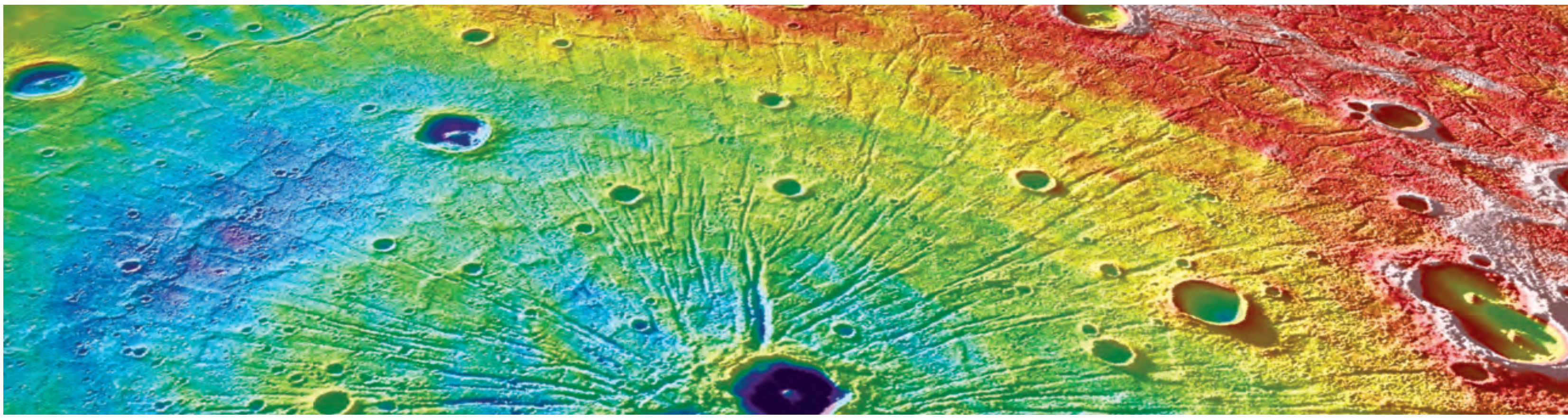
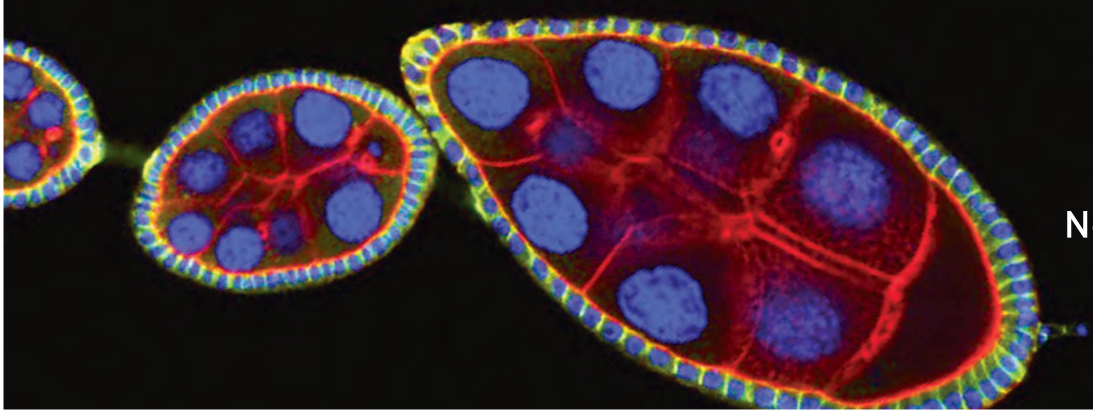
CarnegieScience

The Newsletter of the Carnegie Institution

SUMMER 2015

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

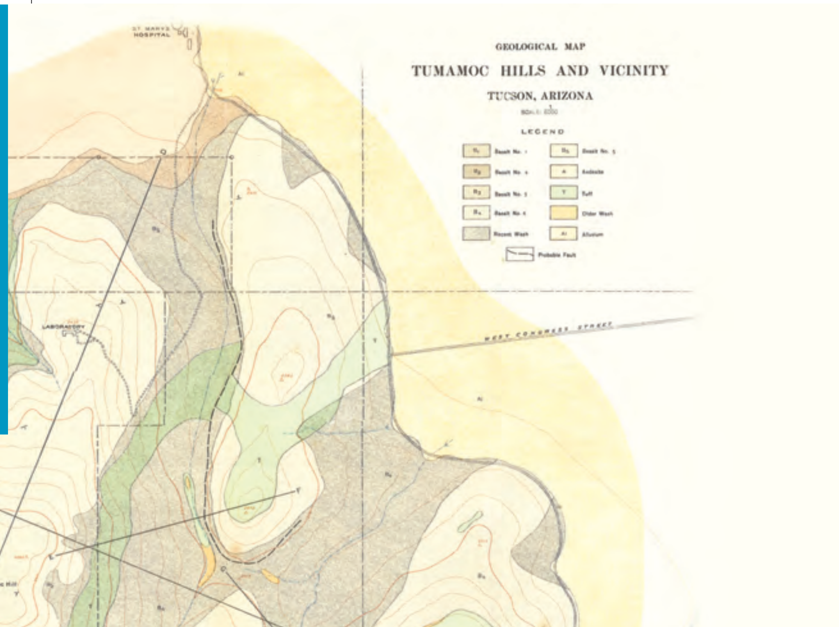




On the Inside

LETTER FROM THE PRESIDENT

Deep into Deserts



In 1903 the Carnegie Institution established a Desert Laboratory to explore the properties of desert plants. From that humble stone building in Tucson, Arizona, eventually emerged our spectacular Department of Plant Biology on the Stanford University campus and, by descent, our Department of Global Ecology at the same site.

The Carnegie scientists who came to Tucson had a central goal of understanding how desert plants manage in seemingly impossible conditions. Tucson provided an ideal environment because the Sonoran Desert has stunningly rich biota in spite of its extreme heat and desiccation. As documented in Patricia Craig's centennial history of Carnegie Plant Biology, an early Tucson scientist—William Cannon—wrote "even the most hardened liar among the natives will not defend this summer climate." About 30 centimeters (12 inches) of water lands on Tucson in an average year, though a single storm last January delivered more than 13 centimeters (5 inches)...and dramatic floods. The most familiar and dramatic plant of the Tucson desert is the Saguaro cactus, a prickly giant so emblematic of cowboy movies. The cactus has the scientific name *Carnegiea gigantea* in honor of none other than our founder, Andrew Carnegie. Perhaps he was viewed as prickly.

To cope with desert life, Tucson people have done an exceptional job of responsible gardening, planting native plants that are perfectly happy in baking hot gravel. Carnegie's present day plant and ecology laboratories lie in what, at first glance, looks like a completely different environment. Lush gardens of Palo Alto incorporate many plants that are far from drought-tolerant, including moisture-loving redwoods. Yet the Stanford area receives scarcely more water than Tucson, about 35 centimeters (14 inches) each year. That blooming of the Bay Area desert, fed by a pipeline from Yosemite National Park, has been severely challenged by years of intense drought that affect much of the American West. The Sierra Nevada mountains have been deprived of their normal snowpack for years, with the lowest level of snowpack on record this past spring. The snowpack serves as a water storage system, slowly releasing melt water during the summertime drought. Similar water storage occurs in most mountain ranges of the world and dwindling glaciers, even among the world's highest peaks, are causing changes in what farmers can produce, and when.

Fieldwork by Carnegie scientists has been a constant source of discovery for understanding how plants survive extreme heat and desiccation. In the 1960s Olle Björkman arrived at Carnegie from Sweden and, exploring a climate that could hardly have been more unlike his home, began work in Death Valley in 1968. He and colleagues found a plant called Arizona honeysweet *(Tidestromia suffruticosa v. oblongifolia)* that was beautifully adapted to heat. In a paper published in *Science* in 1972, he reported that *Tidestromia* performed photosynthesis best in 120°F heat conditions that kill most plants. We still do not know how *Tidestromia* works its miracle. The Björkman group also showed that certain desert shrubs changed the composition of their membranes as the springtime temperature rose so that they would remain stable at Death Valley's summertime temperature extremes. Investigating plants that have such abilities may reveal ways to transfer certain of those abilities to crop plants to increase their resilience.

The start of World War II reduced endowment income for Carnegie, a drought of another sort, and the Desert Laboratory in Tucson was closed. However seeds had spread and by 1929 Carnegie had established a Division of Plant Biology on the campus of Stanford University. To this day, the original laboratory and office building remains occupied by the Department of Plant Biology. The original lease from Stanford required that Carnegie scientists shoot all the squirrels on the property. This has not been enforced, and the property now has an ample population of squirrels, and jackrabbits.

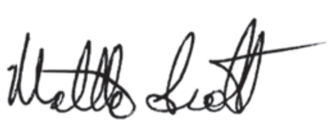
Carnegie Plant Biology department scientists continue to be at the forefront of learning the molecular, cellular, and developmental mechanisms that underlie the wonders of plant physiology, development, and evolution that shape our geologic, climatic, and human world. After years of the current drought in the American West, understanding the basis of plant resilience in arid conditions may extend growing seasons, allow survival of crops through short periods of highly extreme weather, and provide ideas about how to protect plants from drought vulnerability.

Most plants obtain water and other resources from a normally hidden network that can extend deep underground: their roots. Carnegie's José Dinneny (https://dpb.carnegiescience.edu/labs/dinneny-lab) investigates root growth, behavior, and sensing. How do roots find their way to water and nutrients? How do they respond to salinity or toxins? He and his coworkers have made spectacular progress in developing new methods to watch living roots behave. They find that root branching and growth patterns respond to signals with exquisite precision, sensing even slight differences in moisture over distances as small as 100 microns.

What happens below ground is half the story. Water travels up through plants and is released through leaf pores called stomata. These have two "guard" cells that swell or shrink in response to conditions to open or close stomata. How much water is retained or released by a desert plant will affect how much must be found in the first place. Thus stomata have elaborate systems of opening and closing that allow CO_2 to enter the plant for photosynthesis while controlling water loss. Carnegie's Kathy Barton studies the genes that control growth and patterning of plant stem cells, the cells that give rise to all the specialized cells of the plant including leaf structures like stomata. She and her colleagues have identified genes that control whether stem cells stay active during drought stress. Changing the threshold at which plant stem cells enter a dormant state in response to dry conditions may allow plants to remain productive in periods of moderate drought.

The growth and patterning of plants, as well as their daily physiological and biochemical functioning states, are controlled by elaborate signaling networks. Hormones are signals that can work locally or globally to tell cells what to do. The molecular biology of responses to signals is a major area of study in multiple Carnegie labs, such as those of Zhiyong Wang (https://dpb.carnegiescience.edu/labs/wang-lab) and Seung (Sue) Rhee (https://dpb.carnegiescience.edu/labs/rhee-lab). This work requires multidisciplinary approaches including genetics, biochemistry, and computational science. Knowing how to manipulate such control networks will be key to exploiting new understanding of how plants cope with stress including dehydration. Dinneny comments, "A future challenge is to broaden this understanding, to place it in an ecological, evolutionary and physiological context to ultimately understand the adaptive mechanisms plants use to grow in a desert, be it the cactus of Arizona or the almond tree of the central valley." We at Carnegie see every prospect for substantial advances in, first, understanding how plants can and do cope with stress and, second, using that information to create more resilient crop plants and improved agricultural methods.

Let's drink (water) to that!



Matthew Scott, *President*

TRUSTEES MEET

MAY 2015

The trustees met at the administration building May 7th and 8th. The Employee Affairs, Finance, and Nominating and Governance Committees met on the 7th, followed by a full board session. The full board met again on the 8th. The trustees elected two new board members, Marshall Wais, president of the steel company of Marwais International LLC, based in Luxembourg; and former Carnegie president, energy expert, and attorney, Richard Meserve. Both full sessions of the board featured scientific talks by researchers from each of the departments.

New Techniques Push Carnegie Science

Unlike many research enterprises, Carnegie researchers have a long tradition of building their own instruments and developing novel techniques to explore questions that cannot be advanced without technical improvements. Although not every researcher is involved in instrument development, technology is at the heart of the discovery process. That theme was hit upon time and again during the scientific talks at the May 2015 trustees' meetings, as the descriptions at right reveal.

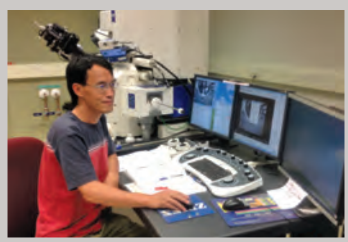
Joe Berry of Global Ecology described his team's new approach for measuring photosynthetic activity on a global scale by using satellite technology. The new technique will improve the monitoring of agricultural productivity and can be applied to natural ecosystems.

Lara Wagner of Terrestrial Magnetism, talked about her team's new approach to seismic imaging in Peru, Chile, and Colombia to understand what is happening to the water that is cycled into the deep Earth.

Embryology's Joe Gall has been using the giant chromosomes in amphibian eggs for decades to study myriad problems. He talked about using super-resolution microscopy for this work, a recent advancement that is two to three times better than the previous generation of instrumentation.

Martin Jonikas of Plant Biology takes the unusual approach of combining plant science with his engineering background to learn how to enhance photosynthetic organisms to improve crop yields.

Observatories' Rebecca Bernstein discussed her 15-year project developing new tools to study galaxy formation and evolution. She discussed the challenge of studying the chemistry in galaxies other than our own Milky Way. Farther galaxies have been too far for measurements until the development of tools like the MIKE spectrograph, an instrument project that she led.



Yingwei Fei of the Geophysical Laboratory, talked about how new instrumentation has advanced his area of research—visualizing planetary core formation in the lab. A recently installed focused ion beam and high-resolution field emission scanning electron microscopy crossbeam, has helped make huge strides in this area with 3-D visualization.

BYE-BYE MESSENGER:

Mercury Crater-Naming Contest Celebrates Finale

The little engine that could makes history! The tiny MESSENGER Mission to Mercury spacecraft was launched on August 3, 2004, and entered orbit about the innermost planet on March 18, 2011, for a yearlong study of the planet. MESSENGER ended its mission April 30, 2015, over three years longer than planned and far surpassing goals. The plan was to take 2,500 images of the planet, but the little workhorse returned more than 250,000.

Carnegie's Larry Nittler is the mission's deputy principal investigator, while former director of Terrestrial Magnetism Sean Solomon has been leading the project as principal investigator for about two decades.

The MESSENGER Education and Public Outreach (EPO) Team, coordinated through Carnegie and led by Julie Edmonds, organized a crater-naming competition to celebrate the mission's achievements. The results were announced to coincide with the craft's impact into the planet, ending the mission.

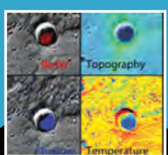
The competition to name five impact craters on Mercury was announced in 2014. The International Astronomical Union (IAU)—the governing body of planetary and satellite nomenclature since 1919—made the selections from a semifinal submission of 17 artists' names. The newly selected crater names are Carolan, Enheduanna, Karsh, Kulthum, and Rivera.

Under IAU rules, all new craters on Mercury must be named after an artist, composer, or writer who was famous for more than 50 years and has been dead for more than three years. Turlough O'Carolan (Carolan) was an Irish composer during the late 1600s and early 1700s. Enheduanna, an Akkadian princess who lived in the Sumerian city of Ur in ancient Mesopotamia (today's Iraq and Kuwait), is regarded by many scholars as possibly the earliest known author and poet. Yousuf Karsh was an Armenian/Canadian and one of the greatest portrait photographers of the twentieth century. Umm Kulthum was an Egyptian singer, songwriter, and film actress of the 1920s to the 1970s. Diego Rivera was a prominent Mexican painter and muralist from the 1920s to the 1950s.

The winners come from many different countries. Carolan was suggested by Fergal Donnelly (Belgium); Joseph Brusseau (USA); and Deane Morrison (USA). Enheduanna was submitted by Gagan Toor (India). Karsh was submitted by Elizabeth Freeman Rosenzweig (USA). Kulthum was suggested by Molouk Ba-Isa (Saudi Arabia); Riana Rakotoarimanana (Switzerland); Yehya Hassouna (USA); David Suttles (USA); Thorayya Said Giovannelli (USA); and Matt Giovannelli (USA). Rivera was suggested by Ricardo Martinez (Mexico); Rebecca Hare (USA); Arturo Gutierrez (Mexico); and José Martinez (USA).

Edmonds remarked, "The IAU working group that chose the names was very happy with the submissions. In all we had 3,600 contest entries, a resounding success for the excitement that the MESSENGER mission to Mercury has generated." □

MESSENGER COMPETITION RESULTS: **5 New Crater Names on Mercury!**



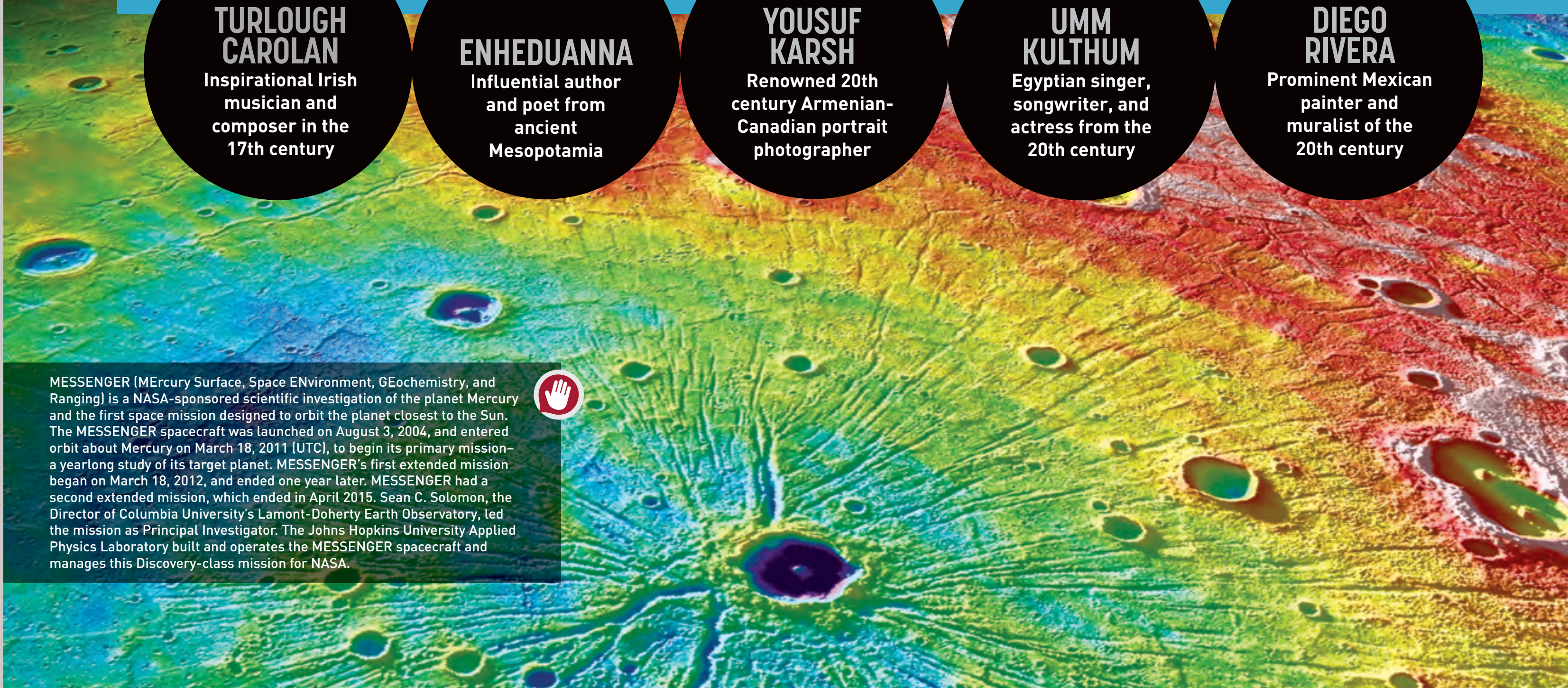
TURLOUGH CAROLAN
Inspirational Irish musician and composer in the 17th century

ENHEDUANNA
Influential author and poet from ancient Mesopotamia

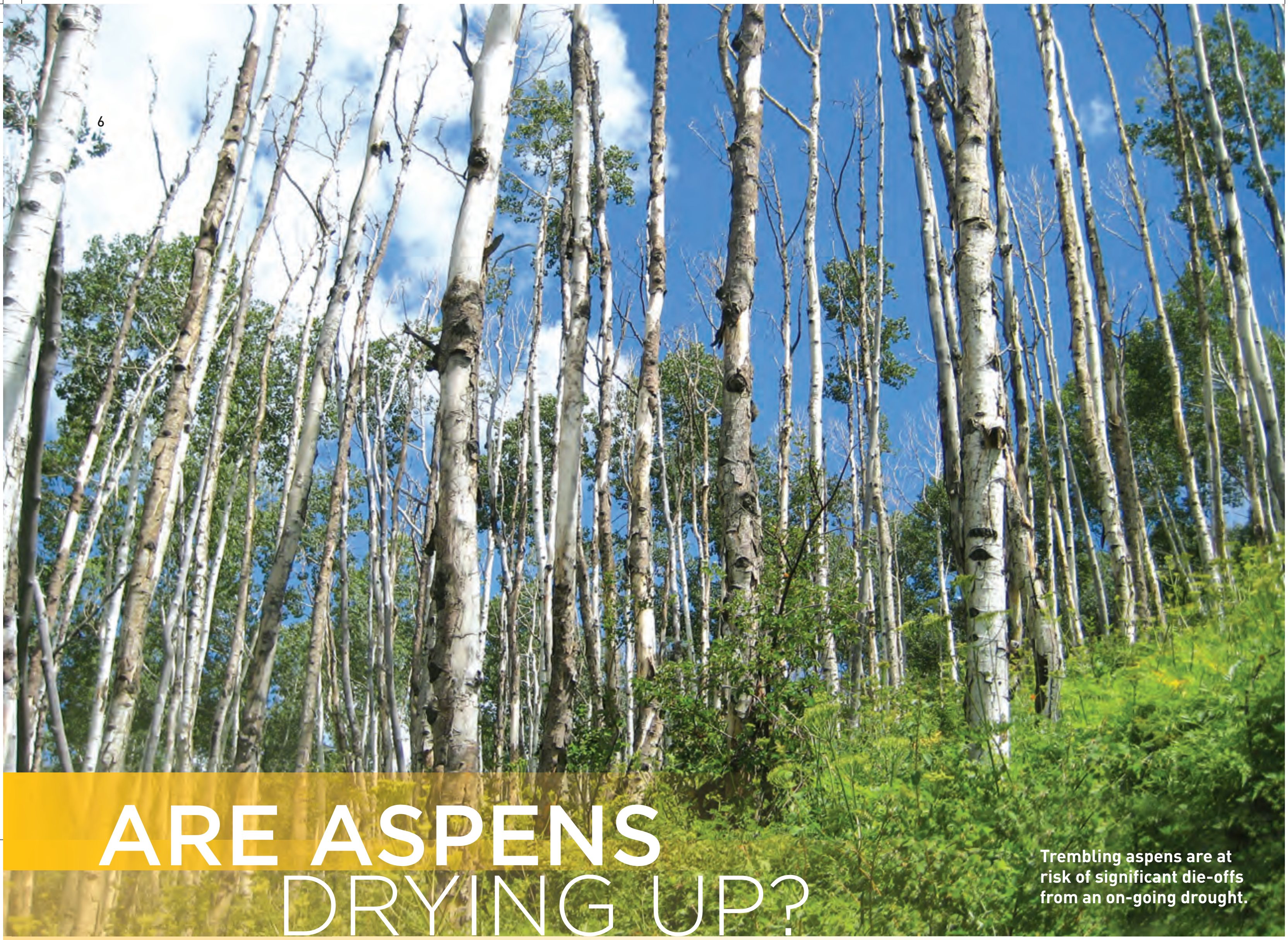
YOUSUF KARSH
Renowned 20th century Armenian-Canadian portrait photographer

UMM KULTHUM
Egyptian singer, songwriter, and actress from the 20th century

DIEGO RIVERA
Prominent Mexican painter and muralist of the 20th century



MESSENGER (MErcury Surface, Space ENvironment, GEochemistry, and Ranging) is a NASA-sponsored scientific investigation of the planet Mercury and the first space mission designed to orbit the planet closest to the Sun. The MESSENGER spacecraft was launched on August 3, 2004, and entered orbit about Mercury on March 18, 2011 (UTC), to begin its primary mission–a yearlong study of its target planet. MESSENGER's first extended mission began on March 18, 2012, and ended one year later. MESSENGER had a second extended mission, which ended in April 2015. Sean C. Solomon, the Director of Columbia University's Lamont-Doherty Earth Observatory, led the mission as Principal Investigator. The Johns Hopkins University Applied Physics Laboratory built and operates the MESSENGER spacecraft and manages this Discovery-class mission for NASA.



ARE ASPENS DRYING UP?

Trembling aspens are at risk of significant die-offs from an on-going drought.

The 2000-2003 drought in the American Southwest triggered a widespread die-off of forests around the region. It affected about 17 percent of aspen forests in Colorado, as well as parts of the western United States and Canada. A Carnegie-led team of scientists developed a new modeling tool to explain how and where trembling aspen forests died as a result of this drought. To make an accurate model, the team focused on the physiology of how drought kills trees, based on damage to an individual tree's ability to transport water under these stressed conditions.

The team included Carnegie's William Anderegg (now at Princeton University), Joseph Berry, and Christopher Field. Their work addressed a long-standing disagreement over how climate change caused by the emission of greenhouse gases will affect forest ecosystems. On one hand, rising concentrations of carbon dioxide can benefit trees and help them use water more efficiently. On the other hand, rising temperatures and resulting droughts from climate change can cause many forest trees to die off. Most current models cannot predict when or where forests might die from temperature and drought stress. The new model fills this gap by accurately simulating the widespread aspen mortality caused by the 2000-2003 drought. It predicts widespread die-offs could occur by the 2050s.

They found that droughts cause damage to the vascular system that transports water throughout a tree. The threshold for a lethal amount of vascular damage was not previously known in any tree species. But using data from forests in southwest Colorado, they were able to identify a threshold over which drought conditions start to degrade an aspen's water-transporting vascular system. They incorporated this information into a model designed to predict drought-induced forest mortality. They tested the model against regional forest mortality observations from scientific forest plots, aerial surveys done by the U.S. Forest Service, and satellite measurements.

When this model was then applied to the future, they found that in a world of continuing high greenhouse gas emissions, the threshold for widespread drought-induced vascular damage would be crossed and initiate widespread tree deaths on average across climate model projections in the 2050s. Crucially, lower greenhouse gas emissions scenarios did not always lead to widespread tree mortality. □

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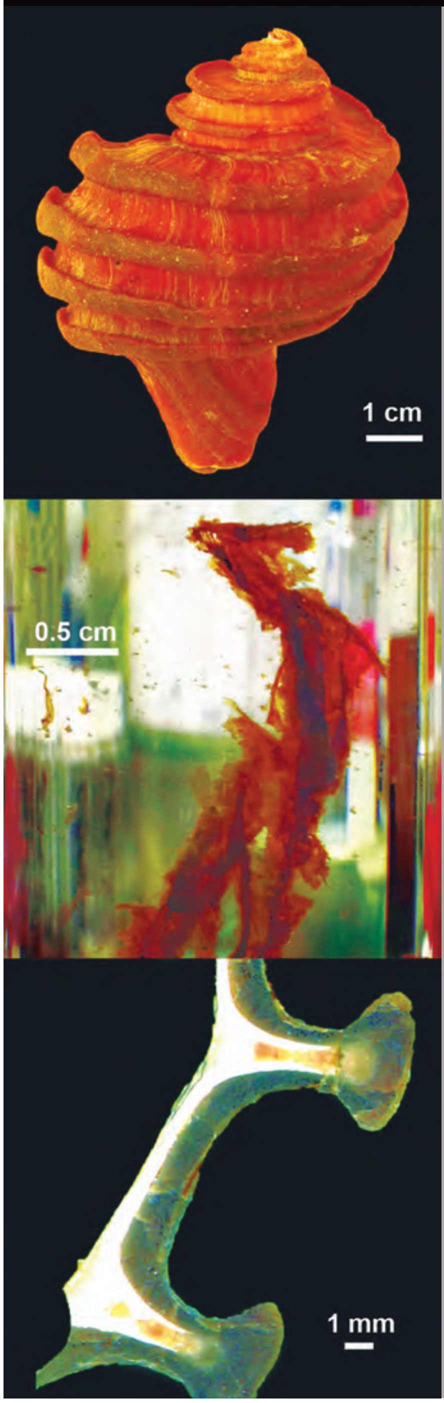
Nature Geoscience published the work in March.

An NSF Doctoral Dissertation Improvement Grant, the NOAA Climate and Global Change Postdoctoral Fellowship program, the Department of Energy Office of Science Graduate Fellowship Program, the Ministry of Science and Technology of Taiwan, National Taiwan University, the NSF MacroSystems Biology Program, and the Carnegie Institution for Science funded this work.

This photograph of the Calvert Cliffs, along the shoreline of the Chesapeake Bay in Maryland, is where the samples were collected. Bob Hazen is shown looking for fossils.

Found: 15 MILLION-YEAR-OLD MOLLUSK PROTEIN

A team of Carnegie scientists found "beautifully preserved" 15 million-year-old thin protein sheets in fossil shells from southern Maryland. They say these are some of the oldest and best-preserved examples of a protein ever observed in a fossil shell.



This composite picture has a photo of an *Ecphora* shell (top), a magnified cross-section of the shell showing the colored outer layers (bottom), and a vial with floating protein sheets—15 million-year-old intact organics!

Image provided courtesy John Nance

The team—John Nance, John Armstrong, George Cody, Marilyn Fogel, and Robert Hazen—collected samples from Calvert Cliffs, along the shoreline of the Chesapeake Bay, a popular fossil collecting area. They found fossilized shells of a snail-like mollusk called *Ecphora* that lived in the mid-Miocene era, between 8 and 18 million years ago.

Ecphora is known for its unusual reddish-brown shell color, making it one of the most distinctive North American mollusks of its era. This coloration is preserved in fossilized remains, unlike the fossilized shells of many other fossilized mollusks from the Calvert Cliffs region, which have turned chalky white over the millions of years since they housed living creatures.

Shells are made from crystalline compounds of calcium carbonate interleaved with an organic matrix of proteins and sugars. These proteins are called shell-binding proteins by scientists because they help hold the components of the shell together. They also contain pigments, such as those responsible for the reddish-brown appearance of the *Ecphora* shell. These pigments can bind to proteins to form a pigment-protein complex.

The fact that the coloration of fossilized *Ecphora* shells is so well preserved suggested to the research team that shell proteins bound to these pigments in a complex might also be preserved. They were amazed to find that the shells, once dissolved in dilute acid, released intact thin sheets of shell proteins more than a centimeter across. Chemical analysis including spectroscopy and electron microscopy of these sheets revealed that they are indeed shell proteins that were preserved for up to 15 million years.

Remarkably, the proteins share characteristics with modern mollusk shell proteins. They both produce thin, flexible sheets of residue that's the same color as the original shell after being dissolved in acid. Of the 11 amino acids found in the resulting residue, aspartate and glutamate are prominent, which is typical of modern shell proteins. Further study of these proteins could be used for genetic analysis to trace the evolution of mollusks through the ages, as well as potentially to learn about the ecology of the Chesapeake Bay during the era in which *Ecphora* thrived. □

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The inaugural issue of *Geochemical Perspectives Letters* published their findings.

ANCIENT SUPER-BRIGHT QUASAR DISCOVERED

Quasars—supermassive black holes found at the center of distant massive galaxies—are the most-luminous beacons in the sky. These central supermassive black holes actively accrete the surrounding materials and release a huge amount of their gravitational energy. An international team of astronomers including Carnegie's Yuri Beletsky has discovered the brightest quasar ever found in the early universe, powered by the most massive black hole observed for an object from that time.

Yuri Beletsky

The quasar was found at a redshift of $z = 6.30$. Redshift is a measurement of how much the wavelength of light emitted from it that reaches us on Earth is stretched by the expansion of the universe. As such, redshift can be used to calculate the quasar's age and distance from our planet. A higher redshift means longer distance and hence farther back in time.

This new quasar is seven times brighter than the most distant quasar known.

At a distance of 12.8 billion light years from Earth, this quasar was formed only 900 million years after the Big Bang. Named SDSS J0100+2802, this quasar will help scientists understand how quasars evolved in the earliest days of the universe. There are only 40 known quasars that have a redshift of higher than 6, a point that marks the beginning of the early universe.

With a luminosity of 420 trillion that of our own Sun's, this new quasar is seven times brighter than the most distant quasar known (which is 13 billion years away). It harbors a black hole with a mass of 12 billion solar masses, proving it to be the most luminous quasar with the most massive black hole among all the known high-redshift quasars.

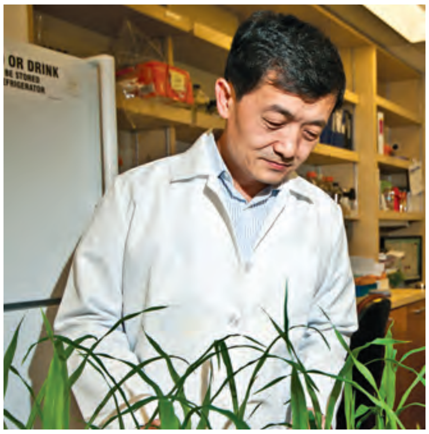
The quasar is a unique laboratory to study the way that a quasar's black hole and host galaxy co-evolve. The team's findings indicate that in the early universe, quasar black holes probably grew faster than their host galaxies, although more research is needed to confirm this idea. □

Nature published their work in February.

The above image is an artist's rendering of a very distant, very ancient quasar.
Image courtesy M. Kornmesser, European Southern Observatory

The National Natural Science Foundation of China, the Strategic Priority Research Program "The Emergence of Cosmological Structures" of the Chinese Academy of Sciences, the National Key Basic Research Program of China, and the NSF funded this work.

Hormones & Root Growth



Zhiyong Wang

A plant's roots grow and spread into the soil, taking up necessary water and minerals. The tip of a plant's root is a place of active cell division, followed by cell elongation as the roots expand into new depths of the soil. Achieving an optimal root growth rate is critical for plant survival under drought conditions, as well as for maximizing resource allocation to the important plant parts such as the fruits and seeds. This is why root-expansion mechanisms are of great interest to scientists and to those interested in improving agricultural yields, such as by increasing the efficiency of water uptake, which could help during a drought.

On a cellular level, as the tips of a plant's roots expand downward, they must coordinate two different, but related, balancing acts. The first is between proliferation and strategic inactivation of the stem cells that make up the root's tip; strategic inactivation, called quiescence, helps maintain the stem cell niche under stress conditions. The second is between continued stem cell proliferation and the differentiation of these stem cells into elongated, mature cells. New work from Carnegie's Juthamas Chaiwanon and Zhiyong Wang reports the mechanisms that control the balance between these aspects, which together determine the rate of root growth.

One of the major driving factors of root tip growth is the class of steroid hormones called brassinosteroids. These hormones are found throughout the plant kingdom and regulate many aspects of growth and development, as well as resistance from external stresses. In many parts of a plant's physiology, brassinosteroids function cooperatively with another plant hormone called auxin. The two hormones coordinate several developmental processes, including the differentiation of a plant's water-transporting vascular system, the elongation of a germinating seeding, and many shoot organs. Chaiwanon and Wang found that the brassinosteroids act on a concentration gradient to regulate root growth patterns.

Surprisingly, Chaiwanon and Wang's results show that in root tip growth brassinosteroids and auxin work antagonistically, as opposed to their usual synergy. The two hormones were distributed in opposite concentration gradients and had opposite effects on root cell elongation. The balance between their actions regulated a root's growth rate. The team identified over two thousand genes that are regulated by both brassinosteroid and auxin, and about 70 percent of these co-regulated genes responded to brassinosteroids and auxin in opposite directions demonstrating their antagonistic relationship in roots. □

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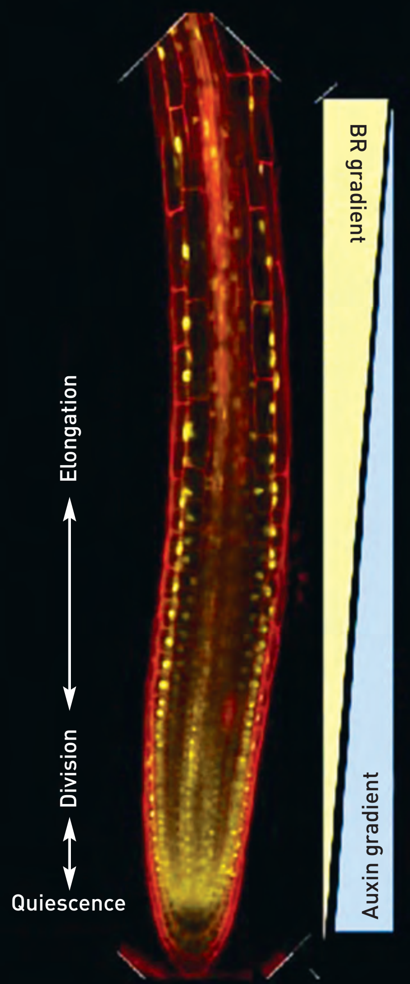
Current Biology published the work in April.

The National Institutes of Health supported this study.

This image shows roots of an eastern gamagrass plant.
Image courtesy Keith Weller, *Agricultural Research Magazine*, courtesy USDA Agricultural Research Service

The balances between stem cell quiescence, cell division, and cell elongation are crucial for the continuous growth of plant roots. These balances are maintained by two opposite gradients of antagonistic hormones, auxin and brassinosteroid.
Image courtesy Zhiyong Wang



Carnegie Launches New Airborne Laboratory

Above: The newly upgraded Carnegie Airborne Observatory-3 was on display at the May 1, 2015, launch event.

Below: Principal investigator Greg Asner addresses the crowd at the Carnegie Airborne Observatory-3 (CAO-3) launch event at the Hiller museum.

Images courtesy Robin Kempster

Carnegie launched the Carnegie Airborne Observatory-3 (CAO-3) on May 1, 2015, at an event at the Hiller Aviation Museum in San Carlos, California. The new observatory is the most scientifically advanced aircraft-based mapping and data analytics system in civil aviation today. "The future of ecosystem research takes off," remarked principal investigator Greg Asner of Carnegie's Department of Global Ecology.

Guests study the carbon map of Panama produced from data obtained by an earlier version of the CAO.

Image courtesy Robin Kempster

The third generation aircraft has been completely overhauled from previous models, boasting a multitude of cutting-edge improvements to its onboard laboratory. Until 2014, the CAO was leased. Now, CAO-3 is owned and operated by Carnegie to increase the flexibility over operational decisions. The new laboratory is now 40% lighter, and features a radically updated sensor package with expanded computing, data collection, and image processing capabilities. Additional improvements include advancements to its satellite and ground communications and upgrades to the engine and avionics. The plane also features a state-of-the-art "guest investigator" port, allowing new technologies to be flown in concert with the current CAO imaging spectrometer and dual-laser scanning system.

For Asner, these enhancements are nothing less than game changing. "Improvements to the new plane and instrumentation mean that more flights can be made and more scientists can take advantage of them." The new plane, with its new look, will be able to fly farther than ever before and operate over higher-altitude regions. It will reach twice the number of ecosystems a day, in regions never accessed until now. CAO's ability to gather global data is expected to make a huge impact on climate change research. Additionally, the data gathered from these flights will expand on other research topics including animal habitats, carbon stock quantification, rain forest biodiversity, and land-use changes and degradation.

These future expectations for the CAO are firmly rooted in its past achievements. Previous generations made remarkable contributions to conservation, sustainable resource use, and environmental policy around the world. It facilitated pioneering research of tropical forest health, and even exceeded its original mission by detecting illegal gold mining in the Amazon, capturing surprising lion behavior in African savannas, and uncovering archeological sites in Hawaii.

"We have an exciting wish list of new projects including the world's first 3-D animal mapping and new photosynthesis maps across huge areas using a new Solar-Induced Fluorescence (SIF) imaging sensor at the guest port," said Asner.

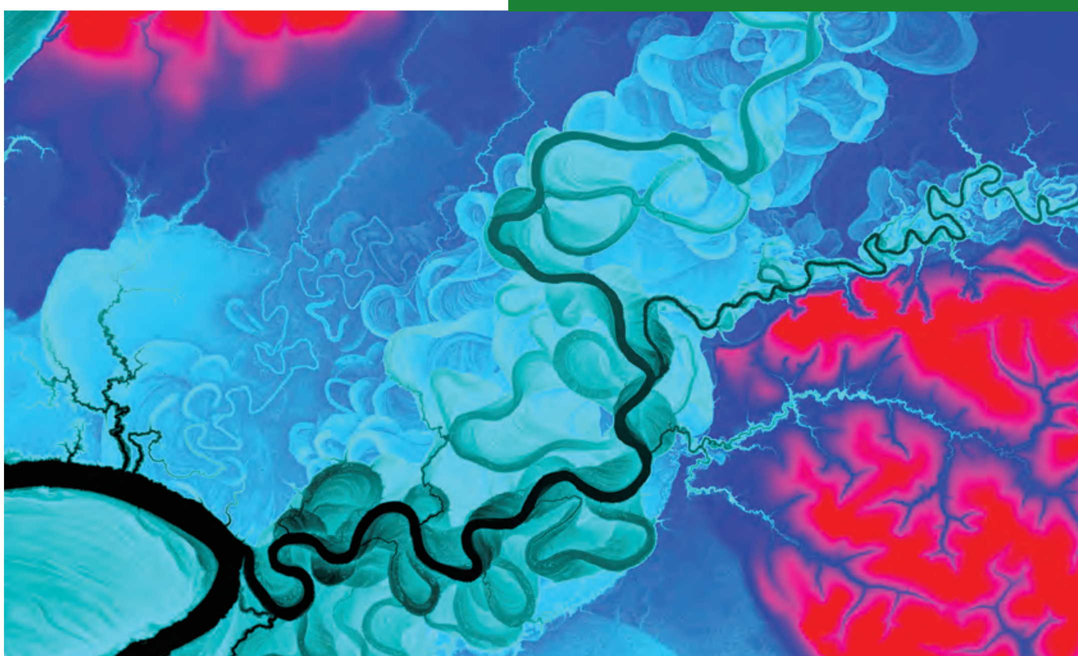
Asner's team also plans to map highly diverse forests throughout the world, including the mountains of the Ecuadorean Andes and the "Heart of Borneo" in Malaysia-Indonesia. By monitoring the vertical tree line movement for montane forests, the team hopes to answer long-standing questions about how climate change-driven fluctuations in temperature and precipitation will impact forest growth patterns. This critically important issue can now be addressed with this retrofit.

Lastly, CAO data produces stunning, full-color, 3-D imagery, provided free to thousands of organizations in science, art, education—even music and fashion. The possibilities are endless. □

Viewing the Past

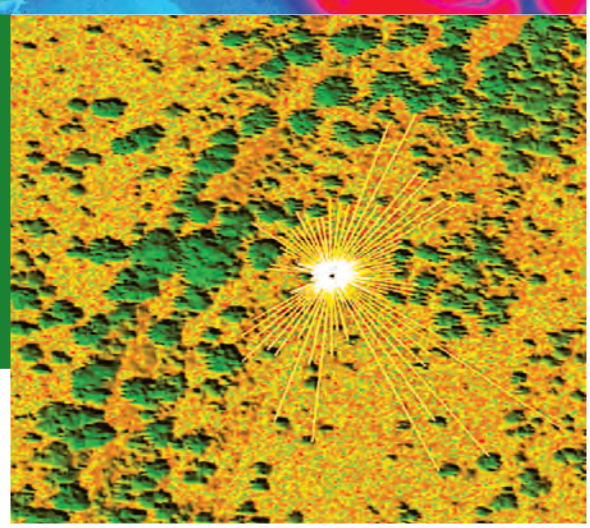
This high-resolution LiDAR image shows the surface terrain along the Tambopata River in the Peruvian Amazon. The ancient meanders and oxbows are shown in blue, extending out from the current location of the river in black as it flows between the higher terrace regions in pink.

Images courtesy Greg Asner



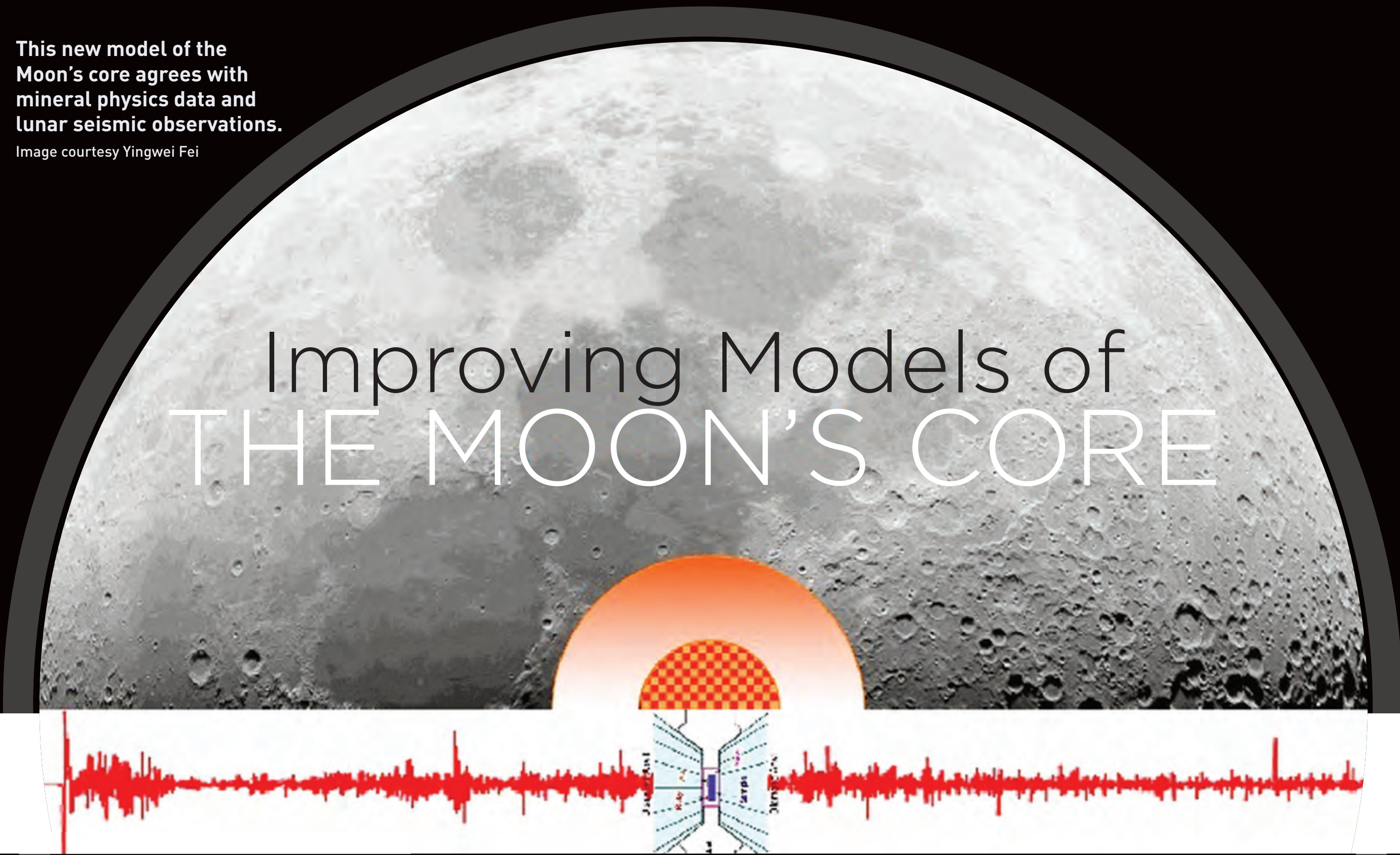
Animal Behavior

Male lions are not as dependent on females for hunting as thought. The 3-D CAO vegetation mapping was combined with GPS data on lion hunting behavior (white lines). The team found that male lions tend to hunt in dense areas, while females tend to hunt in more open savannas.



Current, core CAO Sponsors are Avatar Alliance Foundation, John D. and Catherine T. MacArthur Foundation, The Andrew Mellon Foundation, Mary Anne Nyburg Baker and G. Leonard Baker Jr., and William R. Hearst III.

This new model of the Moon's core agrees with mineral physics data and lunar seismic observations.
Image courtesy Yingwei Fei



Improving Models of THE MOON'S CORE

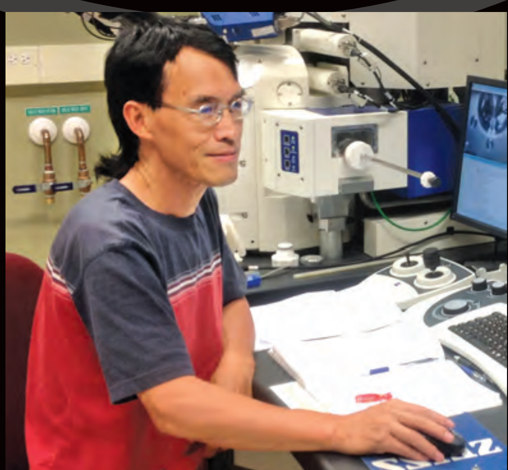
The cores of terrestrial planets and satellite bodies, including our own Moon, all contain large quantities of iron. As a result, understanding the physical properties of iron at high temperatures, and under extreme pressures, is crucial to studying planetary interiors and interpreting the observed seismic data. The Moon is the only other terrestrial body besides Earth on which multiple seismic observations have been made—during the Apollo missions. Work from a team including Carnegie's Yingwei Fei provided new measurements of iron at lunar core conditions that help us to build a direct compositional and velocity model of the Moon's core in conjunction with limited lunar seismic data.

The terrestrial planets all share a similar layered nature: a central metallic core composed mostly of iron, a silicate mantle, and then a thin, chemically differentiated crust. However differences in planetary masses mean that each planet will have different pressure and temperature conditions in their cores.

In the Earth's core, iron is stable with a closely packed hexagon structure called hcp iron (for hexagonal close-packed) under extreme pressure. As a result, most studies have focused on physical properties of hcp iron. However, the stable iron in the cores of smaller planets and satellites, such as Mars, Mercury, and the Moon, has a cubic structure called face-centered cubic, or fcc, instead of the hexagonal form found in Earth's core. Lack of accurate sound velocity data for fcc iron prevents a reliable compositional and velocity model of the Moon's core.

The team took measurements of the sound velocity through fcc iron under high pressures and temperatures, as well as of its density. Their measurements ranged from no atmospheric pressure to about 188,000 times normal atmospheric pressure (0 to 19 gigapascals) and temperatures ranging from 80 to about 1600°F (300 to 1150 K). The data can be directly used to model the velocity and density profile of the Moon's core and to compare with lunar seismic observations.

The new velocity model of the Moon's core shows significantly higher compressional and shear sound velocities than previous estimates for the solid inner core. The team's results also provide estimates of the inner core and outer core sizes that are consistent with the observed seismic travel times from the Apollo missions. □



Yingwei Fei

Proceedings of the National Academy of Sciences published the research in March.

The French National Research Agency, NASA, and the Programme National de Planétologie program of Centre National d'Études Spatiales—Institut National des Sciences de l'Univers supported this work.

Food-Delivery Process Inside SEEDS Revealed

Inside every seed is the embryo of a plant, along with—in most cases—food to power the initial growth of the young seedling. A seed consists mainly of carbohydrates, which have to be transported from the leaf to the seed's outer coat from the parent plant and then accessed by the embryo. If not enough food is delivered then the seeds won't have the energy to grow at germination. But very little is understood about this delivery process.

New work from a team led by Carnegie's Wolf Frommer identifies biochemical pathways necessary for stocking the seed's food supplies. These findings could be targeted when engineering crops for higher yields. The research identifies three members of the SWEET family of sugar-transport proteins that are used to deliver the sugars produced in the plant's leaves to the embryonic plant inside a seed.

Frommer's lab has done extensive work on SWEET proteins, which have an array of functions in plants, including nectar secretion. SWEET transporters are also vulnerable to takeover by pathogens that hijack the plant's food and energy supplies.

The research team—including Carnegie's Li-Qing Chen, Winnie Lin, Xiao-Qing Qu, Davide Sosso, and Alejandra Loñdono—found that SWEETs 11, 12, and 15 use multiple pathways to funnel sucrose toward the developing plant embryos. Specially created mutants that eliminate these three SWEET transporters show wrinkled seeds similar to those Gregor Mendel used to track down the basic rules of genetics. Embryonic development is clearly retarded in these mutants because they are unable to move sugars from the seed's coat to the embryo inside. □

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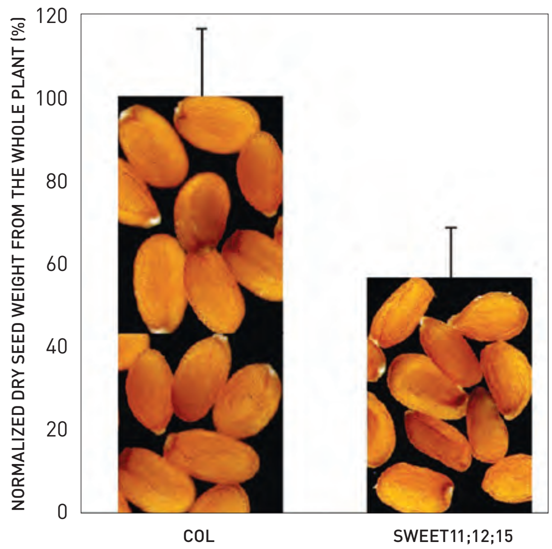
The Plant Cell published the work in March.

The Department of Energy and the Carnegie Institution of Canada funded this work.



This figure is a comparison of normal seeds and seeds lacking SWEETS 11, 12, and 15, which are wrinkled (similar to those Gregor Mendel used to track down the basic rules of genetics). Embryonic development is clearly retarded in these mutants because they are unable to move sugars from the seed's coat to the embryo inside.

Image courtesy Wolf Frommer

This is a seedling of the model plant *Arabidopsis*, a cousin of mustard.

A First-Generation Supernova?

A Carnegie-based search of nearby galaxies for their oldest stars has uncovered two stars in the Sculptor dwarf galaxy that were born shortly after the galaxy formed, approximately 13 billion years ago. The unusual chemical content of the stars may have originated in a single supernova explosion from the first generation of Sculptor stars.

The Sculptor dwarf is a small galaxy that orbits around our own Milky Way. Because Sculptor's stars are all located the same distance away from us, their ages can be determined by studying the pattern of their colors and their brightness. This technique tells astronomers that Sculptor, like many dwarf galaxies, stopped evolving long ago. While the Milky Way has been forming stars throughout the universe's 14-billion-year existence, Sculptor's youngest stars are 7 billion years old. Dwarf galaxies thus provide scientists an opportunity to see what galaxies looked like in the early epochs of the universe.

In all galaxies, stars are born out of collapsing clouds of dust and gas. Only a few million years after they begin burning, the most massive of these stars explode in titanic blasts called supernovae. These explosions seed the surrounding gas with the elements that were manufactured by the stars during their lifetimes. Those elements are then incorporated into the formation of the next generation of stars. Generally this process is cyclical, with each generation of stars contributing more elements to the raw material from which the next set of stars will be formed.

The Sculptor dwarf galaxy, as composed from data from the Digitized Sky Survey 2.
Image courtesy ESO/Digitized Sky Survey 2

Josh Simon

Astronomers hoping to learn about the first stages of galaxy formation after the Big Bang can use the chemical composition of stars to help them unravel the histories of our own and nearby galaxies. Elements heavier than hydrogen, helium, and lithium can only be produced by stars. The more stars a galaxy forms, the more enriched in heavy elements it becomes.

The team—which included Carnegie's Josh Simon, Ian Thompson, and Stephen Shectman, as well as former Carnegie postdoc Josh Adams—studied five stars in Sculptor, measuring the abundance of 15 elements in each one. The two most primitive stars have less than half as much magnesium and calcium as would be expected and just 10 percent as much silicon as similar stars in other galaxies. The only way to explain the shortage of magnesium, calcium, and silicon in these stars is if their heavy elements were made by fewer than four supernovae.

The astronomers concluded that these two primitive stars were probably formed from a gas cloud that had been seeded with heavy elements made by just one previously exploded star. This parent star is thought to be one of the very first stars ever formed in Sculptor. □

The Astrophysical Journal published the findings in March.

The National Science Foundation supported this work in part. Researchers made use of NASA's Astrophysics Data System Bibliographic services and data gathered by the 6.5-meter Magellan telescopes at Carnegie's Las Campanas Observatory in Chile's Atacama Desert.

SOLAR Could Meet California Energy Demand Five Times Over

In the face of global climate change, increasing the use of renewable energy resources is one of the most urgent challenges facing the world. Further development of one resource, solar energy, is complicated by the need to find space for solar power-generating equipment without significantly altering the surrounding environment.

Rebecca R. Hernandez was a postdoctoral researcher at Global Ecology and is now at UC-Berkeley.
Image courtesy Rebecca R. Hernandez

Research from Carnegie's Rebecca R. Hernandez (now at UC-Berkeley), Madison K. Hoffacker, and Christopher Field found that the amount of energy that could be generated from solar equipment constructed on and around existing infrastructure in California would exceed the state's demand by up to five times.

Just over eight percent of all of the terrestrial surfaces in California have been developed by humans—from cities and buildings to park spaces. Residential and commercial rooftops present plenty of opportunity for power generation through small- and utility-scale solar power installations. Other compatible opportunities are available in open urban spaces, such as parks.

Likewise, there is opportunity for additional solar construction in undeveloped sites that are not ecologically sensitive or federally protected, such as degraded lands.

The study included two kinds of solar technologies: photovoltaics, which use semiconductors and are similar to the solar panels found in consumer electronics, and concentrating solar power, which uses enormous curved mirrors to focus the Sun's rays. A mix of both options would be possible, as best suits each particular area of installation, whether it is on a rooftop, in a park, on degraded lands, or anywhere else deemed compatible or potentially compatible.

Overall they found that California has about 6.7 million acres (27, 286 square kilometers) of land that is compatible for photovoltaic solar construction and about 1.6 million acres (6,274 square kilometers) compatible for concentrating solar power. There is also an additional 13.8 million acres (55,733 square kilometers) that is potentially compatible for photovoltaic solar energy development with minimal environmental impact and 6.7 million acres (27,215 square kilometers) also potentially compatible for concentrating solar power development.

The team found that small- and utility-scale solar power could generate up to 15,000 terawatt-hours of energy per year using photovoltaic technology and 6,000 terawatt-hours of energy per year using concentrating solar power technology.

Their work shows it is possible to substantially increase the fraction of California's energy needs met by solar without converting natural habitat and causing adverse environmental impact and without moving solar installations to locations remote from the consumers. □

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Nature Climate Change published their findings in March.

The McGee Research Grant of the Stanford's School of Earth Sciences, the TomKat Center for Sustainable Energy, the Jean Langenheim Research Fellowship of Graduate Women in Science Society, the Hispanic Scholarship Fund's William Randolph Hearst Endowed Scholarship Fund, and the Vice Provost Office of Graduate Education's Diversifying Academia Recruiting Excellence Program supported this work.

This image shows the Puertollano Photovoltaic Park in Puertollano, Spain, a 47.6 MW installation in the Mediterranean biodiversity hot spot.
Image courtesy Rebecca R. Hernandez

Awards & Recognition

2014 Service to Science Awarded to Eric Rod and Oscar Duhalde

Eric Rod of the Geophysical Laboratory and Oscar Duhalde of the Observatories are the 2014 recipients of Carnegie's Service to Science Award. The award recognizes outstanding and/or unique contributions to science by employees who work in administration, support, and technical positions at Carnegie. They received their honors at this year's Carnegie Evening on May 6.

Eric Rod could not attend the event as he was in the final stages of classes for his engineering degree. He is the only technician at the High Pressure Collaborative Access Team (HPCAT), a facility for Carnegie's high-pressure research located at the Advanced Photon Source (APS) at Argonne National Laboratory. HPCAT operates four simultaneously operational beamlines consisting of nine x-ray optics and experimental stations. Eric is responsible for installing all major equipment, monitoring protection equipment systems, and making adaptive parts for every individual experiment. Over 500 users each year come from all over the globe to use the facility. Eric works closely with each scientist to meet their needs in developing tailor-made adaptive parts.

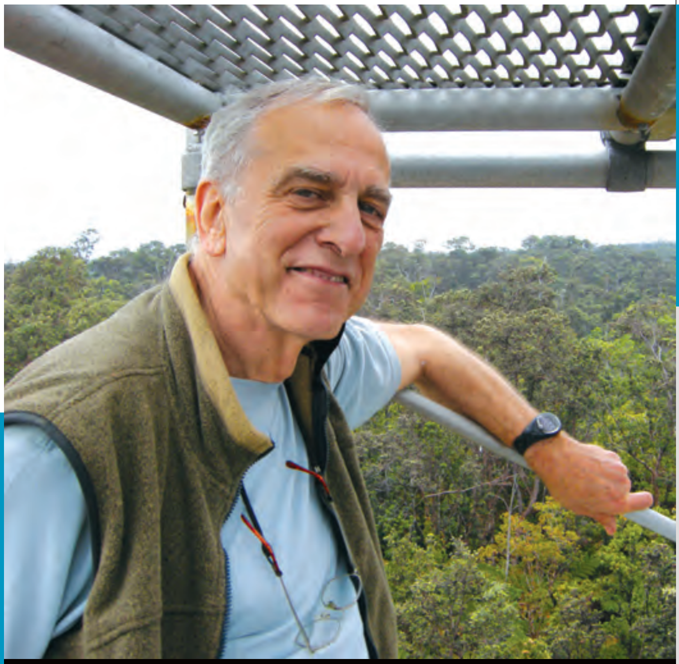
Eric quickly and expertly constructs conceptual designs in 3-D with various options.

Oscar Duhalde and his wife Esther Saez attended a reception in the library before the Carnegie Evening award ceremony.

Oscar Duhalde has been a member of the Observatory's technical staff in Chile since 1980 when he first assisted visiting astronomers as a skilled telescope operator for the 1-meter Swope telescope. He later became a mechanical specialist, playing key roles in commissioning new instruments and upgrades for the Swope and the 2.5-meter du Pont telescopes.

When a telescope or instrument requires mechanical repairs or modifications, Oscar quickly carries out the work as precisely and efficiently as possible. Instrument builders in Pasadena often request his skills for final commissioning work at the telescopes.

The highlight of Oscar's career occurred on February 23, 1987, with the discovery of the first naked-eye supernova since the invention of the telescope. The astronomers tell the story about the usual banter taking place at Las Campanas, and Oscar's sudden comment, "Oh yes, by the way, there is a bright star in the Magellanic Cloud." Jaws dropped. This discovery led to a wealth of research, and it sparked renewed interest in supernovae that led, eventually, to the discovery of dark energy and the 2011 Nobel Prize. □



Carnegie's Joe Berry Elected to National Academy of Sciences

Joseph A. Berry, staff scientist at Carnegie's Department of Global Ecology, was elected to the National Academy of Sciences (NAS), one of 84 new members and 21 foreign associates. Election to the NAS is one of the highest honors given to scientists.

Berry has been a staff scientist at Carnegie since 1972. Over the years he has pioneered laboratory and field techniques for understanding the exchange of carbon dioxide and water between plants and the atmosphere. His models and methods are widely used for understanding local, regional, and global matter and energy fluxes, with important applications to crop yields, water resources, and climate change.

"Joe Berry has been a driving force in establishing the field of global ecology," remarked Chris Field, founding director of Carnegie's Department of Global Ecology. "His work has been foundational for the field. Joe has made major, fundamental discoveries in biochemistry, plant biology, global ecology, and climate science."

Berry's seminal papers include studies on modeling photosynthesis and water loss and a method for inferring water-use efficiency based on the composition of a leaf. Recently, most of his work has been at the global scale, where he is developing techniques for measuring photosynthesis in forests using satellite data.

"Joe's science links so many fields, and in each of them he has innovated. He is a quintessential Carnegie scientist, original and inspiring. I've tremendously enjoyed learning from him. He also played a key role in the founding of our Department of Global Ecology a little over a decade ago," remarked Carnegie president Matthew Scott. "The accomplishments of Joe and others in that department have had a very substantial impact."

Berry received his B.S. in Chemistry from UC-Davis in 1963 and his masters in soil science from UC-Davis in 1966. He earned a Ph.D. in botany from the University of British Columbia in 1970.

David Ehrhardt Named Royal Microscopical Society Honorary Fellow

Carnegie's David Ehrhardt has been awarded an honorary fellowship of the Royal Microscopical Society. It was announced during the society's Botanical Microscopy 2015 meeting at Exeter University.

Potential fellows must be nominated and recommended by five or more current fellows, of which there are never more than 65 at any given time. The proposed honoree is then put before the society's council, which approves or rejects the nomination.

"Looking at the list of the other honorary fellows, I am surprised and honored to be considered part of this eminent group of scientists," Ehrhardt said when he learned of the award.

Ehrhardt's work features application of advanced microscopy and image analysis to visualize and quantify molecular activities in live plant cells, revealing mechanisms of subcellular choreography inside plant tissues. His methods allow him and his team to explore cell-signaling and cell-organization events as they take place.

Incorporated by a royal charter in the United Kingdom, the society is "dedicated to advancing science, developing careers, and supporting wider understanding of science and microscopy." It has been selecting honorary fellows since 1840. It also publishes *The Journal of Microscopy.*

Image courtesy Robin Kempster

Carnegie's Zhao Zhang Receives 2015 Larry Sandler Memorial Award

The newest member of the staff at the Carnegie Department of Embryology, junior investigator Zhao Zhang, received the prestigious Larry Sandler Memorial Award at the 56th Annual Drosophila Research Conference of the Genetics Society of America in Chicago in March. The annual award is given for the best research that led to a Ph.D. using *Drosophila*, the genetically tractable fruit fly that is employed in a wide range of biological and medical research.

Zhang, who joined Carnegie in November 2014, studies how elements with the ability to "jump" around the genome, called transposons, are controlled in egg, sperm, and other somatic tissues to understand how transposons contribute to genomic instability and to mutations that lead to inherited disease and cancer. He particularly focuses on transposon control and its consequences in gonads compared to other tissues; he has discovered novel connections to how gene transcripts are processed in the nucleus. To accomplish this work, Zhang frequently develops new tools and techniques, a characteristic of many outstanding Carnegie researchers.

Embryology director Allan Spradling remarked, "We congratulate Zhao on this exceptional honor. He is exactly the sort of original, unconventional, and self-motivated researcher that Carnegie seeks to support. We look forward to his many accomplishments that lie ahead."

Zhang received a B.S. in biotechnology from Shandong Agricultural University in Tai'an, China, and an M.S. in cell biology at Beijing Normal University. He was awarded a Ph.D. in November 2013 from the University of Massachusetts Medical School in interdisciplinary studies.

Zhao Zhang received the plaque for the Genetics Society of America's 2015 Larry Sandler Memorial Award for the best research that led to a Ph.D. using the fruit fly *Drosophila*.

Image courtesy Zhao Zhang

John Mulchaey Appointed Director of the Carnegie Observatories

Image courtesy Tim Neighbors

John Mulchaey has been appointed the new Crawford H. Greenewalt Director of the Carnegie Observatories. He is the eleventh director of the historic department, which was founded in 1904. He follows in the footsteps of such astronomical giants as George Ellery Hale and Horace Babcock. Mulchaey was appointed acting director in 2014.

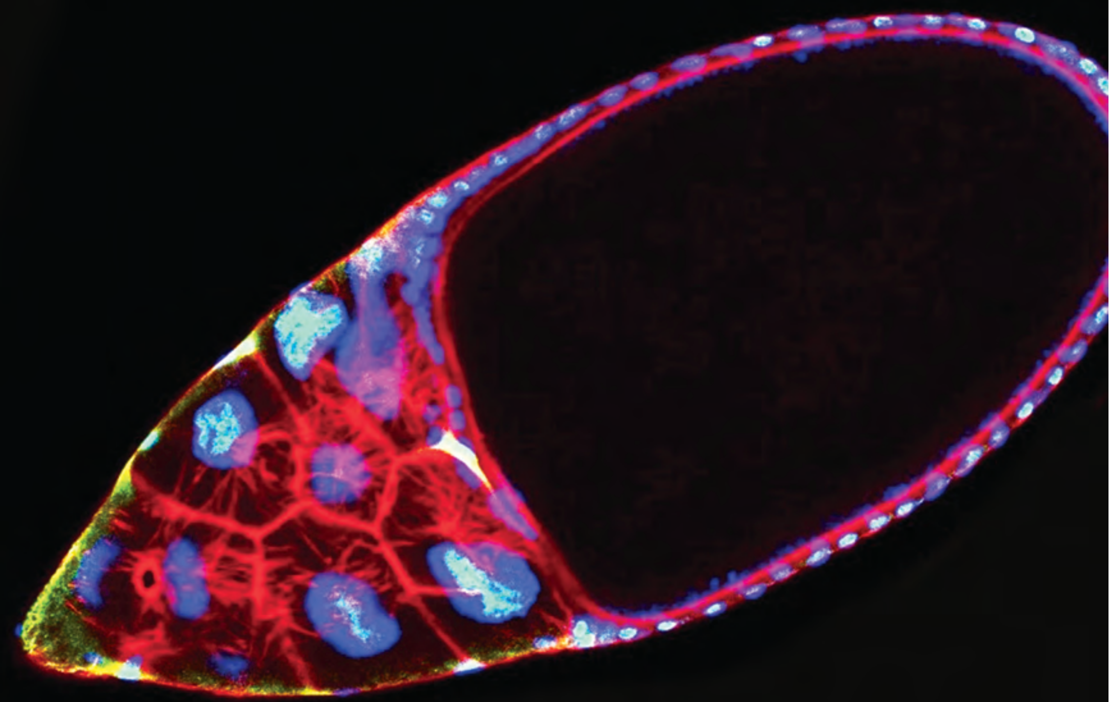
"We could not be more pleased," remarked Carnegie president Matthew Scott. "John has been with Carnegie for 20 years and has been intricately involved in all the research and telescope development during his tenure. In addition to his outstanding scientific accomplishments, he has proven to be a terrific leader, effective and highly popular with our astronomers. He has run our postdoctoral fellowship program beautifully. His scientific expertise, his judgement about how to foster scientific education and projects, and his leadership experience will be crucial for launching Carnegie into the next era of astronomical research. He has been heavily involved in planning the Giant Magellan Telescope, which will be built on our land in Chile, and will continue to be a key coordinator for GMT research as it comes on line in the next decade."

Mulchaey investigates groups and clusters of galaxies, elliptical galaxies, dark matter—the invisible material that makes up most of the universe—active galaxies, and black holes.

As a graduate student, Mulchaey led the team that discovered that some galaxy groups are bright X-ray sources. This work suggested that galaxy groups are dominated by elusive dark matter that does not emit light but has a strong gravitational pull.

Mulchaey works extensively with space-based, X-ray telescopes, and the extraordinary optical Magellan telescopes at Carnegie's Las Campanas Observatory in the Atacama desert of Chile. X-ray images alone are not sufficient to uncover the nature of galaxy groups. Follow-up observations with large-aperture optical telescopes, such as the Magellans, are necessary to determine galaxy type and distance.

Mulchaey received his B.S. in astrophysics from UC-Berkeley and his Ph.D. from the University of Maryland. He was a graduate student fellow at the Space Telescope Science Institute in Baltimore and a postdoctoral fellow at the Carnegie Observatories in Pasadena, before joining the Carnegie staff.



The image right is an ovarian follicle. The cytoskeleton is stained red, the DNA blue. The green shows the activation of SREBP, which controls the activation of genes that induce accumulation of lipids in immature oocytes, immature eggs.

The image below is from a *Germaria*, a type of fly. The fusome organelle and follicle cells are stained green, the cytoskeleton red, and the DNA blue.

Images courtesy Matthew Sieber

Egg Development and Fat Accumulation

Nutrition and metabolism are closely linked with reproductive health. Several reproductive disorders including polycystic ovary syndrome, amenorrhea, and ovarian cancer have been linked to malnutrition, diabetes, and obesity. Furthermore, fasting in numerous species can result in decreased fertility, because the development of immature egg cells, called oocytes, is arrested.

Understanding how nutrients accumulate in immature oocytes will provide valuable insights into the link between metabolic disease and reproductive dysfunction. New work from Carnegie's Allan Spradling and Matthew Sieber focused on the accumulation of triglyceride and a certain kind of steroid called sterols during oocyte development. They were able to identify an insect steroid hormone that is crucial to both lipid metabolism and egg production in fruit flies.

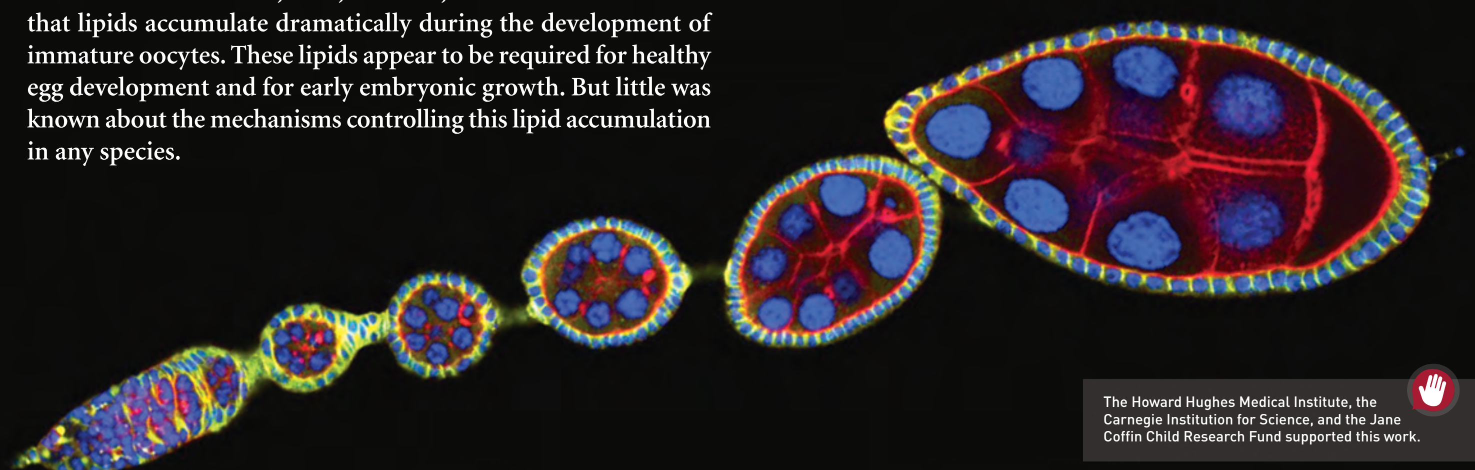
Recent studies in flies, mice, livestock, and humans have shown that lipids accumulate dramatically during the development of immature oocytes. These lipids appear to be required for healthy egg development and for early embryonic growth. But little was known about the mechanisms controlling this lipid accumulation in any species.

Spradling and Sieber discovered that the insect steroid hormone ecdysone stimulates a protein called SREBP, which controls the activation of genes that induce accumulation of lipids in immature oocytes. The lipids are important stored nutrients for the maturation of the oocytes and their development after fertilization. The SREBP control system has been shared by many species during evolution and controls lipid metabolism in humans as well.

They found that ecdysone also promotes a female-specific accumulation of high levels of stored fat and sugars throughout the body that is required for normal fertility.

Overall ecdysone acts to regulate systemic metabolism of the female fruit fly to support egg cell production. Without this female increase in stored body fat and sugar, oocyte development is slowed significantly and fewer eggs are produced. □

Current Biology published their findings in March.



The Howard Hughes Medical Institute, the Carnegie Institution for Science, and the Jane Coffin Child Research Fund supported this work.

Carnegie Evening: Spradling's "Fountain of Youth" Eggs

Allan Spradling was this year's Carnegie Evening speaker.

Eggs are the fountain of youth, Embryology director Allan Spradling said during his talk, "Insights From Eggs" at the May Carnegie Evening celebration with trustees, scientists, support staff, and guests.

Eggs are special, in part, because they are the only cell that can accomplish "reverse aging," Spradling explained. "The mother's cells get older and older, but she can still produce a young animal again." And this is because of the ability of her eggs to reverse the aging clock. He said this phenomenon is likely similar to the way a cell phone starts to "act up" and needs to be rebooted before it can function again. Egg cells probably contain some kind of "reboot" programming that keeps them able to accomplish this age reversal. The other special thing about egg cells, Spradling said, is that they're able to develop. Sperm cells are not required, they just contribute a set of genes, he added.

Spradling explained how research from his lab and others is demonstrating that egg-development processes really are not that different in insects and mammals. In fruit flies, immature egg cells always form in 16-cell groups known as germline cysts. The first cell in the cyst becomes the oocyte, the immature egg cell, others become nutrition-supplying nurse cells. At first glance, the mammalian ovary appears quite different, but recent findings from Lei Lei in Spradling's lab have shown that mouse germ cells develop in cysts. Furthermore, information is emerging that a major fruit fly steroid plays a similar role to the one estrogen does in mammals. Spradling said these similarities go back to a common ancestor between insects and mammals.

In introducing Spradling, Carnegie president Matthew Scott noted that it is rare to do something "truly creative" in science, but that Spradling had done so with his idea of using so-called "jumping genes," or transposons, to insert genetic material into a fruit fly's DNA. Spradling discussed how he is currently applying his research techniques to trying to find the developmental programming in an egg cell.

Spradling concluded his talk with a rousing call for "visionary leadership" in science, and for Carnegie and other institutions to continue pursuing broad-based biological research programs. "This will be the best thing we can do for patients, for our country, and for science," he said. □

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A Clearer Look at THE HEAVENS

In early May for the first time, astronomers from the University of Arizona and Carnegie's Yuri Beletsky at Las Campanas Observatory used the Clay Magellan telescope with Magellan Adaptive Optics (MagAO) to look at the sky through an eyepiece of 6.5-m mirror. Adaptive optics corrects for the blurring effects of the atmosphere. This has never been done before on any large telescope. They watched as a corrected image of Alpha Centauri emerged. Beletsky documented the moment with his camera. □

Laird Close is the Magellan Adaptive Optics principal investigator. He is observing Alpha Centauri as the adaptive optics system corrects the image on the 6.5-meter Clay telescope. The inset shows the corrected image.
Image courtesy Yuri Beletsky