dinneny's team—which included current and former Carnegie plant biologists Jose Sebastian, Muh-Ching Yee (co-lead author), Willian Goudinho Viana, Rubén Rellán-Álvarez, and Charlotte Trontin—was able to demonstrate that water shortages suppress crown root growth in grasses.

The crown region of the plant is crucial for sensing water in the topsoil. When water is scarce, the development of crown roots is suppressed and the grass maintains a more limited root system, the team found.

"We normally think about roots as providing access to water, thus it was initially unclear why a plant would shut down root growth under drought," Dinneny explained. "We discovered, however, that this response allows the plant to slow the extraction of water from soil and bank these reserves for the future, sort of like the plant version of economic austerity."

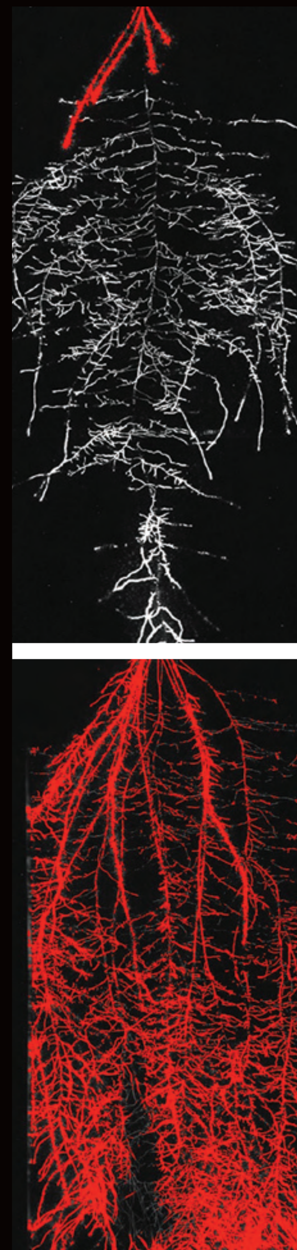
These "austerity measures" are not permanent. When moisture is reintroduced into the soil, crown root growth is quickly reactivated. Crown-root suppression is much less dramatic in domesticated grasses such as maize and millet than it is in the wild.

"This suggests to us that plant breeding has unintentionally affected these crop plants' abilities to cope with drought," Dinneny said.

This makes crown root development a potentially interesting target for those trying to improve crop yields, particularly under water-limiting conditions. Targeted breeding aimed at fine-tuning this response to drought in maize and other crop plants could improve their productivity and preserve precious ground-water resources.

Other members of the team include Max Feldman, Henry Priest, Hui Jiang, Ivan Baxter, Todd Mockler, and Thomas Brutnell of the Donald Danforth Plant Science Center; Tak Lee of Yonsei University; and Frank Hocholdinger of University of Bonn. ■

SUPPORT:
The Biosystems Design initiative at the Department of Energy, Office of Biological and Energy Research provided primary funding for this work.



Roots systems of plants are revealed using the GLO-Roots luminescence imaging system, which uses a firefly protein to visualize roots in soil. The root system on the top is from an early stage plant that is just beginning to initiate crown roots, whereas the plant on the bottom has a crown root system that is fully established. Crown roots are colored in red.
Image courtesy Jose Sebastian

(Above left) Lead author, Jose Sebastian (left) stands with José Dinneny (right) and co-lead author Muh-Ching Yee (front) in the Plant Biology greenhouse.
Image courtesy Robin Kempster

RE-TOOLING THE EXOPLANET HUNT

This image is an artist's conception of an exoplanet.
Image courtesy NASA/Ames/JPL-Caltech

OTHER AUTHORS & SUPPORT:

Other members of the team were: Guillem Anglada-Escude of U. London and the Centre for Astrophysics Research; Elise Furlan, Carolyn Brinkworth, Chas Beichman, and David Ciardi of the NASA Exoplanet Science Institute (Brinkworth also of the National Center for Atmospheric Research); Cassy Davison, Todd Henry, and Russel White of Georgia State U.; Angelle Tanner of Mississippi State U.; Adric Riedel and Michael Bottom of the California Institute of Technology (Caltech); David Latham and John Johnson of the Harvard-Smithsonian Center for Astrophysics; Sean Mills of U. Chicago; Kent Wallace, Bertrand Mennesson, Gautam Vasisht, and Timothy Crawford of the Jet Propulsion Laboratory (JPL); Kaspar Von Braun and Lisa Prato of Lowell Observatory; Stephen Kane of San Francisco State U.; Eric Mamajek of U. Rochester; Bernie Walp of the NASA Dryden Flight Research Center; Raphael Rougeot of the European Space Research and Technology Centre; Claire Geneser of Missouri State U.; and Joseph Catanzarite of NASA Ames Research Center.

An Infrared Processing and Analysis Center (IPAC) fellowship, a grant from the Fonds de recherche Québec—Nature et technologies and the Natural Science, a grant from the Engineering Research Council of Canada, an iREx postdoctoral Fellowship, and a JPL Research and Technology Development Grant supported this work. This work was performed in part under contract with Caltech/JPL funded by NASA through the Sagan Fellowship Program executed by the NASA Exoplanet Science Institute.

Planet hunting is resulting in the discovery of more and more planets orbiting distant stars. As the hunters learn more about the variety among the tremendous number of predicted planets out there, it is important to refine their techniques. Carnegie's postdoctoral fellow Jonathan Gagné, Caltech's Peter Gao, and Missouri State University's Peter Plavchan report on a technological upgrade for one method of finding and confirming these exoplanets. *The Astrophysical Journal* published their results.

One of the most successful planet-hunting techniques is the radial velocity method. This technique takes advantage of the fact that a planet's gravity affects its star; astronomers are able to detect the tiny wobbles of a star from its tugging planet.

For certain kinds of low-mass stars, however, there are limitations to the standard radial velocity method, which can cause false positives; it finds something that looks like a planet, but isn't.

To address this issue, Gagné, Gao, and Plavchan decided to use the radial velocity technique at a different, longer wavelength of light.

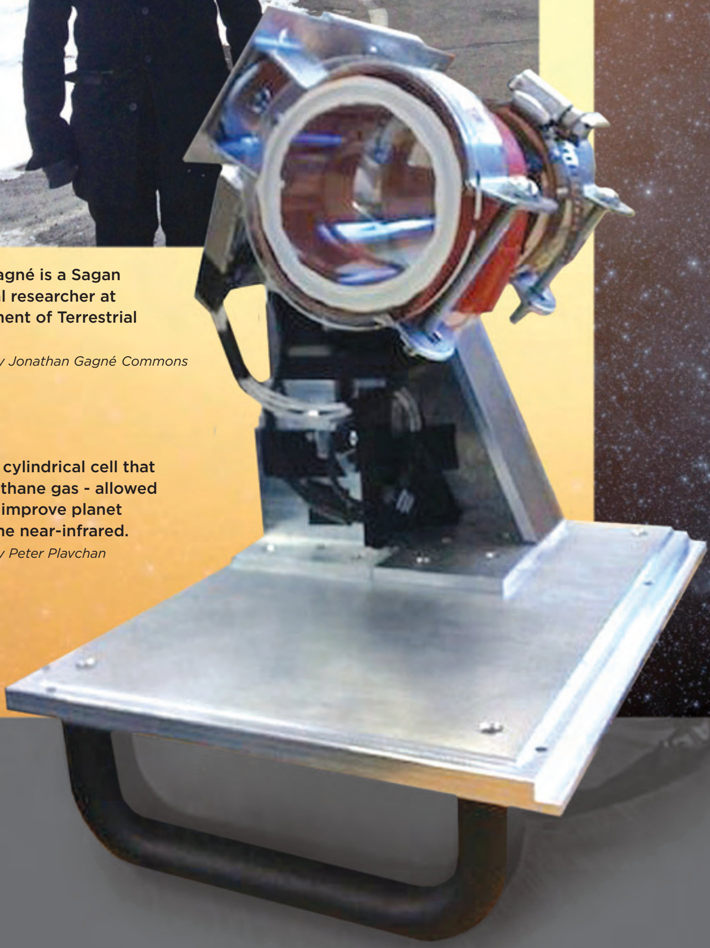
"Switching from the visible spectrum to the near-infrared, the wobble effect caused by an orbiting planet will remain the same regardless of wavelength," Gagné explained. "But looking in the near-infrared will allow us to reject false positives caused by sunspots and other phenomena, which will not look the same in near-infrared as they do in visible light."

Radial velocity work in the near-infrared wavelengths has been conducted before, but it has trailed behind planet hunting in the visible spectrum, partially due to technical challenges. The team was able to develop a better calibration tool to improve the overall technology for near-infrared radial velocity work, which should make it a better option going forward.

They examined 32 low-mass stars using this technological upgrade at the NASA Infrared Telescope Facility atop Mauna Kea, Hawaii. Their findings confirmed several known planets and binary systems and identified a few new planetary candidates.

"Our results indicate that this planet-hunting tool is precise and should be a part of the mix of approaches used by astronomers going forward," Gao said. "It's amazing to think that two decades ago we'd only just confirmed exoplanets actually existed, and now we're able to refine and improve those methods for further discoveries." ■

Jonathan Gagné is a Sagan postdoctoral researcher at the Department of Terrestrial Magnetism.
Image courtesy Jonathan Gagné Commons



This tool - a cylindrical cell that contains methane gas - allowed the team to improve planet hunting in the near-infrared.
Image courtesy Peter Plavchan

As weather patterns become more extreme under climate change, so will water quality impacts.

This image shows the algal blooms in Lake Erie in July 2015.
Image courtesy NASA Earth Observatory by Joshua Stevens, using Landsat data from the U.S. Geological Survey

TOXIC WATERS & CLIMATE CHANGE

Carnegie's Anna Michalak says it is imperative that society learns more about how climate change contributes to severe water quality impacts, such as the harmful algal bloom that caused Florida to declare a state of emergency this summer. She discussed the matter in a commentary published by *Nature*.

Carnegie's Anna Michalak wrote the commentary that appeared in *Nature*.
Image courtesy Robin Kempster

"The scientific community has made remarkable progress in understanding the role of climate in the occurrence and intensity of droughts, storms, and other extreme events relating to water quantity," Michalak writes. "It is time for a similar examination of extremes in water quality."

Severe and periodic water quality issues are a growing problem around the world and affect water that is used for drinking, agriculture, and recreation. They range from harmful algal blooms and hypoxic "dead zones" to microbial and chemical contamination.

"Cases of extreme [water quality] impairment often lead to disproportionate human and ecosystem impacts," Michalak writes. "The costs can be huge."

Last year, a toxic algal bloom in Lake Erie was the largest ever recorded, spreading well over 100 miles across most of the lake. A similar 2014 Lake Erie bloom spurred city officials in Toledo, Ohio, to warn more than 500,000 neighboring residents against drinking their tap water. It contained liver toxins 2.5 times higher than World Health Organization safety standards.

Another harmful bloom last year stretched between Baja Mexico and Alaska in the Pacific Ocean and was dominated by neurotoxin-producing algae. It shut down fisheries and caused severe brain damage in sea lions.

Most severe water quality issues are exacerbated by weather. As climate change alters weather patterns, the conditions that create severe water quality problems are likely to become more frequent, Michalak argues.

Michalak writes, "There is a pressing need to understand which meteorological conditions, in what combination, make extreme water quality impairments most likely."

Algal blooms in Lake Okeechobee this year are shown in this image.
Image courtesy NASA Earth Observatory by Joshua Stevens, using Landsat data from the U.S. Geological Survey

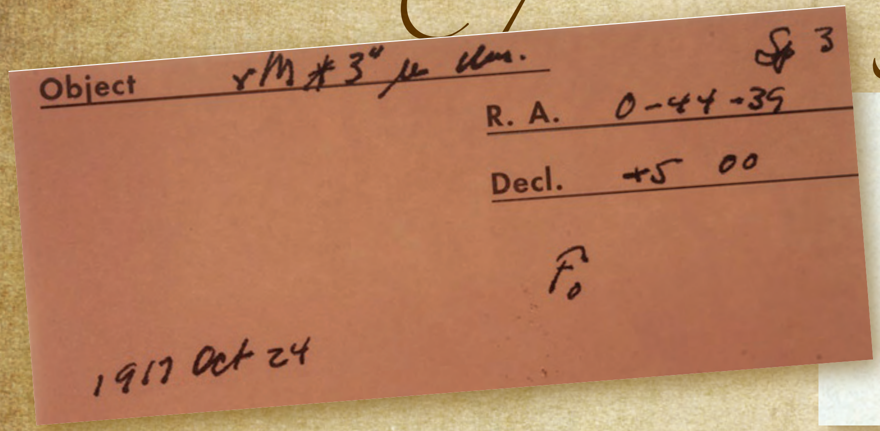
The three harmful algal bloom examples listed above have both commonalities and differences. In Florida, heavy rainfall led the Army Corps of Engineers to release water from Lake Okeechobee into the St. Lucie Estuary to prevent flooding; the pulse of nutrient-rich water triggered the bloom. In Lake Erie, area farming leads to fertilizer being flushed into the lake each year; the amount of fertilizer and its impact on the lake are affected by rainfall patterns and lake circulation, which is also impacted by temperature and winds. On the West Coast last year, unusually warm waters in the Pacific likely contributed to the growth of that bloom.

All of these extreme events can be linked to weather events. As weather patterns become more extreme under climate change, so will water quality impacts.

Once scientists learn more about the links between climate change and extreme water quality, they must inform the broader global discussion around water policy, Michalak adds.

Last autumn, for example, the United Nations adopted 17 Sustainable Development Goals for 2030. One of these was to "ensure availability and sustainable management of water and sanitation for all." To achieve this goal, it is necessary to understand what drives extreme impacts and to figure out how to anticipate what the future holds for our crucial water. ■

1917 First-Ever Evidence of an Exoplanetary System



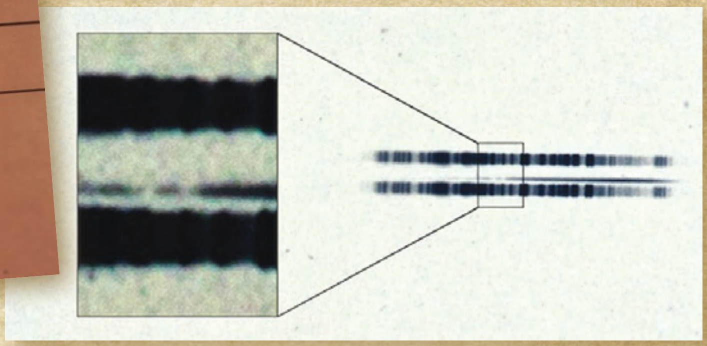



Image courtesy Tim Neighbors

John Mulchaey has been the director of the Carnegie Observatories since April 2015.

You can never predict what treasure might be hiding in your basement.

It turns out that a 1917 image on an astronomical glass plate from the Carnegie Observatories' collection shows the first-ever evidence of a planetary system beyond our own Sun. This unexpected find was recognized in the process of researching an article about planetary systems surrounding white dwarf stars in *New Astronomy Reviews*.

About a year ago, the review's author, Jay Farihi of University College London, contacted Observatories' Director John Mulchaey. He was looking for an archival plate that contained a spectrum of van Maanen's Star, a white dwarf discovered by Dutch-American astronomer Adriaan van Maanen in the year the plate was made.

The plate showed stellar spectra. Spectra spread out all component colors of light. These patterns of light reveal a star's chemical composition. They can also tell how the light emitted: A star's light is affected by the chemistry of the material that it passes through before it gets to Earth.

Spectral images allowed 19th century astronomers to develop a system for classifying stars that is still used today. For decades, astronomers used glass photographic plates to take images of the sky and to record stellar spectra.

The Observatories located the 1917 plate, made by former Observatories Director Walter Adams at Mount Wilson Observatory—then part of Carnegie. Everything seemed very ordinary. However, when Farihi examined the spectrum, he found something quite extraordinary.

The clue was in what's called an "absorption line" on the spectrum. Absorption lines indicate that the star's light passed through something and had a particular color of light absorbed by that substance. These lines indicate the chemical makeup of the interfering object.

Carnegie's 1917 spectrum of van Maanen's Star revealed the presence of heavier elements, such as calcium, magnesium, and iron, which should have long since disappeared into the star's interior due to their weight.

Only within the last 12 years has it become clear to astronomers that van Maanen's Star and other white dwarfs with heavy elements in their spectra represent a type of planetary system featuring vast rings of rocky planetary remnants that deposit debris into the stellar atmosphere. These recently discovered systems are called "polluted white dwarfs." They were a surprise to astronomers, because white dwarfs are stars like our own Sun at the end of their lifetimes, so it was not at all expected that they would have leftover planetary material around them at that stage.

"The unexpected realization that this 1917 plate from our archive contains the earliest recorded evidence of a polluted white dwarf system is just incredible," Mulchaey said. "And the fact that it was made by such a prominent astronomer in our history as Walter Adams enhances the excitement."

"Carnegie has one of the world's largest collections of astronomical plates with an archive that includes about 250,000 plates from three different observatories—Mount Wilson, Palomar, and Las Campanas," concluded Mulchaey. "We have a ton of history sitting in our basement and who knows what other finds we might unearth in the future?" ■

Top right: The photo shows the 1917 photographic plate spectrum of van Maanen's Star from the Carnegie Observatories' archive. The pull-out box shows the strong lines of the element calcium, which are surprisingly easy to see in the century-old spectrum. The spectrum is the thin, (mostly) dark line in the center of the image. The broad dark lanes above and below it are from lamps used to calibrate wavelength; they are contrast-enhanced in the box to highlight the two "missing" absorption bands in the star.

Top left: Observer Walter Adams, former Director of Mount Wilson Observatory, made these handwritten notes on the sleeve of the astronomical plate.

Images courtesy Carnegie Observatories

BioEYES 100,000th Student Milestone!

Over the weeklong program, BioEYES students and teachers watch transparent zebrafish develop. They learn about cells, DNA, genetics, and more.
Image courtesy BioEYES

Tiny transparent zebrafish are changing lives through the BioEYES program, run from Carnegie's Department of Embryology. A former BioEYES student in Baltimore, Sih Oka Zeh, shared that BioEYES was the catalyst for following a career path in the sciences.

"I had BioEYES in 7th grade. Before they came I was told we were going to do an experiment with fish and microscopes. I wasn't interested. But then they showed up with all this equipment I'd never seen before. We got to work with the fish and I was so excited. I was mad at the end of the week when they left. I wanted to do more. I wasn't interested in science or research until I had BioEYES. They are the reason I went to a magnet science high school, and why I am majoring in biology and public health at Washington University in St. Louis.

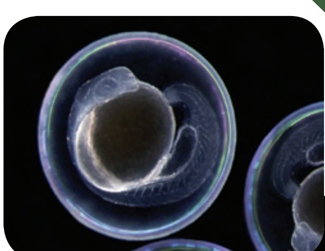
Thank you BioEYES." — SIH OKA ZEH

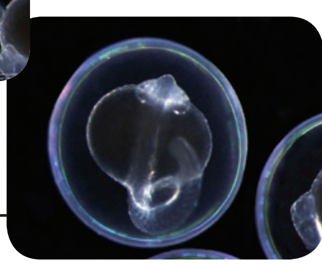
Sih is one of the 100,000 students who have experienced the excitement of BioEYES since the program was founded in 2002. Over the weeklong program, students and teachers alike watch transparent zebrafish miraculously develop and learn about cells, DNA, and genetics. By day four, they marvel at the fish's beating heart and blood flow.

Carnegie biologist Steven Faber started BioEYES with educator Jamie Shuda at the University of Pennsylvania. Farber brought BioEYES to Carnegie in 2007.

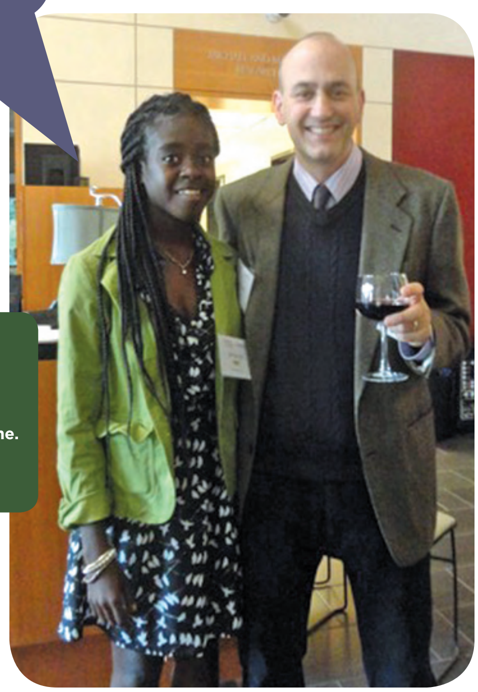
"Jamie and I wanted to foster an interest in and a love for science in elementary, middle, and high school students. It is incredibly gratifying to watch our work over the past 14 years bring the excitement of science to so many," remarked Farber.

The program has engaged 1,400 teachers in two countries—in Australia and in six states in the U.S. "It turns out that our work in training teachers has made a huge impact," Farber said. "When a teacher's understanding of science increases, then their confidence to create innovative and engaging science lessons takes off. I am hoping that since we have now served 100,000 students there will be many more in the STEM (Science, Technology, Engineering, and Math) pipeline." ■





Zerbrafish are widely used for developmental studies. The young fish is entirely clear (below), so researchers and students alike can witness organ development in real time.
Images courtesy International Institute of Molecular and Cell Biology and Michal Bazala



Former BioEYES student Sih Oka Zeh stands with Steve Farber, cofounder of the program.
Image courtesy Stephen Zeh

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

Some Forests Break Rules

The Carnegie Airborne Observatory-3 (above) is an airborne laboratory with many improvements over the previous generation, including technical upgrades and a much lighter lab, which allows the plane to reach twice the number of ecosystems a day over higher altitudes. Carnegie's Greg Asner is the principal investigator (below left).
Image courtesy Matthew Scott

"Some plants are high rollers looking for the quickest-possible returns... other plants are prudent savers that invest in long-term infrastructure..."

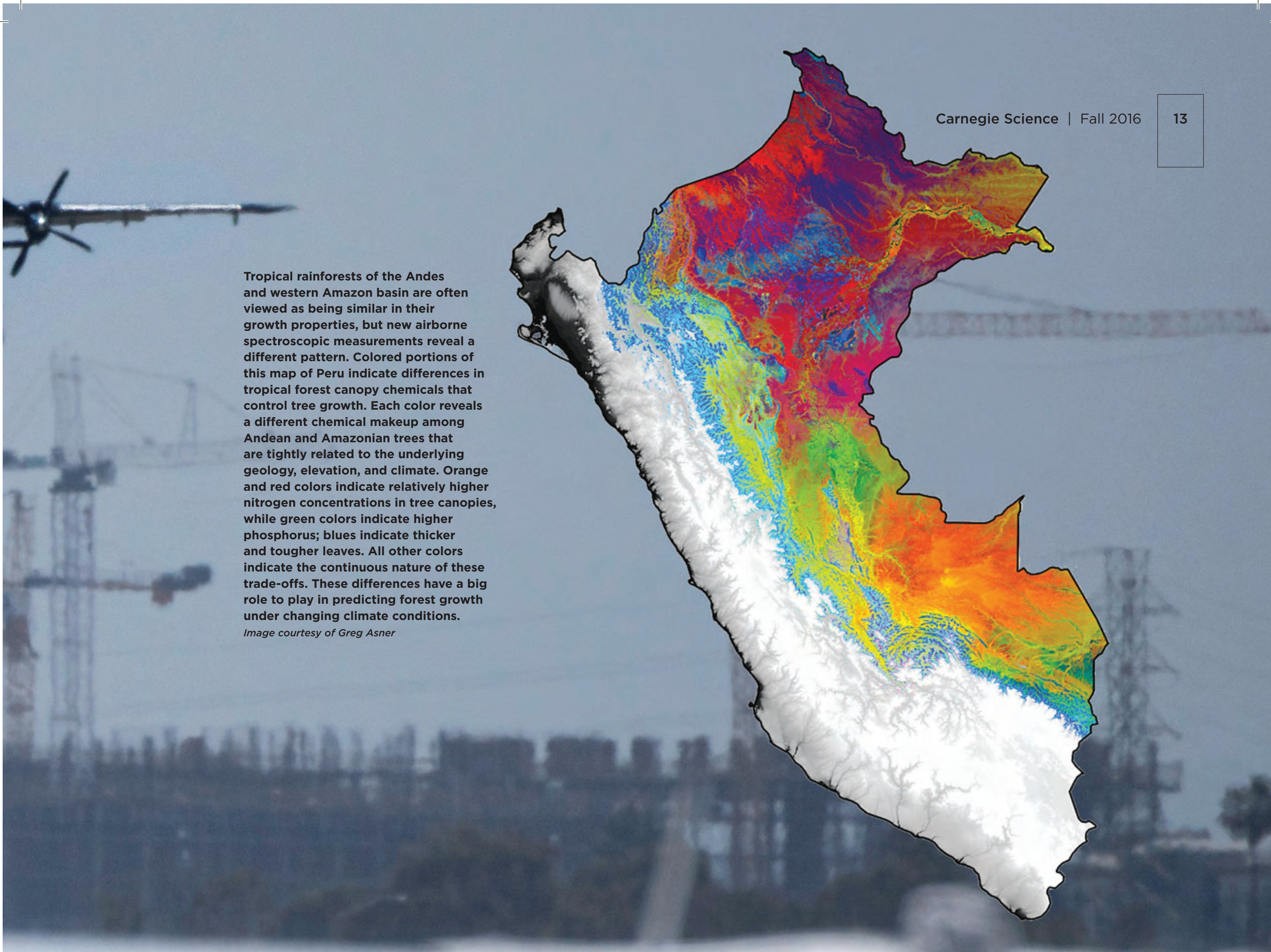
It turns out that forests in the Andean and western Amazonian regions of South America break long-understood rules about how ecosystems are put together, according to new research using remote spectral-sensing led by Carnegie's Greg Asner and published in the *Proceedings of the National Academy of Sciences.* The findings could help scientists understand how tropical forests will respond to global climate change.

One of forest ecology's fundamental undertakings has long focused on how tree growth is influenced by a host of environmental factors ranging from soils and elevation to hydrology and climate. These factors create an economy of resources that the trees must exploit through different strategies, some of which are optimized for quick growth while others favor slow growth.

Using a unique, high-fidelity imaging spectrometer onboard the Carnegie Airborne Observatory, Asner and his team made the first-ever forest canopy maps of leaf nitrogen, phosphorous, and mass over a large portion of the biosphere—covering nearly 200 million acres of Peru.

"We tested a traditional ecological principle at a completely new scale—in this case, the vast and under-explored Andes and Amazon region," Asner explained.

More than a decade ago, ecologists established a framework to measure and quantify the calculus between fast- and slow-growth plant strategies among species. The idea was simple: Some plants are high rollers looking for the quickest-possible returns, in the form of highly efficient photosynthesis—the conversion of the Sun's energy to store carbon. These plants have been associated with environments that supply high concentrations of essential nutrients,



Tropical rainforests of the Andes and western Amazon basin are often viewed as being similar in their growth properties, but new airborne spectroscopic measurements reveal a different pattern. Colored portions of this map of Peru indicate differences in tropical forest canopy chemicals that control tree growth. Each color reveals a different chemical makeup among Andean and Amazonian trees that are tightly related to the underlying geology, elevation, and climate. Orange and red colors indicate relatively higher nitrogen concentrations in tree canopies, while green colors indicate higher phosphorus; blues indicate thicker and tougher leaves. All other colors indicate the continuous nature of these trade-offs. These differences have a big role to play in predicting forest growth under changing climate conditions.
Image courtesy of Greg Asner

such as nitrogen and phosphorous, and warm-wet climatic conditions, which help plants photosynthesize better.

Other plants are prudent savers that invest in long-term infrastructure, growing leaves with strong internal structures and increased mass that are designed to live for a long time. These structural investments allow more photosynthesis to be accomplished per leaf over the plant's lifetime. This strategy is thought to be employed by longer-living plants in areas where nutrients are scarcer, or where climates are colder or drier.

To understand the trade-offs between these high-roller and prudent investor strategies, ecologists often plot leaf nutrients in comparison to leaf mass per area in response to different environmental factors. This is a particularly useful approach for understanding how to predict forest physiological responses to changing environmental conditions, including climate.

Until now, this "leaf economics" approach has never been studied on large geographically continuous scales. The team discovered that the leaf economics of forests are not as straightforward as believed.

"We found that Andean and Amazonian forests have evolved into diverse communities that break simple ecological 'rules' previously developed through field-based studies," Asner added. "These forests are actually much more interesting and functionally diverse than previously thought, and have sorted themselves out across a variety of environmental templates like geology, elevation, and temperature."

It turns out the forests aren't so simply split between high rollers and prudent investors either. Rather the authors found a continuum of forest canopy nitrogen, phosphorous, and leaf mass relationships that are sensitive to the enormous range of geophysical conditions found throughout the region.

Why do these findings matter?

The team believes that the mapped continuum of factors mediating tree growth in response to the environment will play a key role in determining how these forests will respond to climate change. Understanding these relationships is crucial to figuring out how to project changes in Andean-Amazonian forests using the next generation of climate models.

"These findings also make a clear case for taking our airborne science to Earth orbit, as a satellite mission. This is the only way to create new global-scale maps, which are needed to better understand these ecological processes and to predict the roles they will play in Earth's future," Asner said. ■

SUPPORT:
The John D. and Catherine T. MacArthur Foundation funded this study. The Avatar Alliance Foundation, the John D. and Catherine T. MacArthur Foundation, Mary Anny Nyburg Baker and G. Leonard Baker Jr., and William R. Hearst III currently support the Carnegie Airborne Observatory.

Johanna Teske, the first Carnegie Origins Postdoctoral Fellow, is passionate about astrophysics and encouraging underrepresented groups to become interested in science.
Images courtesy Johanna Teske

JOHANNA TESKE RECEIVES THIRD POSTDOCTORAL INNOVATION & EXCELLENCE AWARD

Johanna Teske was awarded the third Postdoctoral Innovation and Excellence (PIE) Award, which is made through nominations from the department directors and chosen by the Office of the President. She is the first Carnegie Origins Postdoctoral Fellow, which is the first fellowship in the history of Carnegie Science that straddles two departments, the Observatories and the Department of Terrestrial Magnetism. In just two years, Teske's efforts to help find and characterize exoplanets, particularly those that might be Earth-like, has generated multiple publications in prestigious journals such as *The Astrophysical Journal*.

The citation for the award noted that "Johanna Teske stands out as an incredibly enthusiastic scientist who loves to learn new things, is passionate about astrophysics, and active in encouraging members of underrepresented groups to pursue careers in science." She has undertaken a remarkable number of new projects in her two years at Terrestrial Magnetism. She moved to Pasadena in August to work at the Observatories.

Teske studies the relationship between the composition of stars and their orbiting planets. She is also passionate about improving diversity within astronomy and has been an indispensable volunteer at Carnegie's First Light Saturday Science School.

Carnegie president Matthew Scott remarked, "The breadth of Johanna's research, her mentoring, outreach, and imaginative perspective on science is what we look for when recruiting Carnegie postdocs. She is the perfect choice for the inaugural Origins Fellowship and is setting a high bar for this new position."

One postdoc is honored every quarter for their extraordinary accomplishments with the PIE Award. The award recipient is given a prize of $1000 and is the guest of honor at a departmental gathering where all postdocs can enjoy some celebratory pies. ■

IMPOSTER:
Elliptical Galaxy Actually a Giant Disk

Above left, in optical light, UGC 1382 appears to be a simple elliptical galaxy. But spiral arms emerged when astronomers incorporated ultraviolet and deep optical data (middle). Combining that with a view of low-density hydrogen gas (shown in green at right), scientists discovered that UGC 1382 is gigantic disk.
Image courtesy NASA/JPL/Caltech/SDSS/NRAO/L. Hagen and M. Seibert

Lea Hagen (above) was lead author on the study, which included Mark Seibert (below).
Images courtesy Lea Hagen and Mark Seibert

SUPPORT:
NASA grants NNX08AK86G and NNX12AE19G supported this work.

Since the 1960s, astronomers have thought that a galaxy dubbed UGC 1382 was a relatively boring, small, elliptical galaxy. Ellipticals are the most common type of galaxy and lack the spirals of disks like the Milky Way. Now, multiwavelength surveys conducted by Carnegie's Mark Seibert, Barry Madore, Jeff Rich, and others have discovered that UGC 1382 is actually a colossal disk galaxy that rivals the champion of this elusive class of so-called giant low surface brightness galaxies. The rival is known as Malin 1, which is seven times the diameter of the Milky Way. *The Astrophysical Journal* published the research.

Giant low surface brightness galaxies are among the most massive and isolated spiral galaxies known. They are very rare and have two components: a high surface brightness disk galaxy with an extended low surface brightness disk surrounding it. So why was galaxy UGC 1382 so misconstrued?

"Although there have been numerous surveys of the now-defunct elliptical since it was first cataloged in the 1960s, the only indication that it may be an unusual system was in 2009 when another survey indicated that there may be a hint of a rotating hydrogen disk," explained Seibert. "UGC 1382 came to our attention while we were looking at star formation in early-type galaxies using NASA's Galaxy Evolution Explorer (GALEX). Spiral arms were visible in the ultraviolet part of the spectrum—something you do not expect to see around elliptical galaxies. Naturally, that finding sent us off on a very different path!"

Further investigation revealed that the hydrogen disk was real with an enormous width, about 7 times as large as the Milky Way. Despite the huge difference in size, the two systems weigh roughly the same, with very similar amounts of stars and gas.

Lead author Lea Hagen—a graduate student at the Pennsylvania State University and a former Carnegie summer student—remarked, "It's unusual and surprising that we would have such a well-studied galaxy and miss its most unique property: a huge set of spiral arms . . . This an exciting object for understanding the most extreme examples of galaxy evolution."

The newly reclassified UGC 1382 is much closer to us than Malin 1, about a quarter of the distance, which is why the researchers could conduct the multiwavelength investigation. This will allow astronomers to unravel how these extreme systems form and evolve. These objects need a low-density environment without other large galaxies nearby to disturb it, but they also need a supply of small but gas-rich "dwarf" galaxies to build the diffuse extended disk. Unlike typical galaxy formation, however, the outer blue spiral disk appears to be older than the inner red disk—a big clue to the formation of oddball giants like this.

So far, about a dozen giant low surface brightness galaxies have been found. The proximity of UGC 1382 will be a boon to revealing other features of such elusive giants and early galaxies in general. ■

Earth's Wacky Old Magnetic Field

The illustration below shows ancient Earth's magnetic field compared to today's magnetic field.
Image courtesy Peter Driscoll

Carnegie's Peter Driscoll suggests Earth's ancient magnetic field was significantly different from the present-day field, with several poles rather than the familiar two. *Geophysical Research Letters* published the research.

Carnegie's Peter Driscoll

Earth generates a strong magnetic field in its core that extends into space. This field shields the atmosphere and deflects harmful high-energy particles from the Sun and the cosmos. Without it, cosmic radiation could prevent life on Earth's surface. The motion of liquid iron in Earth's outer core drives a phenomenon called the geodynamo, which creates the magnetic field. This motion is driven by the loss of heat from the core and the solidification of the inner core.

But the planet's inner core was not always solid. What effect did the initial solidification of the inner core have on the magnetic field? Figuring out when it happened and how the field responded has created a particularly vexing and elusive problem for those trying to understand our planet's geologic evolution, a problem that Driscoll set out to resolve.

Here's the issue: Scientists are able to reconstruct the planet's magnetic record by analyzing ancient rocks that bear a signature of the magnetic polarity of the era in which they were formed. This record suggests that the field has been active with two poles through much of our planet's history. Interestingly, the geological record does not show much evidence for major changes in the intensity of the ancient magnetic field over the past 4 billion years. A critical exception is in the Neoproterozoic Era, 0.5 to 1 billion years ago, where gaps in the intensity record and anomalous directions exist. Could this exception be explained by a major event like the solidification of the planet's inner core?

To address this question, Driscoll modeled the planet's thermal history going back 4.5 billion years. His models indicate that the inner core should have begun to solidify around 650 million years ago. Using further 3-D dynamo simulations, which model the generation of magnetic field by turbulent fluid motions, Driscoll looked more carefully at the expected changes in the magnetic field over this period.

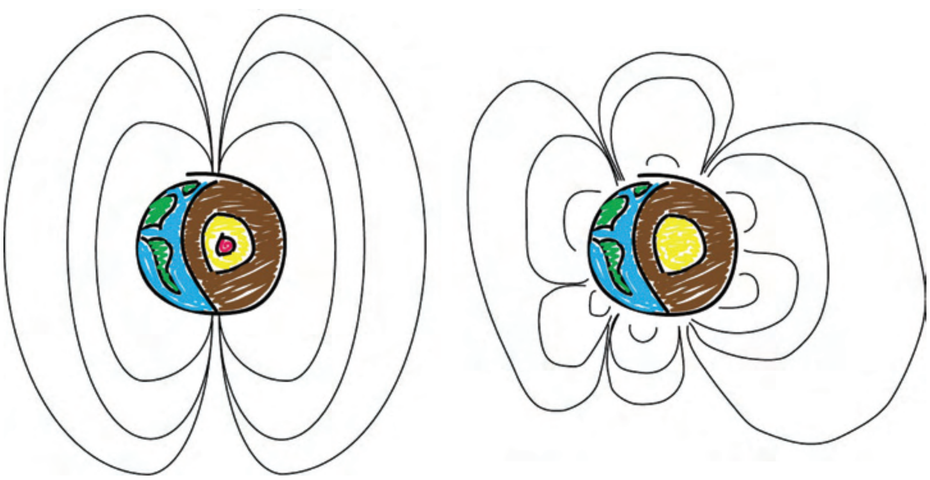
"What I found was a surprising amount of variability," Driscoll said. "These new models do not support the assumption of a stable dipole field at all times, contrary to what we'd previously believed."

His results showed that around 1 billion years ago, Earth could have transitioned from a "strong" modern-looking field, with two opposite poles—north and south—to a "weak" magnetic field that fluctuated wildly in intensity and direction *and* originated from several poles. Then, shortly after the predicted timing of the core solidification event, Driscoll's dynamo simulations predict that Earth's magnetic field transitioned back to a "strong," two-pole version.

"These findings could offer an explanation for the bizarre fluctuations in magnetic field direction seen in the geologic record around 600 to 700 million years ago," Driscoll added. "And there are widespread implications for such dramatic field changes."

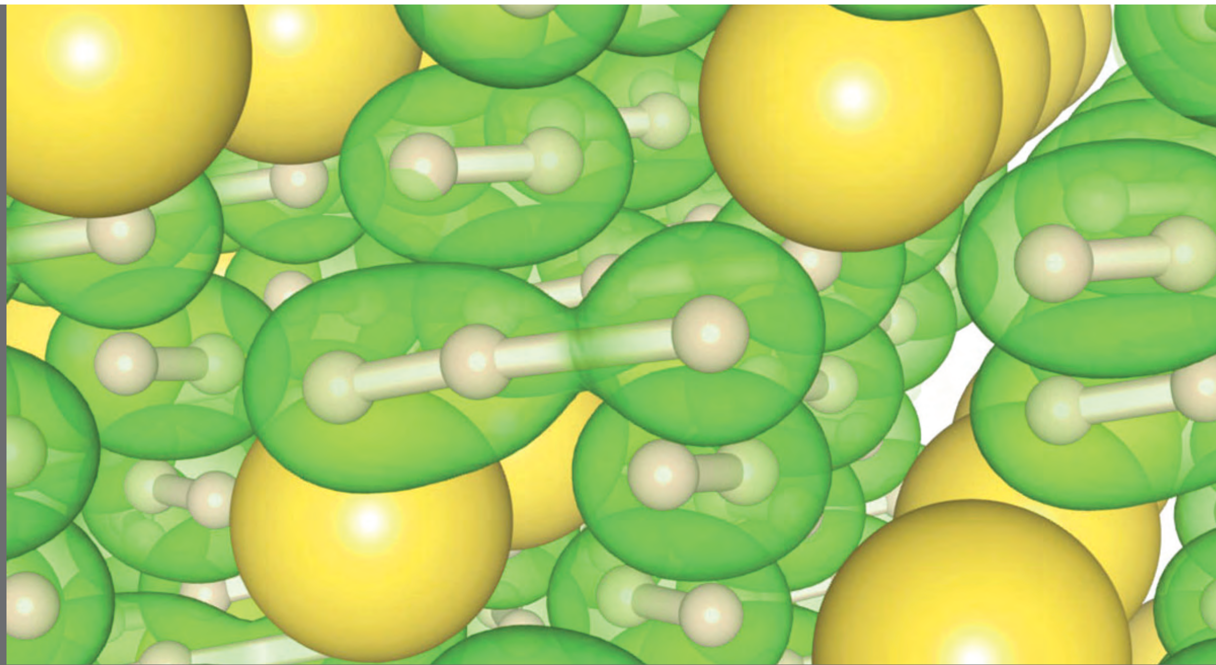
Overall, the findings have major implications for Earth's thermal and magnetic history, particularly when it comes to how magnetic measurements are used to reconstruct continental motions and ancient climates. Driscoll's modeling and simulations will have to be compared with future data gleaned from high-quality magnetized rocks to assess the viability of the new hypothesis. ■

Evolution of Earth's Magnetic Field



MODERN (0-650 Million Years Ago) ANCIENT (650-1000 Million Years Ago)

"These findings could offer an explanation for the bizarre fluctuations in magnetic field direction seen in the geologic record around 600 to 700 million years ago."



At center, in green, is the new three-atom hydrogen "chain." It is surrounded by several "normal" two-atom molecules of hydrogen, also in green. The new chain configuration appears in the new material NaH_7, which was produced under high pressure and high temperature conditions. The new material could change the superconductivity landscape and be useful for hydrogen storage in hydrogen fuel cells. *Image courtesy Duck Young Kim*

New Path to Superconductivity

Carnegie's Viktor Struzhkin led the team that created the material that could open up a new avenue for practical superconductors.

Scientists have tried to force hydrogen into a metallic state for decades. Why? This holy grail for materials science could be used for superconductors, materials that have no resistance to the flow of electrons, increasing electricity efficiency phenomenally. For the first time researchers, led by Carnegie's Viktor Struzhkin, have produced a new class of materials by blending hydrogen with sodium. These materials could alter the superconductivity landscape and be used for hydrogen-fuel cell storage. *Nature Communications* published their research.

It had been predicted that certain hydrogen-rich compounds consisting of multiple atoms of hydrogen with so-called alkali metals like lithium, potassium, or sodium, could provide a new chemical means to alter the compound's electronic structure. This, in turn, may lead the way to metallic high-temperature superconductors.

"The challenge is temperature," explained Struzhkin. "The only superconductors that have been produced can only exist at impractically cold temperatures. In recent years, there have been predictions of compounds with several atoms of hydrogen coupled with alkali metals that could exist at more practical temperatures. They are theorized to have unique properties useful to superconductivity."

Now, the predictions have been confirmed. The Struzhkin team included Carnegie researchers Duck Young Kim, Elissaios Stavrou, Takaki Muramatsu, Ho-Kwang Mao, and Alexander Goncharov along with researchers from other institutions.*

The team used theory to guide their experiments. They measured samples using a method that reveals atomic structure (X-ray diffraction) and a method that identifies molecules by characteristics such as their minute vibrations and rotations (Raman spectroscopy). Theoretically, the sodium/hydrogen material would be stable under pressure, have metallic characteristics and unique structures, and show superconducting properties.

The team conducted high-pressure/high-temperature experiments; matter under these extreme conditions can morph into new structures with new properties. They squeezed lithium and sodium samples in a diamond anvil cell to enormous pressures while heating them using a laser. At pressures between 300,000 and 400,000 atmospheres (30-40 gigapascals, or GPa) and temperatures of about 3100°F (2000 K), they observed, for the first time, structures of "polyhydrides"—sodium with three hydrogen atoms (NaH_3) and sodium with seven hydrogen atoms (NaH_7)—in very unusual configurations: three negatively charged hydrogen atoms in the NaH_7 material lined up, looking like one-dimensional hydrogen chains. This is a new phase that is very different from pure hydrogen.

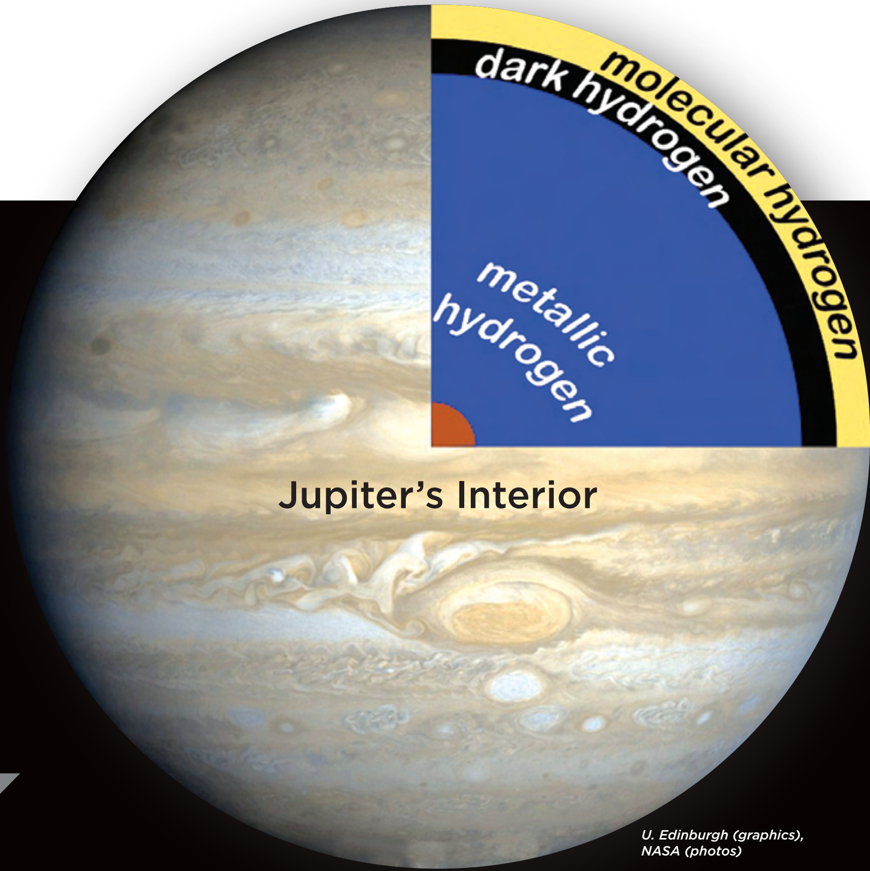
"This configuration was originally predicted to exist in 1972, more than 40 years ago," remarked Duck Young Kim. "It turns out that our experiments are in complete agreement with the theory, which predicted the existence of NaH_3. The bonus is that we also observed the compound with seven hydrogen atoms."

Struzhkin reflected, "Further work needs to be done to see if materials in this class can be produced at lower temperatures and pressures. But this new class of matter opens up a whole new world of possibilities." ■

***OTHER AUTHORS & SUPPORT:**
*Other researchers include Chris Pickard with U. College, London; Richard Needs of the Cavendish Laboratory in the U.K.; and Vitali Prakapenda of U. Chicago. Department of Energy/Basic Energy Sciences, the Energy Frontier Research in Extreme Environments Center (EFree), the Engineering and Physical Sciences Research Council (EPSRC) of the U.K., DARPA, and National Science Foundation of China supported this work.

(Right) This illustration shows the layer of dark hydrogen that the team's high-pressure experiments indicated would be found beneath the surface of gas giant planets like Jupiter.
Image courtesy Stewart McWilliams

(Below) Alexander Goncharov uses high-pressure techniques in the lab to study how matter transforms under extreme conditions.
Image courtesy Alexander Goncharov



U. Edinburgh (graphics), NASA (photos)

NOW THERE IS DARK HYDROGEN

Dark matter, dark energy and, now, there is dark hydrogen.

Hydrogen is the most abundant element in the universe. It's also the simplest—sporting only a single electron in each atom. But that simplicity is deceptive.

One of the biggest unknowns is hydrogen's transformation under the extreme pressures and temperatures found in the interiors of giant planets like Jupiter, where it is squeezed until it becomes liquid metal, capable of conducting electricity. Work published in *Physical Review Letters* by Carnegie's Alexander Goncharov and University of Edinburgh's Stewart McWilliams measures the conditions under which hydrogen undergoes this transition in the lab. They found an intermediate state between gas and metal, which they're calling dark hydrogen.

On the surface of giant planets like Jupiter, hydrogen is a gas. But between this gaseous surface and the liquid metal hydrogen in the planet's core lies a layer of dark hydrogen, according to findings gleaned from the team's lab mimicry.

Using a laser-heated diamond anvil cell to create the conditions likely found in gas giant planetary interiors, the team probed the physics of hydrogen under a range of pressures from 10,000 to 1.5 million times normal atmospheric pressure and up to 10,000 degrees Fahrenheit.

They discovered this unexpected intermediate phase, which does not reflect or transmit visible light, but does transmit infrared radiation, or heat.

"This observation would explain how heat can easily escape from gas giant planets like Saturn," explained Goncharov.

They also found that this intermediate dark hydrogen is somewhat metallic, meaning it can conduct an electric current, albeit poorly. This means that it could play a role in the process by which churning metallic hydrogen in gas giant planetary cores produces a magnetic field around these bodies, in the same way that the motion of liquid iron in Earth's core created and sustains our own magnetic field.

"This dark hydrogen layer was unexpected and inconsistent with what modeling research had led us to believe about the change from hydrogen gas to metallic hydrogen inside of celestial objects," Goncharov added.

The team also included Carnegie's Allen Dalton and Howard University's Mohammad Mahmood. ■

SUPPORT:
The National Science Foundation Major Research Instrumentation program, the Army Research Office, the Carnegie Institution for Science, the Deep Carbon Observatory Instrumentation grant, the British Council Researcher Links program, the Department of Energy (DOE) National Nuclear Security Administration Carnegie/DOE Alliance Center, and the DOE Energy Frontier Research Center for research in Extreme Environments supported this work.

Rewiring Plant "Mouths"

Dominique Bergmann is a former Carnegie postdoctoral fellow, honorary adjunct staff member at Plant Biology, and professor at Stanford University.

Image courtesy Dominque Bergmann

Plants have tiny pores on their leaves called stomata, Greek for mouths, which take in carbon dioxide from the air and evaporate water. New work from the lab of Dominique Bergmann—former Carnegie postdoctoral fellow, honorary adjunct staff member at Plant Biology, and professor at Stanford University—reveals ways that the systems regulating the development of stomata in grasses, which include many food grains, could be harnessed to improve plant efficiency and agricultural yield.

More than 30 percent of all the carbon dioxide in the atmosphere passes through stomata each year. In exchange, stomata release water vapor equivalent to twice the amount present in the whole atmosphere. As such, plants exert a tremendous push-and-pull influence on the global climate and are particularly attuned to climate change.

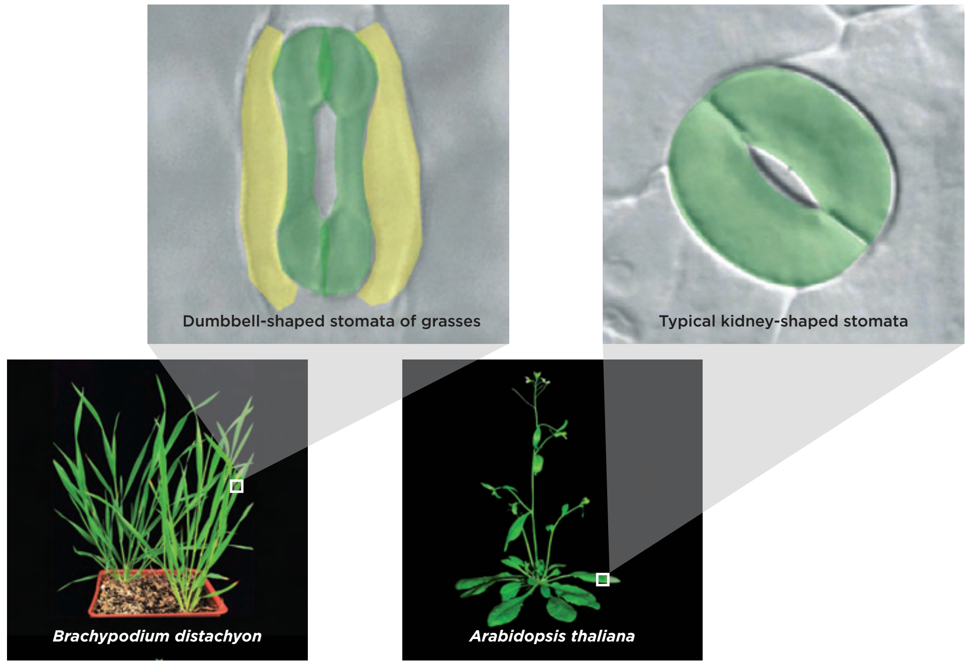
What's more, stomata have been found in fossils dating back 400 million years, and they are features of nearly every land plant alive today. However, they have different appearances in different kinds of plants. Most of what we know about how genes shape stomata comes from studies of the "model" plant, *Arabidopsis*, a relative of broccoli and cabbage, which is very different from the grasses studied here. It was a mystery whether all plants use the same genes as *Arabidopsis* to produce stomata, or whether different stomatal forms and patterns result from each plant using its own unique set of genetic blueprints.

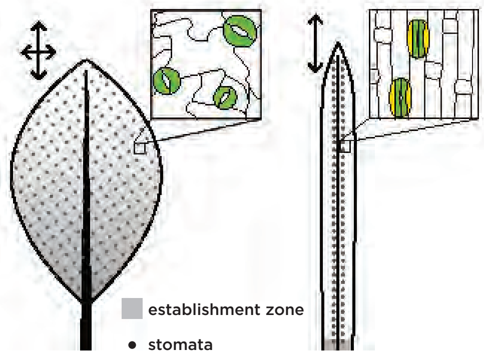
The new work, published in *Proceedings of the National Academy of Sciences* by lead authors Michael Raissig and Emily Abrash, features collaboration between Bergmann and John Vogel (now at the Department of Energy's Joint Genome Institute) who met as Carnegie postdocs.

The decision to study stomata in grasses, which includes maize, rice, and wheat, was because these plants are important to us and because grasses are more efficient in taking up carbon dioxide while limiting water loss. Grass stomata have a different shape—a dumbbell—instead of the kidney bean-shape found in most plants. In addition, grasses have their stomata aligned in rows along the leaf blade, versus the more haphazard distribution on broad-leafed plants. Some scientists have speculated that the shape and distribution of stomata in grasses are the reason for their tremendous evolutionary success.

Using a variety of techniques, Bergmann's team untangled some parts of the regulatory systems that turn certain genes on and off, which determine how grasses control the number of stomata, where to put them, and how to generate their distinct shape. Surprisingly, these differences don't result from unique stomata genes but from the same genes as other plants—in different ways. This is like similar circuits of components, but with different wiring. This "rewiring" can partly explain how grasses form different stomata with superior physiology.

"Now we have a handle on the genes that comprise a universal tool kit for building stomata," Bergmann explained. "Plants apparently use the same common parts, but the ways these parts function and interact with each other are different, which is both interesting from a discovery science perspective and could be harnessed to improve growth performance in grasses that humans use for food or fuel." ■





This photomontage shows a comparison of the dumbbell-shaped stomata found in grasses and the kidney-shaped stomata found in many other plants. The shape of grass stomata is considered one of the reasons for their evolutionary success. The diagram indicates the different distribution of stomata on broad-leaf plants, which are somewhat haphazard, and grasses, where they are aligned.

Photos courtesy Michael Raissig and Dominique Bergman; diagram courtesy PNAS, 8326–8331, July 19, 2016, 113, 29

SUPPORT:
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THURSDAY, SEPTEMBER 29, 2016 — 6:30PM

Dr. Sean Carroll: ***The Serengeti Rules: The Quest to Discover How Nature Works & Why It Matters***
Sean B. Carroll, Professor, Molecular Biology and Genetics, University of Wisconsin; Vice President for Science Education, Howard Hughes Medical Institute.
#SerengetiRules

THURSDAY, OCTOBER 13, 2016 — 6:30PM

Dr. Nadrian Seeman: ***DNA: Not Merely the Secret of Life***
Dr. Nadrian Seeman, Margaret and Herman Sokol Professor of Chemistry, New York University. Co-hosted by the Carnegie Institution for Science with The Kavli Foundation, the Royal Embassy of Norway, and the Norwegian Academy of Science.
#DNAnanotech

WEDNESDAY, NOVEMBER 2, 2016 — 6:30PM

Dr. Piers Sellers: ***Creating the Science of Global Ecology***
Dr. Piers Sellers, Astronaut; Deputy Director of the Science and Exploration Directorate and Acting Director of the Earth Sciences Division, NASA Goddard Space Flight Center.
#GlobalEcology

MONDAY, DECEMBER 5, 2016 — 6:30PM

Dr. Elizabeth Loftus: ***The Fiction of Memory***
Dr. Elizabeth Loftus, Distinguished Professor, University of California Irvine. Co-hosted by the Carnegie Institution for Science with the Council of Scientific Society Presidents and The Kavli Foundation.
#FalseMemories