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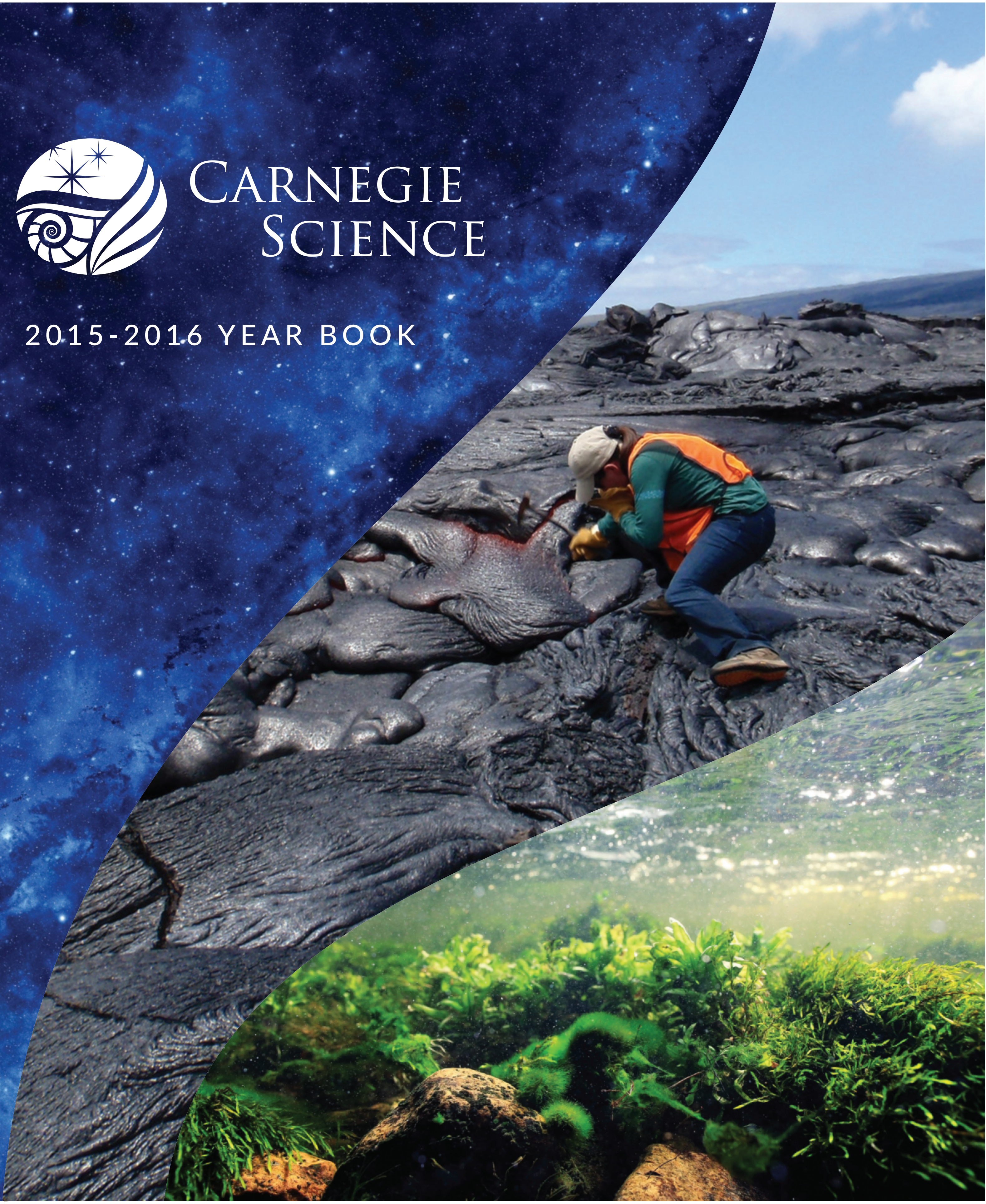
CARNEGIE INSTITUTION FOR SCIENCE 2015-2016 YEAR BOOK

CARNEGIE SCIENCE

2015-2016 YEAR BOOK



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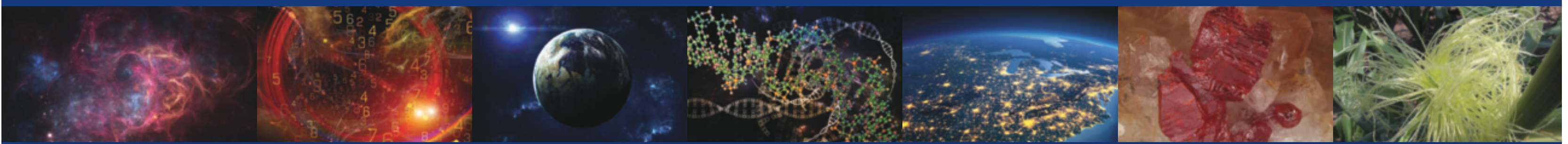

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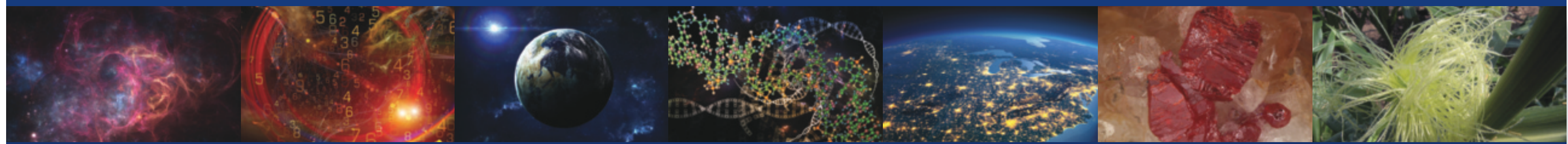
Cover, middle image: Carnegie volcanologist Diana Roman examines a lava flow.

Image courtesy Christelle Wauthier



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2015-2016 YEAR BOOK

The President's Report

July 1, 2015 - June 30, 2016

CARNEGIE INSTITUTION FOR SCIENCE

Former Presidents

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About Carnegie

“. . . to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind . . .”

The Carnegie Institution was incorporated with these words in 1902 by its founder, Andrew Carnegie. Since then, the institution has remained true to its mission. At six research departments across the country, the scientific staff and a constantly changing roster of students, postdoctoral fellows, and visiting investigators tackle fundamental questions on the frontiers of biology, earth sciences, and astronomy.

Carnegie Institution for Science

Contents

Dynamic Scientists for Dynamic Science

Analyzing Seismic Activity of Nicaraguan Volcanoes

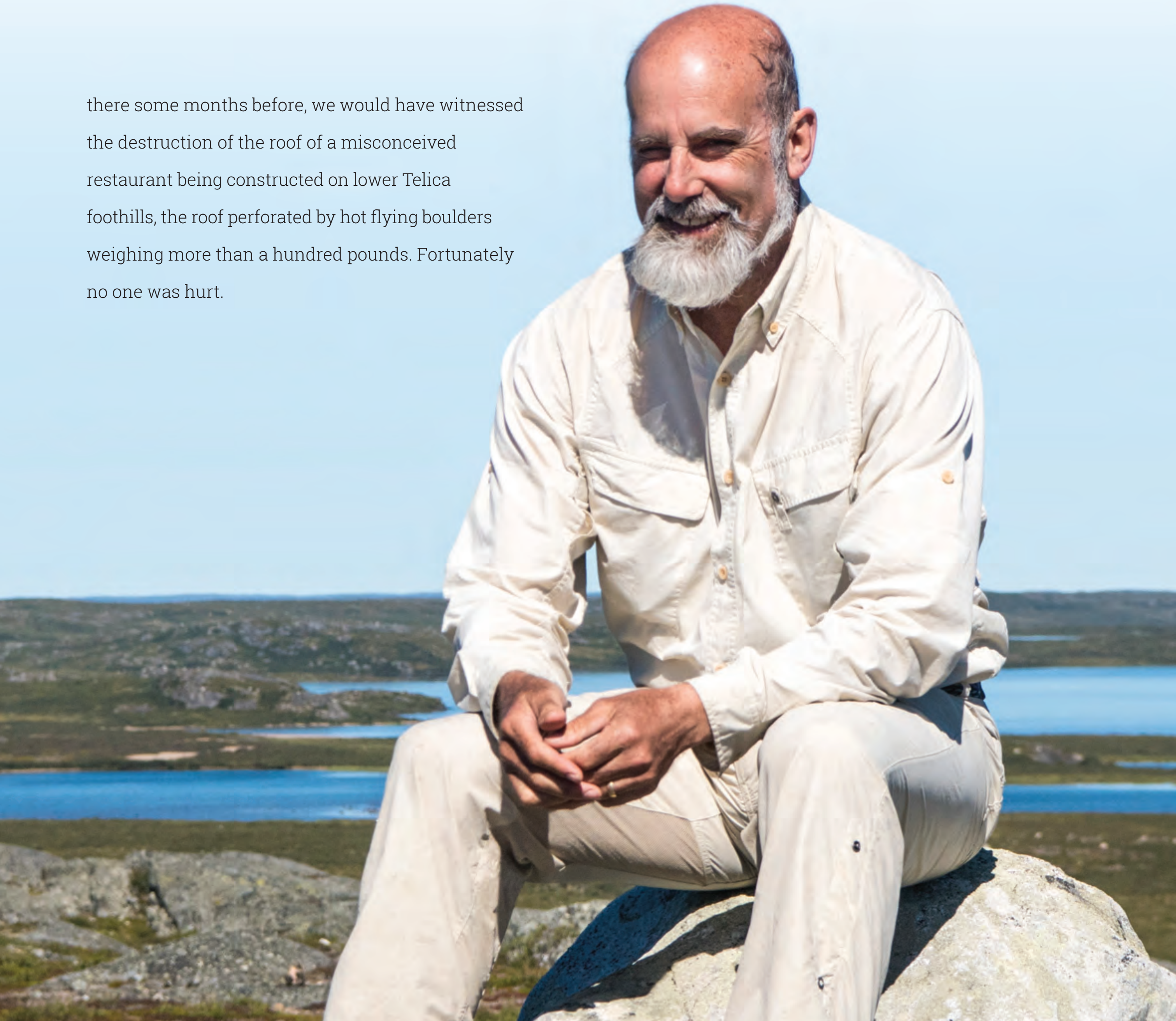
The slopes of Nicaragua's Telica Volcano, where I stood with Carnegie staff scientists Diana Roman and Lara Wagner, are littered with smashed boulders as though a giant with a hammer had gone mad with rage. However, the boulders had flown out of the deep pit of the volcano and arced thousands of feet only to smash into stony slopes formed by past eruptions. Had we been

The Chaitén Volcano in Chile is shown on the previous page. The sandy material on the left is the new dome. At left is the Masaya Volcano with Carnegie researchers Diana Roman (left) and Lara Wagner (right) standing at its edge.

Images courtesy Matthew Scott

"As a bench biologist, I wanted to learn more about Carnegie science by exploring the substance of study."

there some months before, we would have witnessed the destruction of the roof of a misconceived restaurant being constructed on lower Telica foothills, the roof perforated by hot flying boulders weighing more than a hundred pounds. Fortunately no one was hurt.




patagonia

Understanding the Challenges of Fieldwork

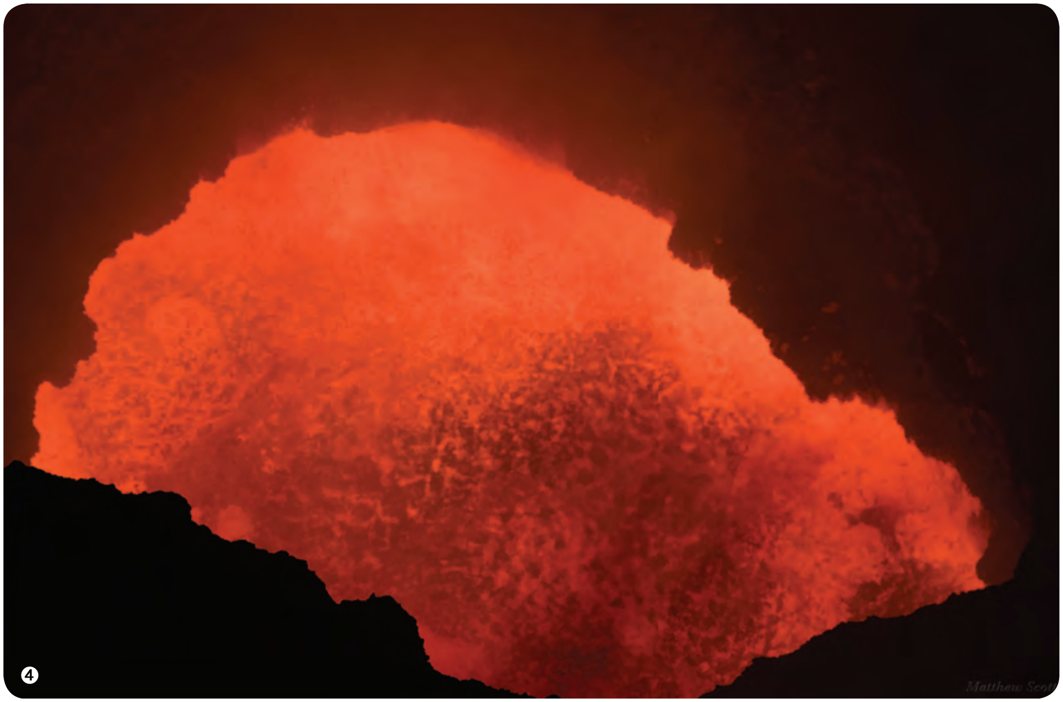
This past year, my second at Carnegie, I accompanied some of our scientists to their field research sites. As a bench biologist, I wanted to learn more about Carnegie science by exploring the substance of study. It's an involved venture! There are complicated logistics of getting to remote locations and returning samples. Instrumentation upkeep and use in remote areas can be dicey. The rustic accommodations and long days are reminiscent of mountaineering trips. What was driven home to me is how much these Carnegie researchers are the essence of our founder's vision—imaginative and exceptional individuals who independently pursue unconventional research that produces outsized results. I saw science at its best.

Science is sometimes described as measurements followed by deductions, but to enjoy the full pleasure of science, and to gain full insight, requires following measurements with imagination, which drives yet more measurements!

On the Masaya Volcano in Nicaragua, Diana and Lara had installed seismometers to understand events before, during, and after eruptions. I had been told about the volcano's lava lake and had envisioned something black with orange cracks with a little smoke rising. Instead the lake was a torrent of surging orange waves. The crater produces some 1,500 *tons* of sulphur dioxide each day, but mercifully the wind often favored us and we did not need gas masks.

❶ Carnegie staff scientists Diana Roman (top left image, left) and Lara Wagner (right) stand on the slopes of Nicaragua's Masaya Volcano. ❷ The researchers also studied the Telica Volcano. Although the crater produces some 1,500 *tons* of sulphur dioxide each day, the wind direction was such that the trio did not need the gas masks they brought along (bottom left image, from left to right: Matthew Scott, Diana Roman, Lara Wagner). ❸ When Telica erupted months before, boulders flew out of the deep pit flying thousands of feet and smashing the roof of a restaurant under construction on the lower Telica foothills. ❹ The Masaya Volcano's lava lake was roiling with orange waves. See video at https://vimeo.com/160568913.

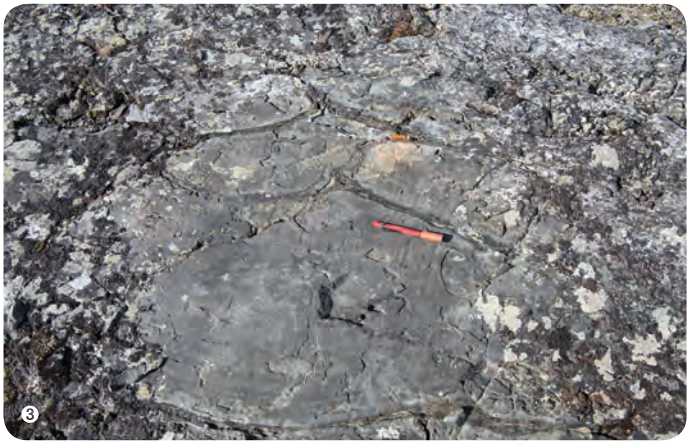
Images courtesy Matthew Scott



Exploring the Canadian "Shield"

The northern Northwest Territories, Canada, is mostly tundra and volcanoes are not instantly obvious. I joined Carnegie postdoctoral fellow Jesse Reimink, Carnegie director Richard Carlson, staff scientist Steve Shirey, and former Carnegie postdoc Graham Pearson (now at the University of Alberta) on part of their expedition to the Slave Craton, a vast chunk of ancient rock that makes up much of the northern Canadian "shield."

We flew from Yellowknife, Canada, in a Twin Otter plane to our destination at about 64 degrees north at Big Bear Lake. Jesse had chosen the lake as a good access point for sampling diverse geology. The goal was to understand the history and properties of the craton, most of which is 2.6 to 3.3 billion years old. From their month of field work, hundreds of kilograms of rock would travel back to our labs in Washington, D.C., for age-dating through uranium-lead radioactive decay measurements, and for other analyses. Though we encountered no active volcanoes, ancient flows of lava were abundant. "Pillow lava" formations could be clearly seen in many places. Three billion years ago, hot magma met water and large pillowy blobs of new rock formed. Jesse and team's samples will help revise and refine the history of our continent and our understanding of the ancient Earth in general—just the kind of objective that our founder envisioned.



❶ The northern Northwest Territories, Canada, is very different from Nicaragua. It is mostly tundra, and volcanoes are not instantly obvious. The team camped on the edge of the water as seen in the aerial drone photo. ❷ ❸ Although the team (from left to right: trustee Mike Long, Rick Carlson, Steve Shirey, Graham Pearson, Matthew Scott, Jesse Reimink) did not encounter any active volcanoes, ancient lava flows were abundant and there were "pillow lava" formations in many places, shown close up. These (above, bottom left) formed three billion years ago, when hot magma met water and formed large blobs of new rock. They can shed light on Earth's evolution. ❹ The team also found some unusually young rock, being examined by Pearson.

Images courtesy Matthew Scott

Examining the Chemistry of Amazonian Forests

In Ecuador, I joined Carnegie staff scientist Greg Asner and his Carnegie Airborne Observatory (CAO) team for a couple of days of flights over the Amazon. The CAO team previously studied the forests of Colombia and Peru with their one-of-kind, big-data ecological approaches. On our trip they were applying the same tools in Ecuador, filling the geographical gap, in partnership with the Ministry of the Interior. Ecuador is dotted with huge volcanoes. For Greg's purposes, the most interesting emission from the mantle is the lava that flowed out of the Andes and down to the east about 40 million years ago, a lava field that underlies the vast forest. Even to the naked eye, tremendous variations are apparent in the sea of green. But the CAO spectrometers reveal tremendous detail in the vegetation's different chemical properties, which reflect the composition of underlying hardened lava.

❶ The Carnegie Airborne Observatory-3 (CAO-3) (top) is an airborne laboratory with many improvements over the previous generation. The technical upgrades and much lighter lab allow the plane to reach twice the number of ecosystems a day over higher altitudes. ❷ ❸ Carnegie President Matthew Scott (second image, left) flew in the aircraft with principal investigator Greg Asner (right) over the snaking river in the Amazon Basin. ❹ Back on the ground, the CAO team with Scott "sampled" some Amazonian fauna (fourth image).

Images courtesy Matthew Scott

Debuting the Carnegie Science Venture Grants

Andrew Carnegie knew the value of investigating highly original scientific questions. New knowledge often arises from collaborations of Carnegie scientists with different scientific expertise. This year we established a new program—the Carnegie Science Venture Grants—to further empower all Carnegie researchers to investigate scientific problems that ignore conventional boundaries. These grants are generously supported, in part, by trustee Michael Wilson and his wife Jane.

The Carnegie Science Venture Grants are designed to bring together cross-disciplinary teams to provide fresh eyes for new questions. Each grant offers $100,000 of support. This last year we awarded grants to six new projects ranging from the Carnegie Massive Open Online Research Platform that will allow Carnegie data sets to be accessed and analyzed by citizen scientists, the investigation of the molecular mechanisms that control how plants sense temperature changes using techniques developed for animals, and a grant to explore the carbon isotope ratios of Earth's mantle. Surprisingly, Earth has so-called isotope-ratio signatures that are different from the other rocky planets.

These internal prizes are awarded twice yearly, following the proposal and review process. The review panel consists of representatives from each department, with members of the Board of Trustees and Science Deputy Margaret Moerchen who manages the program. I am excited about the countless surprises that are bound to result! For a complete listing of these exciting developments see pages 57-58.

Nurturing Postdoctoral Associates

Carnegie has an enormously talented pool of some 150 postdoctoral fellows from all over the world. To recognize their critical contributions, 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 PIE Awards to Matt Sieber of Embryology, Rebecca Albright of Global Ecology and now at the California Academy of Sciences, Johanna Teske of Terrestrial Magnetism and the Observatories, and Zehra Nizami of Embryology. They are all a true testament to Andrew Carnegie's vision of supporting particularly creative individuals (see page 56).

To further support these crucial postdoctoral fellows, postdocs working with department directors and the administration established the Carnegie Institution Postdoctoral Association (CIPA). During 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. These young scientists are the lifeblood of Carnegie and, as has been true in the past, their impact on science will spread far and wide.

Bolstering Our Future

Because the advancement of science and technology is the linchpin to strong economic growth, and because discovery is so tantalizing, we have expanded our science outreach efforts. In particular, our Capital Science Evenings have grown in number and we are partnering with like-minded organizations to extend our reach. With generous support from Margaret and Will Hearst (a longtime Carnegie trustee) we have partnered with FORA.tv who has vastly improved the broadcast quality of these lectures and we have gained new online audiences. We are also launching a new series of events called "Expedition Earth: Roads to Discovery" that will bring the excitement of exploration to even more people and bring them into the Carnegie fold.

Andrew Carnegie and his trustees realized that flexibility and independence are essential to the institution's success. To provide a solid foundation that will allow us to support this kind of science and outreach long into the future we have strengthened our administration team to grow the endowment, expand our development program, better manage our finances, enhance technology transfer, and become more efficient with in-house legal counsel (see pages 59-60).

Carnegie Science nurtures researchers who independently explore new directions, with discovery science as its centerpiece. Support for this kind of science is increasingly rare, and increasingly crucial. We are particularly grateful to those of you who have made contributions to advance this work. As outside funding and government grants become progressively more competitive in an uncertain environment, we must explore other avenues to support our research. Our invigorated team is firmly dedicated to keeping Carnegie Science on the frontier well into the future.

President, Carnegie Science

The administration team has been strengthened to provide a solid foundation for Carnegie to support cutting-edge science and outreach long into the future. Many of the team members met in New York at the September board committee meeting. From left to right: General Counsel Ben Aderson, Associate Director of Financial Planning and Budgeting Jessica Moore, trustee William Gayden, cochair of the board Suzanne Nora Johnson, Chief Development Officer Ann McElwain, trustee Michael Duffy, Chief Operating Officer Tim Doyle, Investment Analyst Brady Stovall, Advisor to the Investment Committee Ashok Chachra, Chief Investment Officer Michael Stambaugh, Investment Director Michael Pimenov, Carnegie President Matthew Scott.

Image courtesy Matthew Scott

2015-2016 YEAR BOOK

Research Highlights

Image courtesy Christelle Wauthier

Astronomy

Investigating the Birth, Structure, and Fate of the Universe

Zooming In On Distant Galaxies

For the first time astronomers have detected the rotation of a distant dead galaxy residing some 11 billion light years away. New stars ceased forming in this galaxy when the universe (now 13.8 billion years old) was only 1.7 billion years old, leaving a massive but compact galactic seed. Astronomers want to understand how these seeds grow into modern galaxies, but observing them is challenging because of their great distances and small sizes.

> "Rather than transforming in a single event, massive galaxies may have reached their appearance in a more gradual metamorphosis."

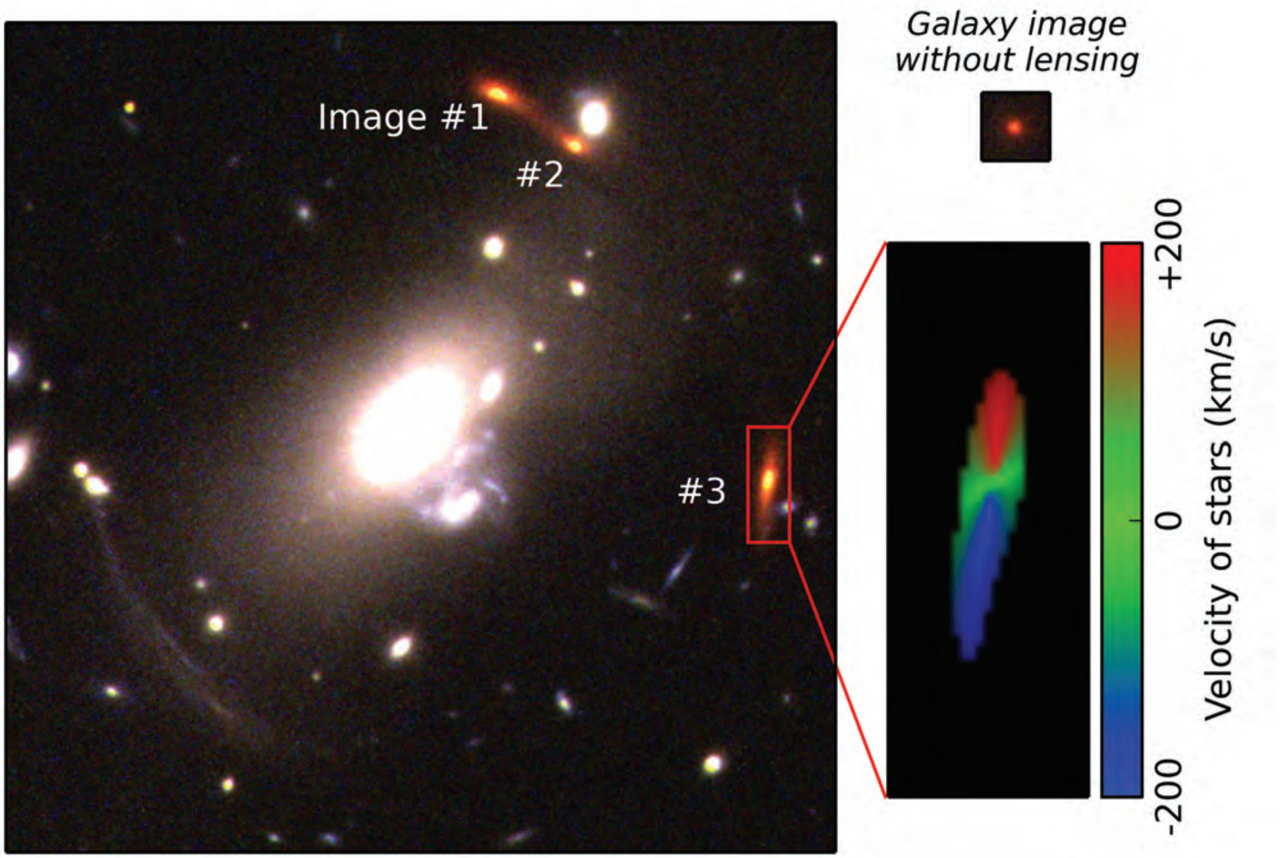
A team led by Carnegie's Andrew Newman has overcome this difficulty by using gravitational lensing, an optical effect that occurs when a distant galaxy of interest is precisely aligned with a closer, massive object along the same line of sight. The gravity of the foreground object bends the light from the more distant object, magnifying it and acting as a natural telescope. This technique allows researchers to peer inside these distant galaxies in much more detail.

Andrew Newman studies various topics in extragalactic astronomy. He is standing at one of the twin Magellan telescopes at Carnegie's Las Campanas Observatory high in the Chilean Andes.
Image courtesy Andrew Newman

The team used state-of-the-art infrared instruments on some of the world's most powerful telescopes, including the Magellan telescopes at Carnegie's Las Campanas Observatory, the Keck telescopes in Hawaii, and the Hubble Space Telescope. Gravitational lenses are rare, but Carnegie's unique access to Magellan enabled Newman and team to undertake an extensive search. They uncovered five cases, including one of the brightest distant galaxies ever discovered.

Massive galaxies today are mostly red, non-star forming, elliptical in shape, and non-rotating. Our Milky Way, in contrast, is a blue spinning disk with young stars. How did massive galaxies become this way? One theory is that a single dramatic event—a collision of two galaxies—causes a complete transformation at once.

Newman's research tested this theory by using gravitational lensing to search for distant galaxies where these transformations are only partly complete.



This image is a Hubble Space Telescope image of the first lensed galaxy the astronomers studied. The giant galaxy in the center of the image has split the light of the distant red galaxy into three images. The box in the upper right shows a model of what this galaxy would look like if it were not being lensed—much dimmer and smaller. Because of the enlarged appearance of Image #3 produced by gravitational lensing, the team—including Sirio Belli of the Max Planck Institute for Extraterrestrial Physics and Richard Ellis of the European Southern Observatory—was able to measure the velocities of the stars within the galaxy and see its rotation (lower right image). This was the first time such a measurement was made in a galaxy so distant—11 billion light years away.

Image courtesy Andrew Newman

In the first measured galaxy, the team found that star formation had died out only 800 million years ago. But they were surprised to find that the galaxy is still spinning rapidly. Since this galaxy is very massive and will probably become a non-rotating elliptical galaxy, it appears that such galaxies might stop forming stars and stop rotating at different times. Rather than transforming in a single event, massive galaxies may have reached their appearance in a more gradual metamorphosis. Newman and team will explore this transition by comparing all five newly discovered lensed galaxies with computer simulations.

Astronomy

Continued

Witnessing Nine Billion Years of History

A few hundred million years after the universe cooled, clumps of gas and dark matter collapsed under their own weight and made the first stars in the first galaxies. For the next few billion years, these galaxies accumulated more gas and dark matter, grew ever more massive, and created more stars. But then galaxy growth started to slow. Why massive galaxies slowed their growth rates is a central mystery in astronomy and astrophysics. Eventually, more and more galaxies, and even those less massive than our own Milky Way, stopped growing rapidly, becoming dominated by older stars with less frequent new star formation.

> "These data represent the most complete picture of the evolution of normal galaxies over the past 9 billion years."

To figure out why, Daniel Kelson formed a team to create the largest data set of distances and masses of galaxies back to a time when the universe was a third of its current age, nine billion years ago. This is the most detailed wide-area map of the history of galaxies to date.

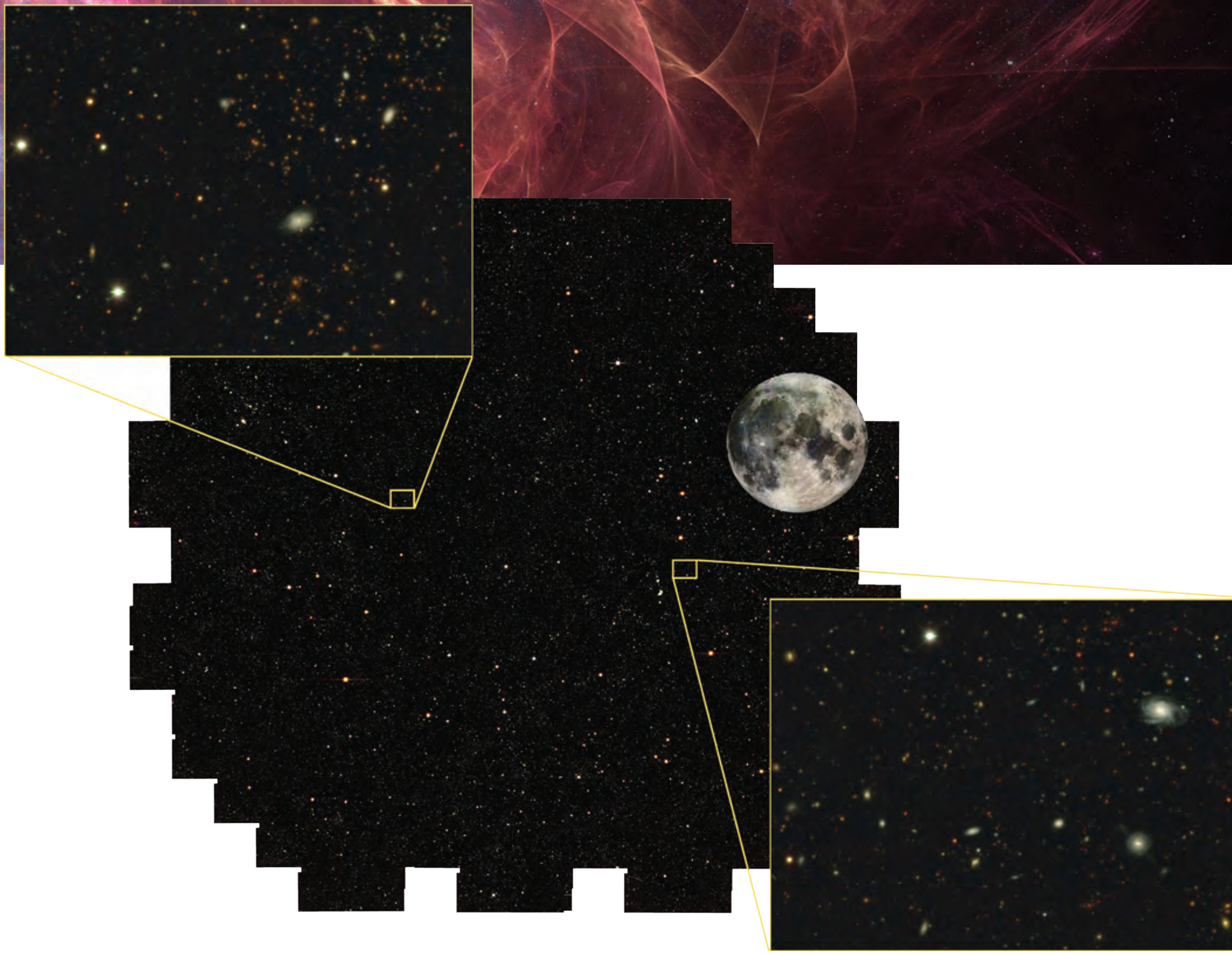
For the past several years, Kelson, with Carnegie's Alan Dressler, Patrick McCarthy, John Mulchaey, and Stephen Shectman, has conducted the largest project undertaken with Magellan—the Carnegie-Spitzer-IMACS Redshift Survey. Using a technique pioneered by Kelson with the wide-field Inamori-Magellan Areal

Carnegie's Daniel Kelson uses the Magellan 6.5-meter telescopes and high-resolution imaging from the Hubble Space Telescope to study how galaxies formed, grow, and evolved.

Image courtesy Scott Rubel

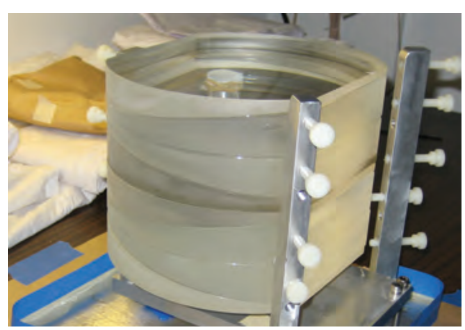
Camera and Spectrograph (IMACS), they collected low-resolution spectra of thousands of galaxies at a time with the Magellan 6.5-meter telescopes. The team collected data over three large areas of the sky, equaling about 75 times the size of the full Moon, measuring distances, masses, and star-formation activity of more than 100,000 galaxies, back to when the universe was about 4.5 billion years old. These data represent the most complete picture of the evolution of normal galaxies over the past 9 billion years.

Their measurements conclusively demonstrate greater diversity in the growth histories of galaxies than most astronomers have assumed, doing so more directly and accurately than any previous research. Earlier, the team tested a key prediction for the Big Bang cosmological model dominated by dark matter, by making the first measurements of the growth of groups of galaxies—in which small groups of galaxies merge over time to form more massive galaxy groups. Kelson and his team are now bringing together the rich histories of both the galaxy groups and their constituent galaxies for the most detailed description of galaxy growth and the evolution of cosmological structure yet.



This large image of the sky was taken by Daniel Kelson using the Dark Energy Camera in Chile for the Carnegie-Spitzer-IMACS Redshift Survey. The team collected data over three similarly large areas of the sky, totaling about 75 times the area of the full Moon, shown here for scale. Galaxies across cosmic time reside in isolation as well as in groups and clusters. The range of typical galaxy neighborhoods is seen within the two magnified regions. Galaxies of similar colors are generally about the same cosmic distance from us, with red galaxies typically containing more old stars than young ones. Rich groups of old galaxies, when the universe was half its current age, can be seen in the upper box. Most of the distant galaxies in the lower box are in sparse groups or in relative isolation. A few bright, blue foreground galaxies are also visible. The most scientifically interesting galaxies in the Carnegie-Spitzer-IMACS Redshift Survey are the ones that appear to be small and are barely resolved, simply because they are so remote, in both cosmic time and distance.

Image courtesy Daniel Kelson



To explore the earliest galaxies, Daniel Kelson and team developed a unique prism, designed by Carnegie's Steve Shectman. It has eight mini-prisms of glass stacked, precisely glued together, and installed into a mount. It weighs about 40 pounds and was placed inside the wide-field Inamori-Magellan Areal Camera and Spectrograph. Prisms disperse the light into its constituent colors, telling astronomers about the ages and chemistry of the stars in distant galaxies. The stacking of multiple prisms allowed the light in this optic to spread out only a little bit. The wide field allowed them to observe many more galaxies at a time.

Image courtesy Jeff Crane

The Carnegie Academy for Science Education & Math for America

Teaching the Art of Teaching Science and Math

CASE Extends its Reach

The Carnegie Academy for Science Education (CASE) celebrates 27 years of science education. Carnegie President Emerita Maxine Singer founded the program to ensure D.C. students have an opportunity to learn science, technology, engineering, and math (STEM) subjects like scientists and STEM professionals—with hands-on experiments that apply scientific concepts to solve problems. CASE was led by Julie Edmonds, who retired in August 2016, and is staffed by Marlena Jones, now Acting Director, with Katia Grigoriants, Strategic Partnerships Manager.

This year, through the DC STEM Network, CASE organized the Elementary DC STEM Fair, in which 3rd through 5th grade students competed for awards and prizes.

Image courtesy Jason Dixson Photography

CASE's student programs, First Light and Summer STARs (Student-Teacher Astrobiology Researchers), have been creating STEM pathways for underserved students in D.C. since its inception, and they are starting to see the long-term results of the students who participated in First Light between 2008 and 2009—39% of them are now pursuing college degrees with a STEM focus, as opposed to 10% of the general D.C. student population. This year, First Light students learned about light and optics by building and using telescopes to make astronomical observations. Summer STARS students spent the summer interning with CASE to learn hands-on skills both in their lab at CASE headquarters, and this year also at the University of the District of Columbia's lab. A student from last year's cohort, Robert Washington, interned this past summer at the Department of Terrestrial Magnetism with Carnegie postdoctoral fellow Sergio Dieterich.

CASE's teacher programs, such as the STEM Teacher Leader Cadre, have trained D.C. teachers across the city to become STEM teacher leaders, using best teaching practices and cutting-edge research.

Last year, CASE joined the D.C. Office of the State Superintendent of Education to launch the DC STEM Network, which unites community partners to prepare students in STEM education. Since then, the Network convened events with more than 250 partners to launch twelve working groups to increase access to high-quality STEM learning opportunities for all D.C. students. Additionally, the Network's website has

This year, First Light students learned about light and optics by building and using telescopes to make astronomical observations.
Image courtesy Garrett Strang Photography

connected students, families, and STEM partners to resources, events, volunteers, and STEM programs. This year, the Network took ownership of the DC STEM Fairs, increasing the participation of students, schools, judges, volunteers, and special award donors from previous years.

"39% of them are now pursuing college degrees with a STEM focus, as opposed to 10% of the general D.C. student population"

Teacher leaders with the STEM Teacher Leader Cadre from across D.C. are shown in this photograph. Julie Edmonds, retired CASE director, is in the first row, far left. Marlena Jones, the Acting Director, is in the top row, far left, with Katia Grigoriants, Strategic Partnerships Manager, next to her.
Image courtesy Blonde Photo

The Carnegie Academy for Science Education & Math for America

Continued

Math for America Cohort 3 just completed their fellowship. From left to right: Jessica Ogle, Joe Hebert, Ariel Kramer, Rebecca Dunn, Lawrence Chien.
Image courtesy Caroline Blair

For Teachers by Teachers

In June, Math for America (M*f*A) DC graduated five fellows who began the program in 2011, bringing the total number of graduates to eighteen. This highly selective fellowship program was launched in 2008 at Carnegie with Bianca Abrams at the helm. Two from M*f*A's recently graduated group have been accepted to the equally selective Master Teacher program.

To qualify for the Master Teacher program, candidates must have a strong math background, have taught math for four or more years, and have exceptional leadership qualities. The selection process is rigorous, with a detailed application, professional skills exams, and interviews with a selection panel. Master Teachers commit to teaching for five years in D.C. public or public charter schools. They receive a stipend and extensive professional development. The number of Master Teachers has grown to twelve since beginning in 2011.

These seasoned Master Teachers conduct many of the professional development (PD) workshops for the D.C. math teaching community, including the dynamic DC Math Ignite, a semiannual event hosted

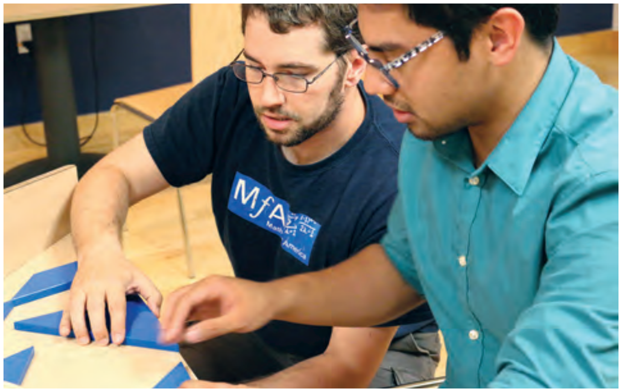
"2,500 D.C. students directly benefit from interactions with all the M*f*A teachers each year."

by Master Teacher Will Stafford. The "Ignite" is an opportunity for math educators to come together and share ideas on math topics, their philosophy of teaching, and what inspires them as a teacher.

At present, some 70 D.C. teachers take part in the M*f*A DC PD workshops. Meetings used to be held exclusively at Carnegie, but now the workshops are often held at different school sites. As a result of this change, many schools are asking to host the sessions.

Caroline Blair, who joined Math for America DC in February, increased outreach to the greater math teaching community through social media and an M*f*A DC newsletter. Blair also helps coordinate the professional development workshops.

Assistant Director Paul Penniman, who joined M*f*A DC last year, has focused on increasing the diversity of the Master Teacher corps. Penniman has had many discussions with area principals regarding good candidates for the program. Many of the principals extol the abilities of the Master Teachers with high praise, citing one particular Master Teacher as the best she'd ever seen in any subject. Another Master Teacher has a flood of students asking for tutoring even though this teacher doesn't have the students in class. In all, an estimated 2,500 D.C. students directly benefit from interactions with all the M*f*A teachers each year.



These photos were taken at the annual "Closeout" for professional development. This year's event was held at the Goethe-Institut in Washington, D.C. The theme of the exhibit was "Math You Can Touch," featuring activities such as the mathematics of differently shaped soap bubbles, a dice game that connects math and music, and much more.

Images courtesy Caroline Blair

Earth/Planetary Science

Understanding the Formation and the Evolution of the Planets

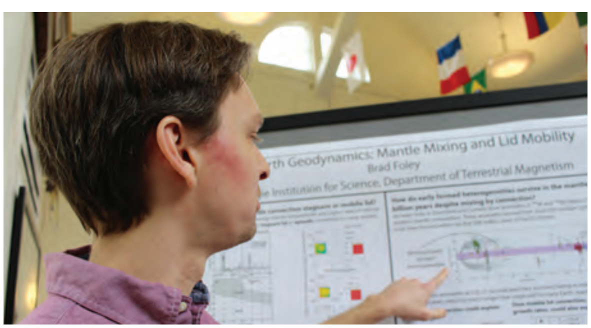
> "…coupling may explain why Venus and Earth, two planets with similar size and composition, have evolved so differently."

New Take on Rocky Planet Evolution

What do plate tectonics, climate, and a planet's magnetic field have in common? Their interplay, and a rocky planet's distance from its star, are key to understanding how such planets evolve, whether life could exist on them, and why two similar planets—Earth and Venus—evolved so differently, as a new review by Bradford Foley and Peter Driscoll suggests.

The surface temperature of a planet influences whether discrete tectonic plates can form and move at a planet's surface. If cool enough, the surface can break into plates because of increasing stresses and because rock "healing" is suppressed along areas that will become plate boundaries. Plate tectonics, in turn, helps sustain a cool climate by cycling carbon and other greenhouse gases from the atmosphere to the deep interior of the planet. Plate tectonics also cools the deep interior efficiently, driving fluid motion and magnetic field generation in the outer core, which protects the planetary surface and atmosphere from stellar and cosmic radiation. The researchers refer to the interaction of these three planetary-scale phenomena as whole planet coupling.

Whole planet coupling, they propose, applies to large rocky planets with silicate mantles and iron cores. Such coupling may explain why Venus and Earth, two planets with similar size and composition, have evolved so differently. Foley and Driscoll propose that Venus, orbiting 30% closer to the Sun, receives too much solar heating to maintain liquid water at its surface. A hot surface temperature and lack of water

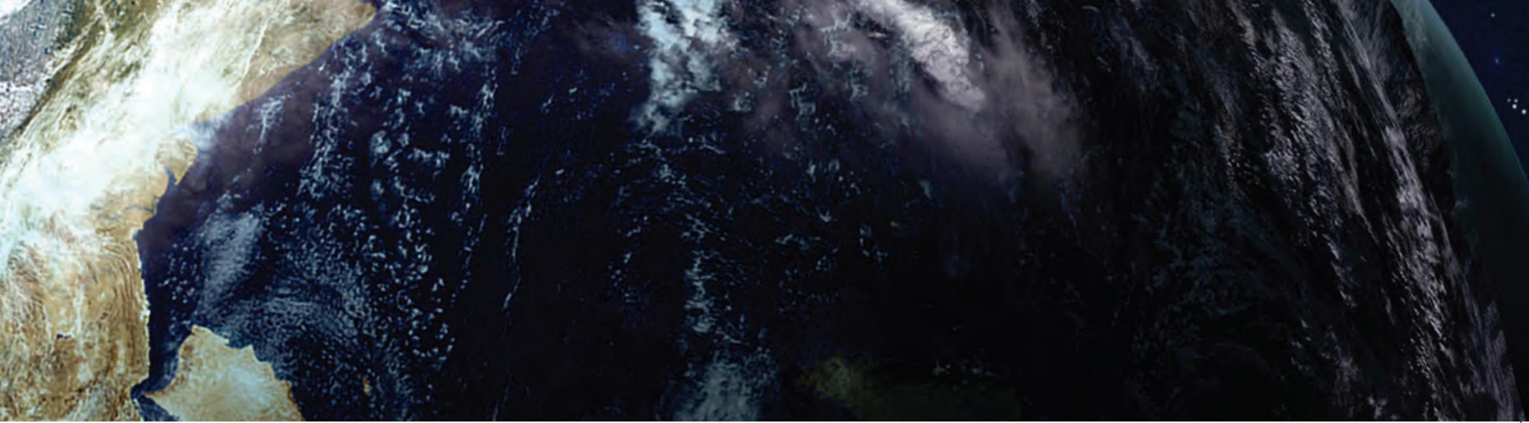


Bradford Foley presents a poster about mantle mixing.

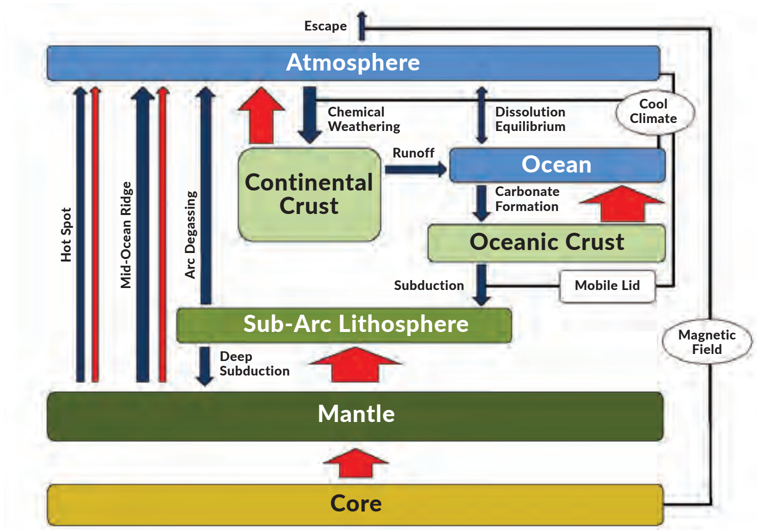
Image courtesy Bradford Foley

Peter Driscoll joined the Carnegie staff in 2015.

Image courtesy Peter Driscoll

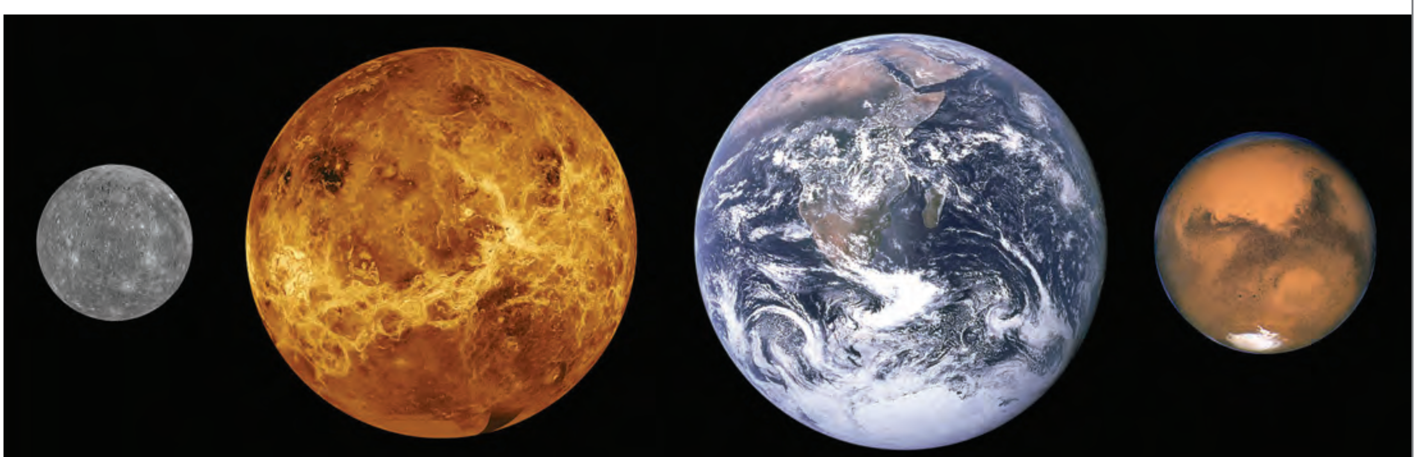


suppresses plate tectonics, which could in turn inhibit Venus from generating a magnetic field. Without the magnetic field, water molecules and their component hydrogen are subsequently lost from the top of the atmosphere. These feedback relationships leave Venus with a CO_2-rich atmosphere that drives surface temperatures to over 800° F (425° C), in a so-called runaway greenhouse effect. The duo also proposes that whole planet coupling could lead to a wide spectrum of evolutionary scenarios for habitable zone planets (i.e., ones where liquid water could be present), some of which could be detrimental for life. Next, the duo intends to investigate and assess the likelihood of alternative planetary evolution scenarios, ideas that will be testable with next-generation exoplanet observations.



This flowchart shows climate-tectonic-magnetic coupling for an Earth-like planet. Arrows between reservoirs indicate volatile (blue) and heat (red) flows. The width of the arrows is roughly in proportion to the magnitude of the flow. Black lines indicate conceptual couplings, such as the influence of magnetic field strength on the escape rate or chemical weathering on climate.

Image courtesy Bradford Foley and Peter Driscoll



The terrestrial planets from left to right are shown to scale: Mercury, Venus, Earth, and Mars. Venus and Earth are almost the same size, but their different distances from the Sun have contributed to very different evolutions.

Images courtesy NASA (Mercury image, Earth seen from Apollo 17), JHUAPL (Venus image), JPL (Mars image)

Volcanoes Get Quiet Before They Erupt!

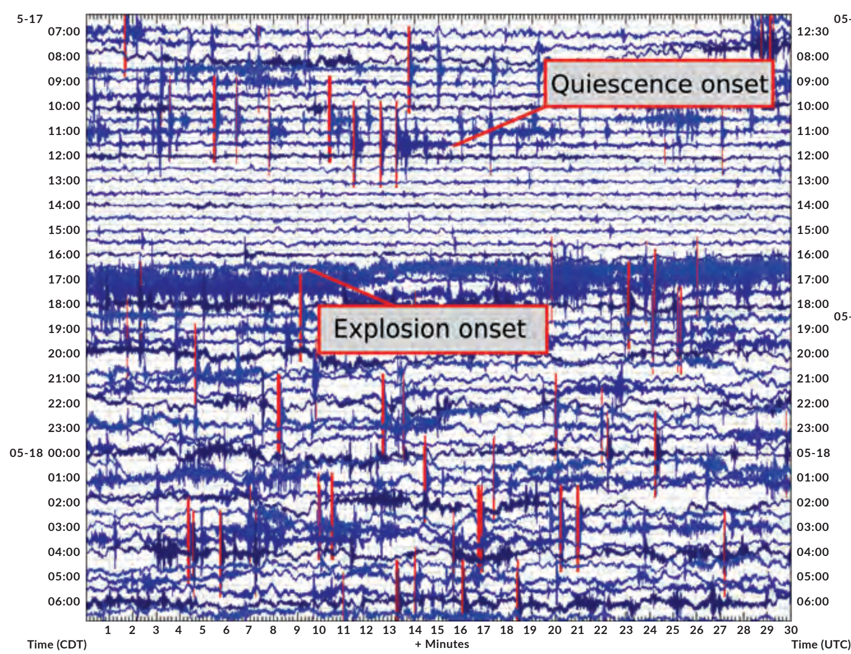
When dormant volcanoes are about to erupt, they show some predictive characteristics—an increase in seismic activity, gas escapes through vents, or the ground deforms. However, until now, there has been no way to forecast eruptions of more restless volcanoes because of the constant seismic activity and gas and steam emissions. Carnegie volcanologist Diana Roman, with a team of scientists from the Pennsylvania State University, Oxford University, the University of Iceland, and Instituto Nicaraguense de Estudios Territoriales, showed that periods of seismic quiet occur immediately before eruptions and can be used to forecast an impending eruption for restless volcanoes. The duration of the silence indicates the level of energy to be released. In other words, longer quiet periods mean a bigger bang.

The team started monitoring the Telica Volcano in Nicaragua in 2009 with various instruments. By 2011, they had a comprehensive network within 2.5 miles (4 kilometers) of the volcano's summit for monitoring eruptions.

The 2011 eruption was a month-long series of small to moderate ash explosions. Prior to the eruption, there was a lack of deep seismicity, or deformation of the ground, and only small increases in sulfur dioxide gas emissions, indicating that the eruption was not magma-driven. Instead, the eruption likely resulted from sealed-off vents that prevented gas from escaping, and the resulting increase in pressure eventually caused the explosions.

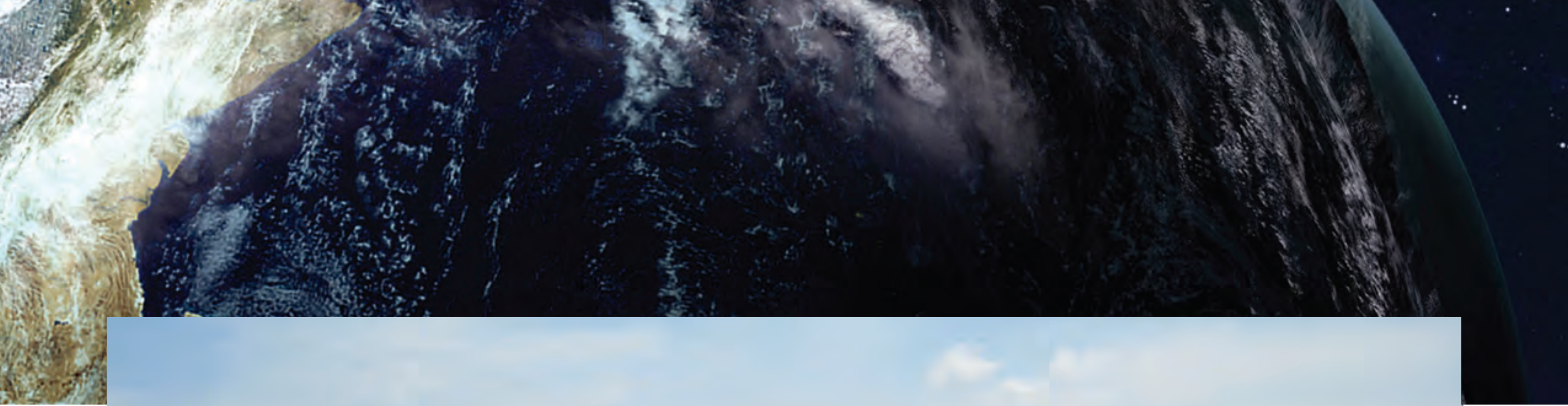
Of the 50 explosions that occurred, 35 had preceding quiet periods lasting 30 minutes or longer. Only two of the 50 did not have any quiet period preceding the explosion. An analysis of the energy released found that the longer the quiet phase lasted preceding an

> "...the longer the quiet phase lasted preceding an explosion, the more energy was released."



The graph points to the onset of a quiet period and an explosion.

Image courtesy Diana Roman



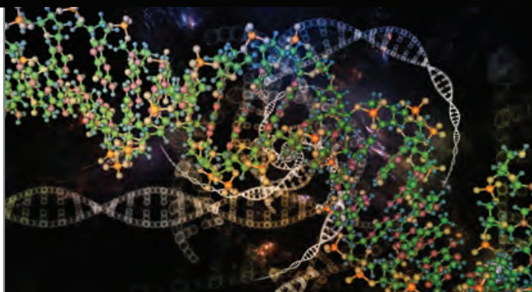
Diana Roman is at the Telica Volcano in Nicaragua with her local field assistant. The volcano is passively "degassing."
Image courtesy Diana Roman

explosion, the more energy was released. The quiet periods ranged from six minutes before an explosion to over 10 hours (619 minutes) for the largest explosion.

The researchers were able to forecast a minimum energy for impending explosions based on the data from the previous quiet/explosion pairs and the duration of the particular quiet period. The correlation between duration of quiet periods and amount of energy released is tied to the duration of the gas pathways being blocked. The longer the blockage, the more pressure builds up and the more energy is released. This work is the first to quantify that quiet periods can be used for eruption forecasts and that longer quiet periods at recently active volcanoes could indicate a higher risk of energetic eruptions.

Genetics/Developmental Biology

Deciphering the Complexity of Cellular, Developmental, and Genetic Biology



"The increased number of satellite cells allowed muscles to regenerate much faster after injury."

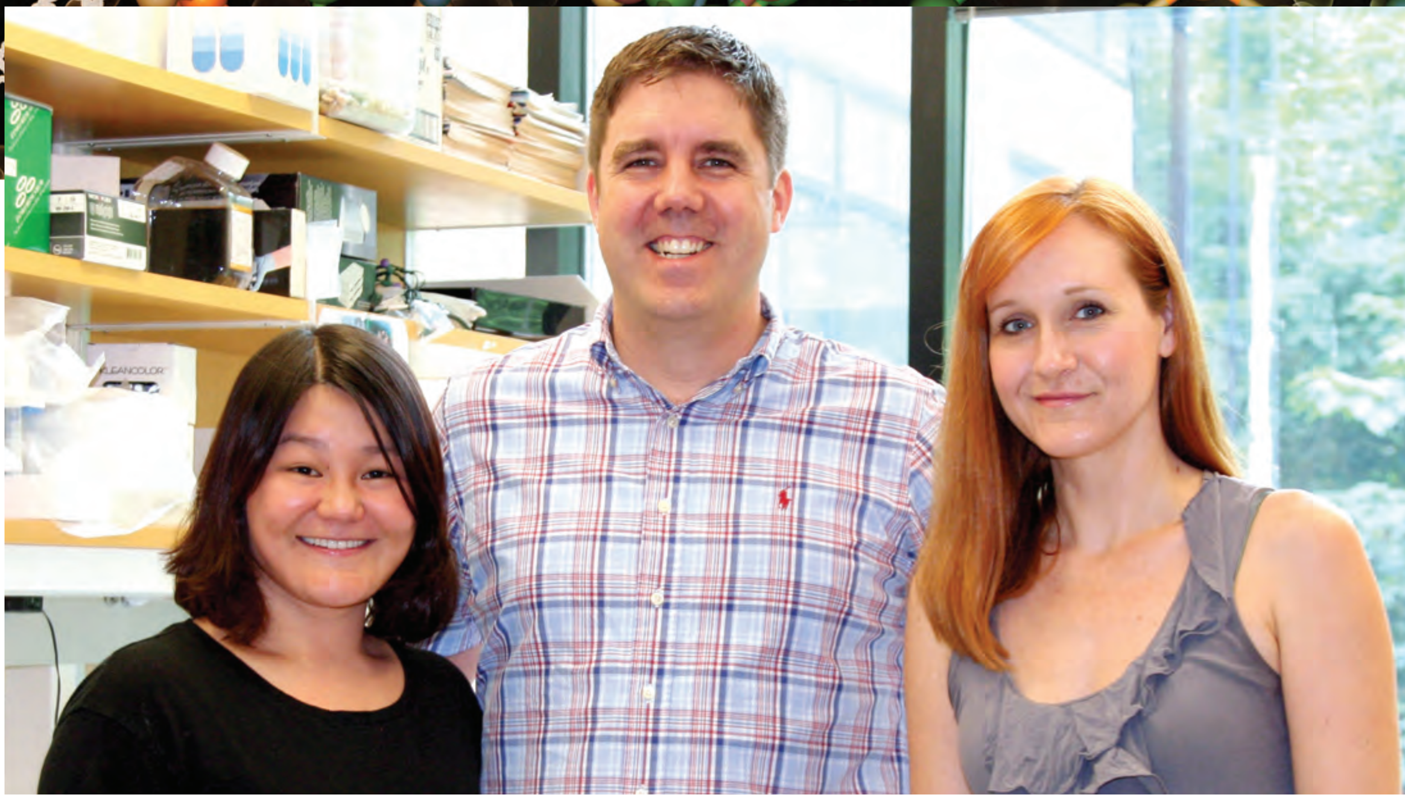
Speeding Up Muscle Repair

When skeletal muscle is injured, muscle stem cells wake up from dormancy and repair the damage. But when muscles age, the tissue function and regenerative ability decline: there are fewer stem cells. Christoph Lepper and team looked at the mechanisms of proportioning stem-cell pool sizes. Using genetically modified mice, they found that they could dramatically increase the number of these stem cells in adult mice. Surprisingly, the overall muscle tissue size was unaffected. These plentiful stem cells were also able to do their job repairing injured muscle and were faster at it than a normal population. Notably, the team also found that this increase reverses the decline of weakened muscles, which could be a boon for fighting muscular dystrophy.

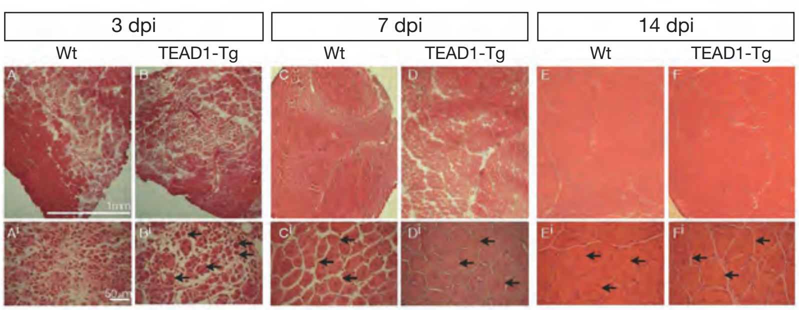
Muscle stem cells, called satellite cells, are undifferentiated muscle cells that promote growth, repair, and regeneration. They make up some 5% to 7% of all muscle cells and are essential to muscle regeneration. When a mouse is born, the satellite cells divide and differentiate for about three to four weeks to drive tissue growth. They then go quiet until an injury is detected. How this active/quiet transition process is regulated and how the stem cell population changes is a knowledge gap that the Lepper team actively explores.

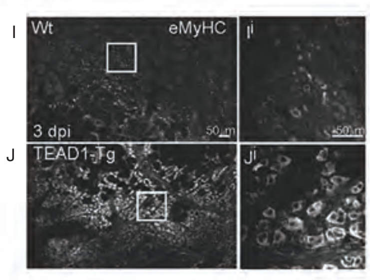
The team generated mice that overexpressed a gene called *TEAD1*, which they had previously found to be important to modulating a type of muscle fiber rich in oxidative function. They found that in TEAD1 adult mice, there was a six-fold increase in the number of satellite cells, but without additional tissue growth. This was true across all analyzed muscle groups. The increased number of satellite cells allowed muscles to regenerate much faster after injury.

Importantly, the scientists found that in mice with Duchenne muscular dystrophy and TEAD1 overexpression, the wasting disease was significantly reversed. Intriguingly, muscle fiber signaling to the satellite cells was found to be the origin of the stem cell increase. The researchers suggest that the increase in the number of satellite cells, without any changes to overall muscle size, renders the TEAD1 mouse to be a model for discovering the molecular cascade that regulates muscle stem cell number. It may also reveal the stop and go signals that cause the cells to differentiate and go quiet.



Team members for this work were (from left)
SiewHui Low, Christoph Lepper, and Sheryl Southard.
Image courtesy Christoph Lepper





Each square block (top row) in the image above shows stained muscle tissue of normal mouse muscle (labeled Wt) and muscle from *TEAD1*-genetically altered mouse at three, seven, and 14 days post-injury. The bottom row shows a higher magnification of regenerating muscles, indicated by the arrows. There is a lack of identifiable fibers in the lowest-left box, Ai. The left column of black and white photos show magnified images for both normal and genetically modified mouse muscle three days after injury. The right images show enlargements of the white inset box at left. They show young muscle fibers that are larger and more abundant in the TEAD1-Tg.
Image courtesy Sheryl Southard

Genetics/Developmental Biology

Continued

Crosstalking Protein Combats Muscle Aging and Disease

While the Lepper lab looked at genes that could be useful for skeletal muscle repair and renewal, Carnegie’s Michelle Rozo, Liangji Li, and Chen-Ming Fan demonstrated that a protein called β1-integrin is a promising target for combating muscle aging or disease, such as muscular dystrophy.

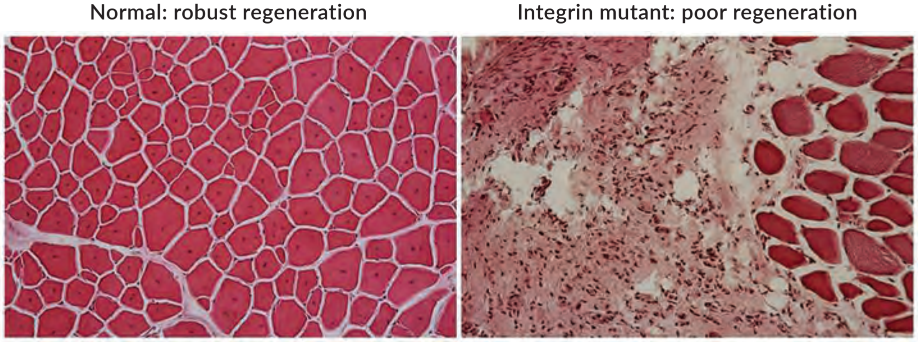
> “a protein called β1-integrin is a promising target for combating muscle aging or disease, such as muscular dystrophy”

Adult muscle stem cells lie dormant until muscle fibers are damaged. They are then activated, multiply, and repair the damage. The process is controlled by a complex chain of events telling most of the new cells to make new muscle fibers and others to return to dormancy for future repairs. As muscles age, there is a decline in these stem cells, and they become deficient in β1-integrin activity.

The researchers found that the poor regeneration of stem cells in aging is not just caused by the decline in stem cells; it is also linked to the changes in the local environment. Stem cells are quieted by repressing a protein involved in limb and nervous system development, wound healing, and tumor growth. This protein is called fibroblast growth factor-2 (FGF-2). Up to now, no one had studied the role of β1-integrin in the molecular cascade of this growth factor in muscle stem cell aging.

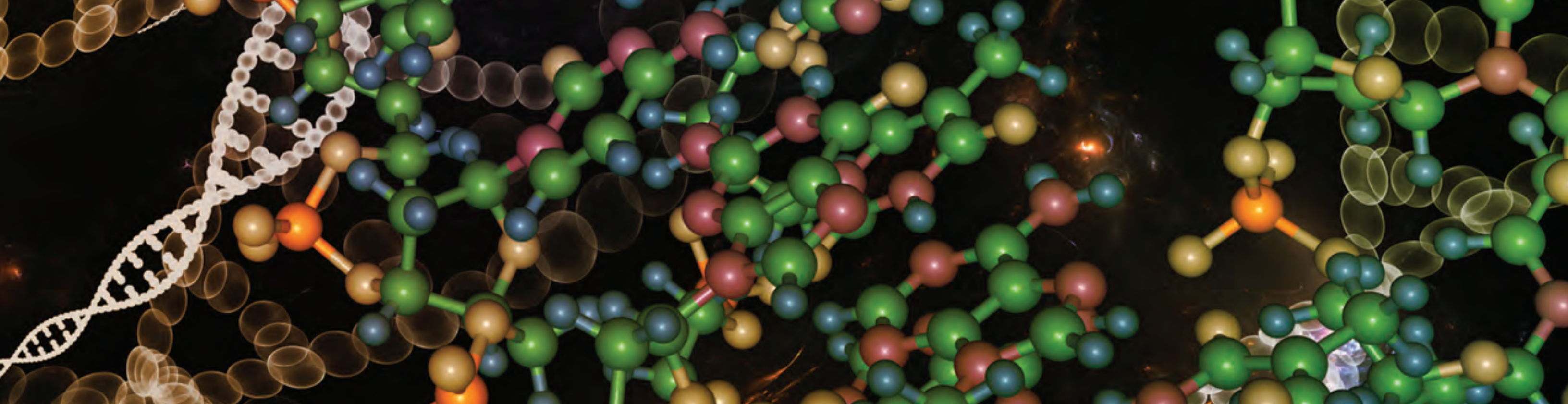
The researchers showed that integrin is a sensor of the local environment surrounding muscle stem cells that maintains the quiet state; it cooperates, or crosstalks, with the growth factor to promote stem cell proliferation and cell renewal after injury. They also showed that activating β1-integrin restores FGF-2 sensitivity in older stem cells and improves muscle

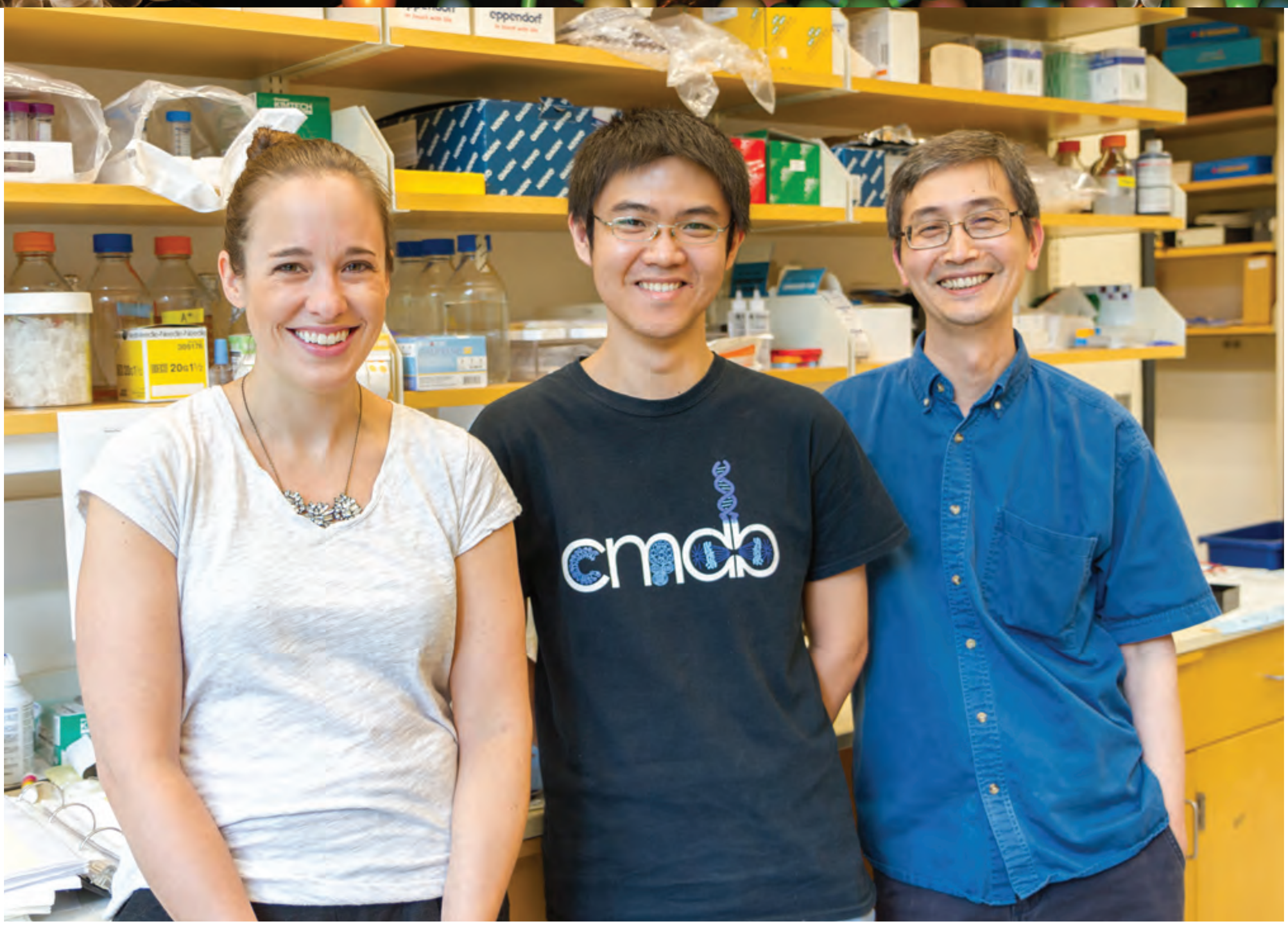
Normal: robust regeneration | **Integrin mutant: poor regeneration**



Healthy, normal muscle tissue appears on left. When β1-integrin activity is suppressed, tissue regeneration suffers (right).

Image courtesy Chen-Ming Fan





Graduate students Michelle Rozo (left) and Liangji Li (middle) and staff scientist Chen-Ming Fan (right) demonstrated that a protein called β1-integrin is a promising target for combating muscle aging or disease, such as muscular dystrophy.

Image courtesy Bill Kupiec

regeneration. Further, they found that activation of β1-integrin in mice with muscle dystrophy promotes stem cell expansion and improves muscle function.

The team believes that integrin can cooperate with many growth factors that contribute to muscle stem cell function. Their research provides a proof of concept that may be broadly applicable to muscle diseases involving the local muscle stem cell environment. This technique would need to be refined to become a valuable therapy. However, the fact that integrin is involved in other stem cell types means that the results from their work have broader implications for aging and the decline of stem cells in general.

Global Ecology

Linking Ecosystem Processes with Large-Scale Impacts

"Near Zero...is ambitiously integrating quantitative analysis with expert judgement to understand... possible paths to a near-zero emission future."

Unprecedented Momentum for Near-Zero Emissions

Limiting the repercussions of climate change depends on globally transitioning to an affordable, near-zero-emission energy system. Near Zero—a new initiative co-conceived by Ken Caldeira and led by Carnegie's Michael Mastrandrea—is ambitiously integrating quantitative analysis with expert judgment to understand how the opportunities and barriers differ for different possible paths to a near-zero-emission future. Any one path has its own hurdles and risks of hitting dead ends.

Near Zero has developed open-source software tools that facilitate structured discussion and elicitation of expert judgment, to examine where professionals agree and disagree (and why) to determine which ways forward are most technically and economically feasible.

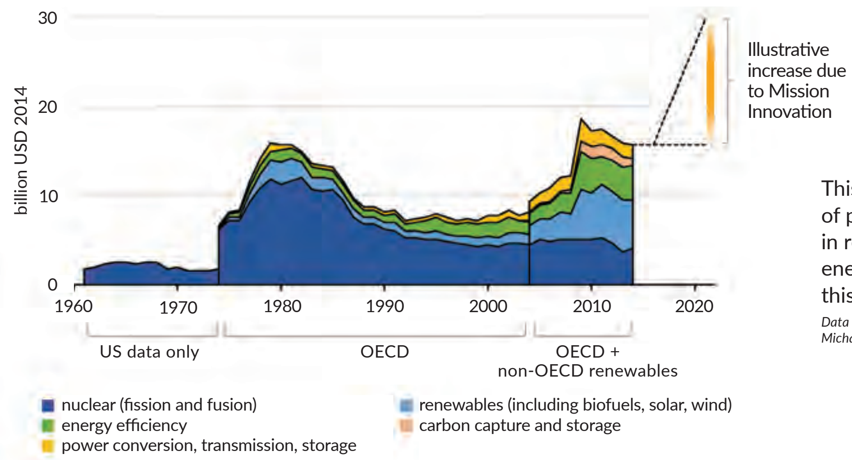
In November 2015, world leaders from 20 nations announced Mission Innovation. The countries represent North America, Latin America, Asia, Europe, the Indian subcontinent, and Australia. In an unprecedented move, they pledged to double their funding for clean energy research and development (R&D) to $30 billion by 2021.

Another unprecedented group, the Breakthrough Energy Coalition—a private initiative led by Bill Gates—secured commitments from 28 significant private capital investors to support developments coming out of Mission Innovation's expanded public research portfolio. Together, these initiatives aim to push innovation and commercial scale-up of cheaper low-carbon energy sources.

To support the collective goals of Mission Innovation and the Breakthrough Energy Coalition, Near Zero arranged an expert discussion and elicitation on global priorities for increased energy innovation. Experts from academia, nongovernmental organizations, and industry were asked to allocate a hypothetical total R&D budget of $30 billion across the clean energy categories the coalition identified. The experts called for the largest share of funding to go to electricity generation and storage, followed by transportation. Most experts advocated a broad R&D portfolio, allocating a portion of the funds across all major categories, also including energy systems' efficiency, agriculture, and industrial use.

The Near Zero group is hosted by the lab of Ken Caldeira (left). Director of Near Zero Michael Mastrandrea stands next to him. Other members are Daniel Sanchez (middle), Matthew Shaner (fourth from left), and Danny Cullenward (right).

Image courtesy Ryder Clayton



This graph shows past funding levels and a range of possibilities for Mission Innovation's investment in research and development spending on clean energy. Twenty nations pledged to double funds for this research by 2021.

Data sources: IEA-OECD, BNEF, PNNL; image courtesy Michael Mastrandrea

Within these broad categories, the participants also identified particular R&D priorities, including grid-scale energy storage, carbon capture and sequestration (CCS) for fossil generation, low-cost/high-density batteries for transportation, and carbon-neutral fuels for transportation that cannot be readily electrified. Next, Near Zero is undertaking deeper technical and economic analysis of options to meet key energy system challenges on the path to near-zero emissions.

Grassland Function in a Warmer Future

The Jasper Ridge Global Change Experiment—one of the longest-running, most comprehensive climate-change experiments—provides a compelling and detailed picture of the prospects for future ecosystems. The 17-year experiment, directed by Chris Field, the founding director of Carnegie's Department of Global Ecology, subjected grassland ecosystems to sixteen possible future climates. It measured ecosystem performance and sustainability, including plant growth, an important bellwether of ecosystem health. Plant growth varied tremendously from year to year, reaching a peak under typical conditions near decades-long averages. Away from these averages—as happens with climate change—plant growth fell.

Most climate-change experiments alter one or two environmental factors. The Jasper Ridge experiment altered four climate-change factors—temperature, precipitation, carbon dioxide concentration, and nitrogen pollution. With all possible combinations of ambient and elevated levels of the factors, the study explored ecosystem responses to sixteen different possible futures.

The experimental design for Jasper Ridge Global Change Experiment includes eight quarter-circle plots for all possible combinations of the four treatments of temperature, precipitation, carbon dioxide concentration, and nitrogen pollution. There are an additional eight sampling sites that control for project infrastructure.

Image courtesy Nona Chiariello

"The Jasper Ridge Experiment provides a compelling and detailed picture of the prospects for future ecosystems."

Plant growth varied more than threefold over the years and the range of treatments. Good conditions tend to look like historic averages, and bad conditions look more common in a world of climate change. But one bad year did not make the next year bad. The researchers believe that year-to-year variability acts as a reset button.

Consistent with an accumulating body of empirical studies, a strong growth response to elevated atmospheric carbon dioxide was absent. While some experiments indicate that elevated carbon dioxide might compensate for negative effects of warming or drought, the effects tend to be small. The absence of strongly increased growth with elevated carbon dioxide emphasizes that the problem requires cutting emissions and planting forests.

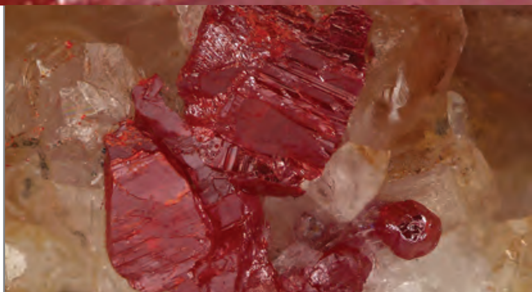
The impacts of individual factors showed that warming had negative effects on plant growth. Plant growth peaked when precipitation was close to historic averages. There was no consistent response to elevated atmospheric carbon dioxide, but elevated nitrogen led to a 23% increase in plant growth, typical for nitrogen-limited ecosystems.

Chris Field, the founding director of Carnegie's Department of Global Ecology, has also been the principal investigator for the Jasper Ridge Global Change Experiment since 1997.
Image courtesy Liz Mangelsdorf

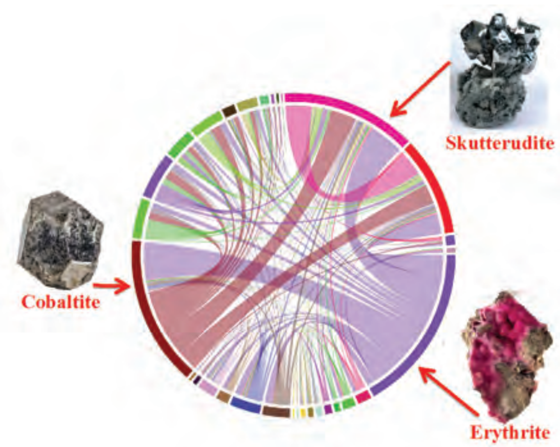
Combinations of factors mostly followed this same pattern, but with a few surprises. Combined warming and increased precipitation had a larger growth increase than the sum of the effects of each factor alone. But the response of plant growth to warming and increased nitrogen was smaller than the sum. The maximum plant growth occurred when both temperature and precipitation were at average levels over the last decades. Plant growth declined with rising temperature and with precipitation either lower or higher than long-term averages. This experiment provides a unique lens on global change, with results that can inform science, policy, and conservation.

Matter at Extreme States

Probing Planetary Interiors, Origins, and Extreme States of Matter

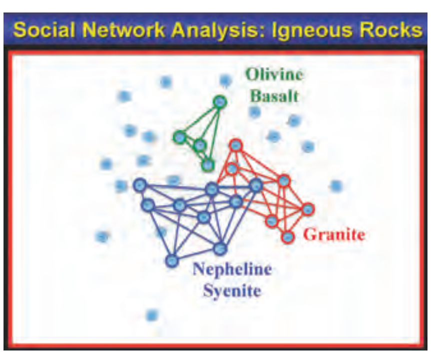


A chord diagram of economically important cobalt minerals employs colored arcs to reveal which minerals commonly coexist with others (below). Each chord of the circle represents a different mineral, with the strength corresponding to the relative abundance of that mineral. Prominent features include links that connect cobalt ore minerals cobaltite and skutterudite with their commonest weathering product, the purple mineral erythrite.



A network map, or sociogram, for minerals in common rocks reveals patterns of occurrence that mimic social networks of friends and colleagues. Granite, olivine basalt, and nepheline syenite are three common rock types in which several minerals coexist.

Images courtesy Bob Hazen



Private Lives of Minerals

It is a bit surprising that Facebook users and minerals have anything in common, but scientists at the Geophysical Laboratory have recently made that remarkable connection. It all started in the mid-2000s when Bob Hazen wondered why only 12 minerals existed before the Solar System formed 4.6 billion years ago; today there are more than 5,000. This question sparked a revolution in understanding mineral evolution. He and colleagues are now investigating how social network analysis (SNA) and sociograms—visual tools to analyze relationships in social networks, the spread of disease, global terrorism networks, and more—can be applied to mineral association data. These powerful visualization techniques permit researchers to see mineral associations, petrology, ore geology, and other topics in an entirely new way.

Studies of Earth's changing mineralogy reveal a dynamic history of mineralization, influenced by plate tectonics and biological processes, including the Wilson Cycle—when oceanic plates have opened and closed—glaciation, oxidation of the near-surface environment, microbial evolution, biomineralization, and the rise of Earth's biosphere.

The Hazen team is applying social network analysis to Earth's most common mineral species, including rock-forming minerals and ore minerals. Analysis of existing large databases of minerals, such as the RRuff/IMA Database of Mineral Properties (rruff.info/ima) and Mindat.org, with data about mineral localities, reveal patterns of mineral coexistence and geographical

Members of the Geophysical Laboratory's mineral evolution team enjoy a meal at the Goldschmidt geochemistry conference in Yokohama, Japan. Front row (from left): postdoctoral fellows Shaunna Morrison and Daniel Hummer and predoctoral fellow Jihua Hao; back row (from left): postdoctoral fellow Chao Liu and staff scientist Robert Hazen.

Images courtesy Robert Hazen

distribution that are remarkably similar to some human social networks. The team developed sociograms that show how individual mineral species are linked to coexisting species. These visualizations reveal the extent to which two mineral species occur together, the tendency of some mineral species to occur with similar species, the extent to which certain key mineral species anchor networks of other mineral subsets, and the development of clusters of mineral species.

This mineral social network analysis presents promising avenues for discovering previously hidden trends in mineral diversity-distribution, and thus new mineral deposits. New techniques used in this research include false-color maps called Klee diagrams that assemble and view large data sets, chord diagrams that display inter-relationships of data in a matrix, and other visualization algorithms. Hazen and team are using them to provide insights into crystal chemistry, the evolution of oxidizing and reducing agents on mineral changes, characteristics that control mineralization that happens episodically, and novel mineral relationships. The findings have the potential to transform Big Data Mineralogy and how mineralogy and petrology are taught.

"This mineral social network analysis presents promising avenues for discovering **previously hidden trends** in mineral diversity-distribution"

Matter at Extreme States

Continued

Carnegie's Doug Rumble (right) stands with coprincipal investigator Ed Young of UCLA during a test of Panorama at the Nu Instruments factory.

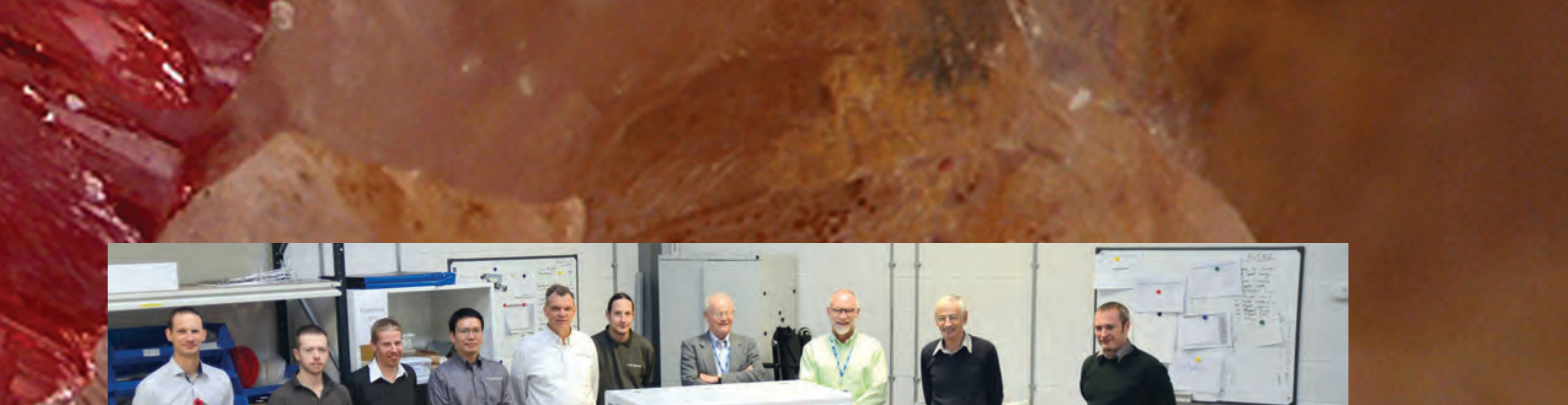
Image courtesy Doug Rumble

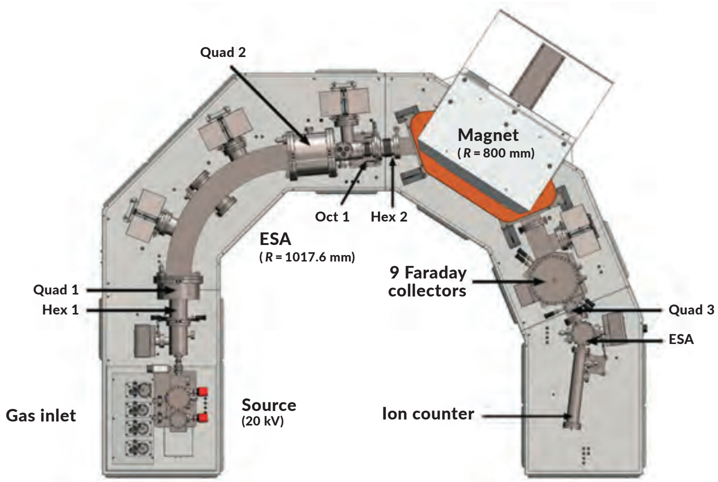
"The instrument is the largest of its kind. It enables measurements with resolution 40 times better than conventional spectrometers."

World's Most Powerful Panorama

The Deep Carbon Observatory (DCO), supported by the Sloan Foundation, looks at how carbon compounds are created, stored, and interact in Earth's deep interior and how organic matter contributed to early life. The DCO, with partners and manufacturer Nu Instruments, built a gas-source isotope ratio mass spectrometer (IRMS) to support this work. Named Panorama, it measures the masses of isotopes—atomic siblings of an element with the same number of protons and different numbers of neutrons. The instrument is the largest of its kind. It enables measurements with resolution 40 times better than conventional spectrometers and three times better than the next best of its kind. Petrologist and geochemist Doug Rumble, coprincipal investigator with former postdoc Edward Young (now a professor at UCLA), has been involved with its development since its inception in 2008.

Different isotopic ratios hold clues to ancient processes an element underwent. For instance, water has different ratios of the oxygen isotopes ^{16}O and ^{18}O depending on the processing history. A mass spectrometer measures a sample and separates the different masses, revealing the ratios and past conditions. The DCO is especially interested in understanding the formation temperatures and sources of methane, the major component of natural gas in the deep Earth. Some methane molecules with ^{13}C and ^{2}H (or deuterium, D) are particularly challenging because they have very similar masses. Thus Panorama was designed to measure molecules of almost identical weight, which was not possible before





The design and manufacturing team of the world's largest gas-source isotope ratio mass spectrometer Panorama is pictured at the Nu Instruments factory, Wrexham, Wales, United Kingdom, in November 2014. A schematic labels the instrument's components.

Group image courtesy Doug Rumble; schematic image courtesy Department of Energy

with other gas-source IRMS. The instrument came online in early 2015 at UCLA.

In essence, samples are introduced as pure gases into the spectrometer. They are charged (ionized) by electrons and accelerated by 16,000 volts through a narrow slit; the narrower the slit, the more focused the beam and the better the resolution. The ions are separated according to their masses by an electromagnet, collected by buckets called Faraday cups, and counted by an ion counter.

What distinguishes Panorama from other IRMS includes some unique features: a double-focused beam for better narrowing, four variable bellows to accommodate samples of different sizes, nine ion Faraday cups that are moveable with variable slits for incoming ions, and a highly sensitive ion counter. These components underlie Panorama's vastly improved resolution and sensitivity. Beyond methane gas, the instrument can be used for countless other molecular applications, which could revolutionize isotope chemistry.

Plant Science

Characterizing the Genes of Plant Growth and Development

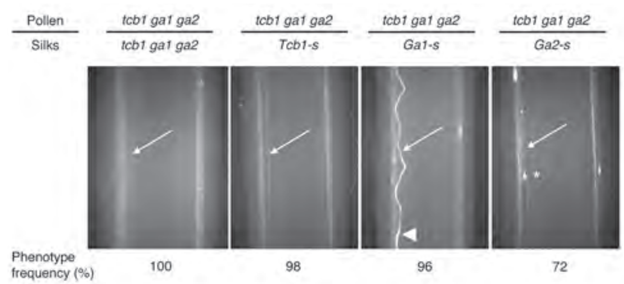
How Plants Choose Suitors

Charles Darwin beautifully illustrated how natural selection produces new species. However, the mechanisms of sexual incompatibility within a species are still not well understood. Matthew Evans and colleagues looked at three varieties in the grass species *Zea mays*, which includes corn (maize) and its wild ancestor teosinte. They discovered the first cellular and genetic basis for rejecting incompatible pollen in these varieties.

All three varieties slowed the growth of the incompatible pollen tube, the conduit that carries sperm to the ovary. Interestingly, the tube structures are different for each variety, suggesting different blocking mechanisms. These systems could be used to prevent cross-hybridization between different maize varieties and provide tools for engineering crops to fertilize only their variety.

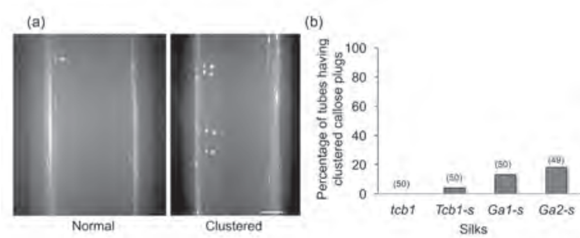
Grasses are wind-pollinated and include the major cereal crops. Fertilization relies on the interaction between pollen and the pistil, where the ovary is housed. Most maize and teosinte plants can self-pollinate or cross-pollinate within or between varieties. However, some varieties reject pollen of other varieties. This system requires a female function that produces a barrier to incompatible pollen tube growth and a male function that allows compatible pollen to overcome this barrier.

The researchers examined three varieties: T*eosinte crossing barrier 1-strong (Tcb1-s)* in teosinte and *Gametophyte factor 1-strong (Ga1-s)* and *Gametophyte factor 2-strong (Ga2-s)* found in both teosinte and maize. Teosinte rejects the pollen of its cultivated maize relative through *Tcb1-s*. The scientists conducted multigenerational inheritance experiments on one natural *Tcb1-s* variant and found that the barrier is unstable in some maize lines.



The structures of the studied pollen tubes differed. *Tcb1-s* is straight, *Ga1-s* is curved, and *Ga2-s* is kinked. This suggests that the three varieties block the pollen by different mechanisms.

Image courtesy Plant Reprod 27:19-29, 2014



The pollen tubes, growing in the silks that are familiar to corn lovers, are shown with normal and clustered callose plugs, which are the barriers to incompatible pollen. They are shown at the asterisks.

Image courtesy Plant Reprod 27: 19-29, 2014

"They discovered the **first cellular and genetic basis for rejecting incompatible pollen** in these varieties."

By successively breeding plants from teosinte to maize, they found that *Tcb1-s* occasionally loses its female barrier function gradually, but it does not lose the capacity to overcome the male barrier. They also found that rare genetic recombination produced plants with only one of the two gender functions. These results demonstrate that separate genes are responsible for the male and female functions.

Analyses of pollen tube growth during pollen rejection showed that tube growth slows early and stops by 24 hours post-pollination. However, the structures of the rejecting tubes differed. Rejection by *Tcb1-s* caused straight pollen tubes, *Ga1-s* caused curved pollen tubes, and *Ga2-s* caused kinked pollen tubes. This suggests that the varieties block the incompatible pollen differently. The work demonstrates that *Zea mays* is the first cereal species with a fertilization barrier between wild and domesticated relatives, and that a crossing barrier system is made up of two genetic elements in maize.

Matt Evans studies the reproductive development of maize.

Image courtesy Robin Kempster

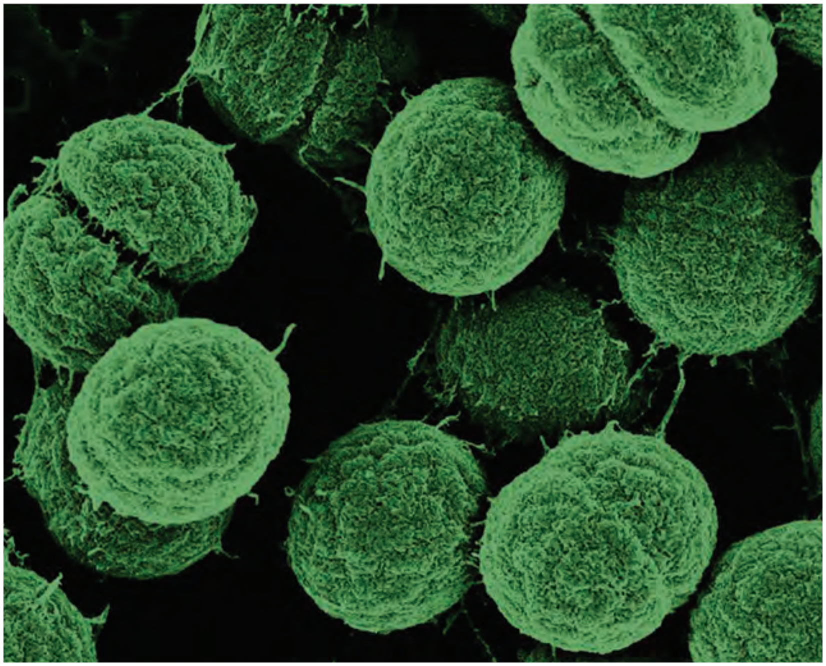
Plant Science

Continued

Members of the research team pose at the 12th Annual Workshop on Cyanobacteria, in Tempe, Arizona, May 2016. From left to right: Haojie Jin (Bhaya lab, Carnegie), Annegret Honsbein (Rosser lab, University of Edinburgh), Devaki Bhaya (Carnegie), Marcia Ortega (Golbeck lab, Penn State University), Jane Paget (Rosser lab, University of Edinburgh).

Image courtesy Devaki Bhaya

"...an international team... is looking at cleaner, alternative ways of boosting nitrogen levels in plants"



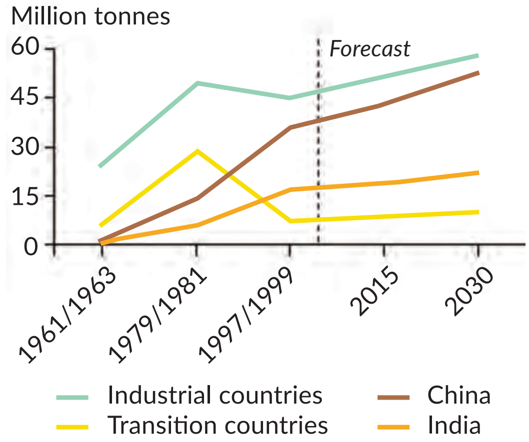
This scanning electron micrograph shows cyanobacterial cells (*Synechocystis* sp.), the model organism used in the Bhaya lab for research on nitrogen fixation.

Image courtesy A. Chandra

New Paths to “Clean” Fertilizers

Fertilizers are a mixed blessing. Chemical fertilizers have greatly boosted crop yields that help feed our growing global population. But nitrogen fertilizers cost a lot of money and energy to produce, add to greenhouse gas emissions, and produce harmful runoff that pollutes our waters. Now, an international team that includes Devaki Bhaya is looking at cleaner, alternative ways of boosting nitrogen levels in plants. To do so, they are looking to exploit the ability of certain microbes to convert abundant nitrogen in the air into readily usable ammonia, i.e., to fix nitrogen. The scientists are creating the technological stepping-stones for optimizing the transfer of this complex process into crop plants.

Projections of fertilizer consumption



The graph shows historical and projected future use of fertilizer through 2030.

Image courtesy Food and Agriculture Organization (www.eea.europa.eu/dataand-maps/figures/projections-of-fertiliser-consumption)

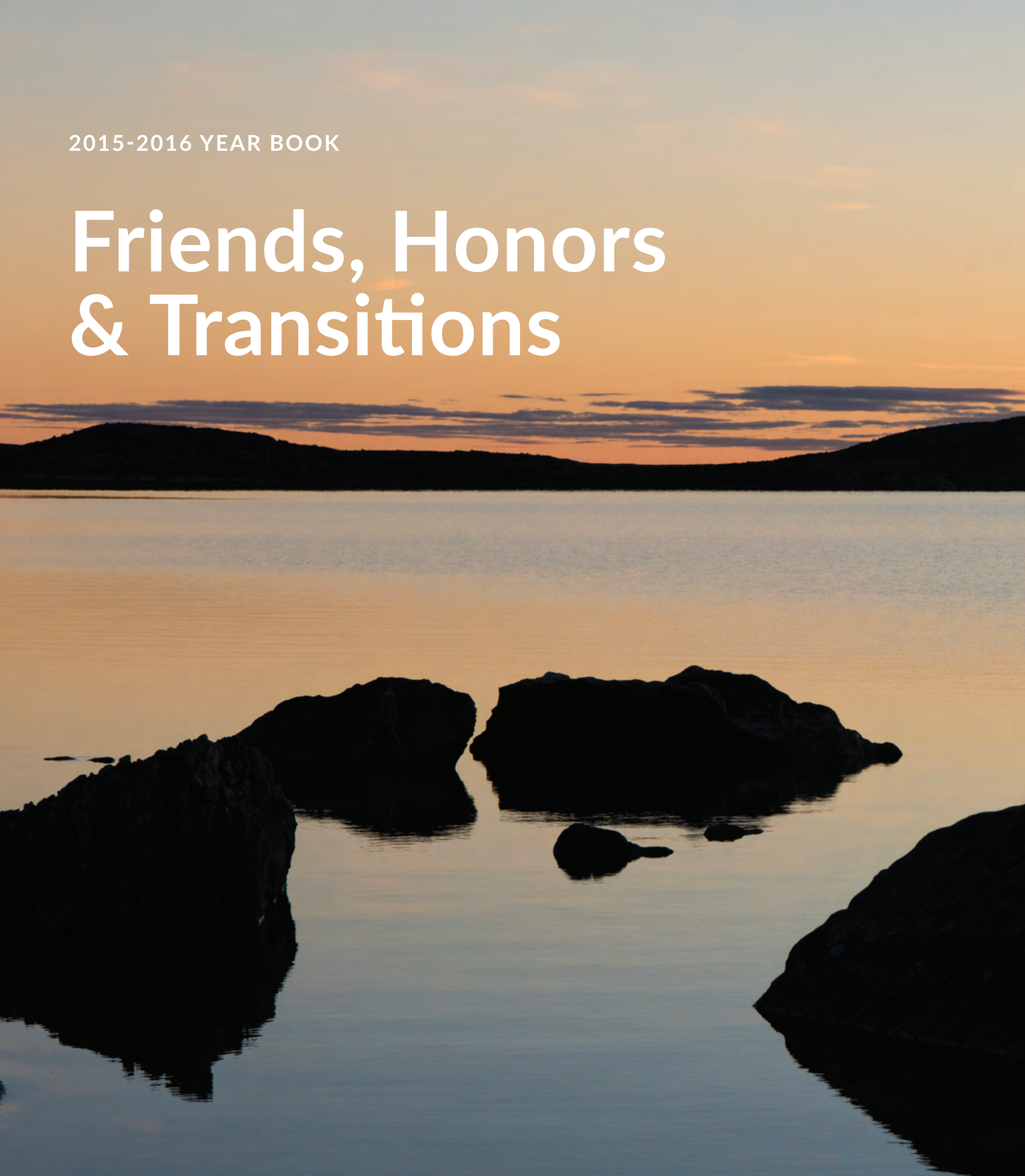
Cyanobacteria (and other microbes) use an enzyme called nitrogenase to fix nitrogen using solar energy (via photosynthesis) to power the process. The team’s first step was to identify the relevant genes and processes required for nitrogen fixation and photosynthesis using bioinformatics—computer analysis of biological data. Now, they are using synthetic biology—the design and construction of new biological parts—to build finely controlled nitrogen-fixing genetic circuits. Chris Voigt, a team member from MIT, pioneered this approach and Bhaya will build on these design principles.

Bhaya has spent almost two decades studying cyanobacteria both in the laboratory and in the extreme environments of Yellowstone National Park. Some of these ancient groups of unicellular organisms perform both photosynthesis and nitrogen fixation, but a big challenge they have to overcome is that nitrogenase is shut down by oxygen, which is a by-product of photosynthesis during the day. To avoid this problem, cyanobacteria fix nitrogen only at night. The scientists are now focusing on how cyanobacteria control these incompatible processes to gain new insights and build better synthetic systems.

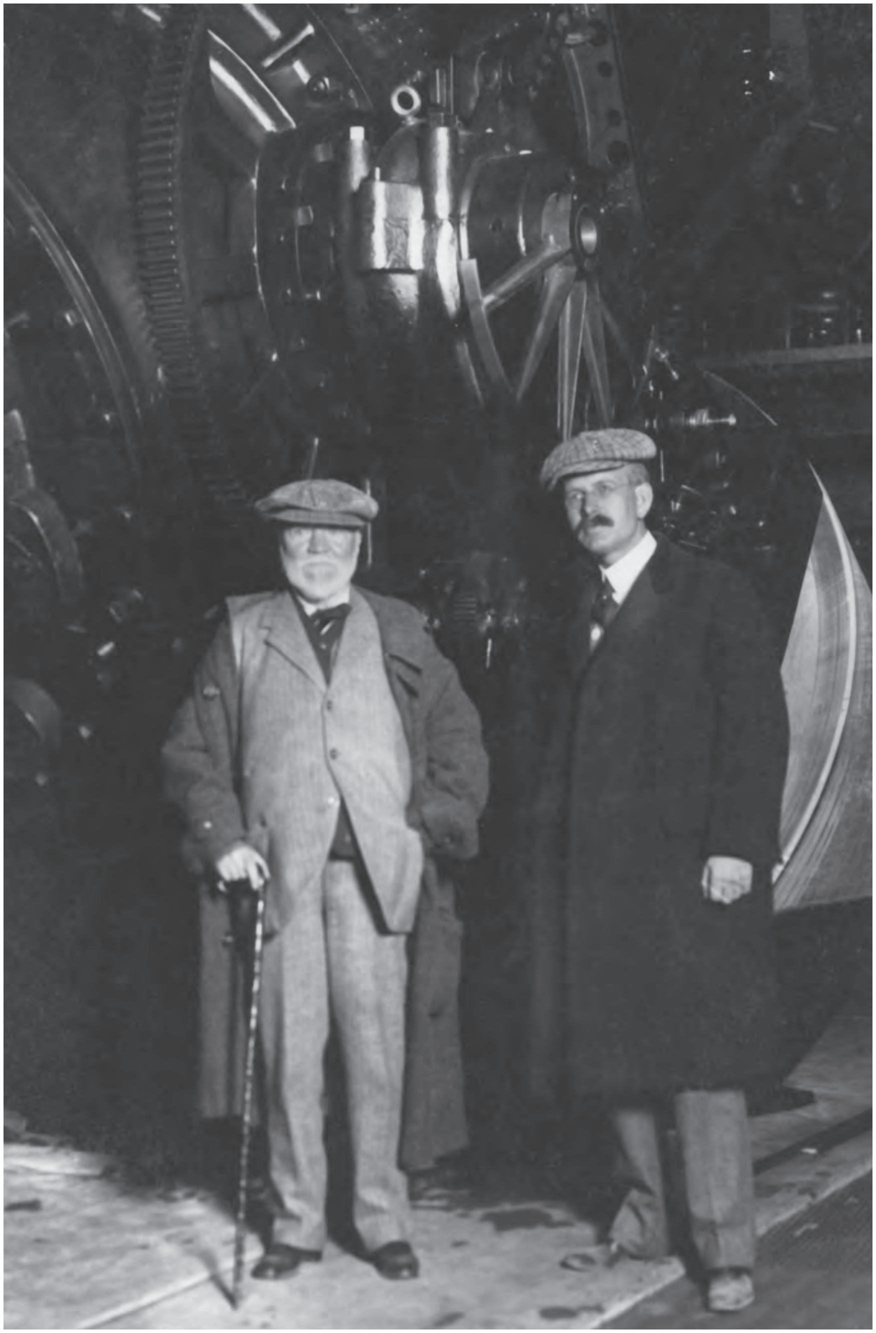
The team comes from diverse scientific backgrounds, including biochemistry and biophysics, bioengineering and genetics. They are coordinating their efforts to develop a genetic toolbox that will allow them to control the nitrogen-fixing pathway and thus set the stage for the insertion of useful functions into crop plants. Bhaya is also a member of the newly formed Plant Nitrogen Network (plannet-rcn.org). The network’s objective is to build an international network of seasoned and junior researchers to continue this work over the long haul to help solve food security and environmental issues.

2015-2016 YEAR BOOK

Friends, Honors & Transitions



Carnegie Friends



Lifetime Giving Societies

The Carnegie Founders Society

Andrew Carnegie, the founder of the Carnegie Institution, established it with a gift of $10 million, ultimately giving a total of $22 million to the institution. His initial $10 million gift represents a special amount. Thus, individuals, including those who have directed contributions from private foundations and donor-advised funds, who support Carnegie with lifetime contributions of $10 million or more are recognized as members of the Carnegie Founders Society.

Caryl P. Haskins*
William R. Hewlett*
George P. Mitchell*

Left: Andrew Carnegie (left) is with George Ellery Hale at the 60-inch telescope at the Mount Wilson Observatory in 1910. Carnegie (above) greets crowds during a parade.

The Edwin Hubble Society

The most famous astronomer of the 20th century, Edwin Hubble, was a Carnegie astronomer. His observations that the universe is vastly larger than we thought, and that it is expanding, shattered our old concept of cosmology. Science often requires years of work before major discoveries like his can be made. The Edwin Hubble Society honors those whose lifetime contributions have helped the institution to foster such long-term, paradigm-changing research by recognizing those who have contributed between $1,000,000 and $9,999,999 in their lifetimes, as well as those individuals who have directed contributions to the Carnegie Institution at that level from private foundations and donor-advised funds.

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The Vannevar Bush Society

Vannevar Bush, the renowned leader of American scientific research of his time, served as Carnegie's president from 1939 to 1955. Bush believed in the power of private organizations and the conviction that it is good for man to know. The Vannevar Bush Society recognizes individuals who have made lifetime contributions of between $100,000 to $999,999, as well as those individuals who have directed contributions to the Carnegie Institution at that level from private foundations and donor-advised funds.

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The Second Century Legacy Society

The Carnegie Institution is now in its second century of supporting scientific research and discovery. The Second Century Legacy Society recognizes individuals who have remembered, or intend to remember, the Carnegie Institution in their estate plans and those who support the institution through other forms of planned giving.

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Annual Giving

(Gifts received between July 1, 2015, and June 30, 2016)

The Barbara McClintock Society

An icon of Carnegie science, Barbara McClintock was a Carnegie plant biologist from 1943 until her retirement. She was a giant in the field of maize genetics and received the 1983 Nobel Prize in Physiology/Medicine for her work on patterns of genetic inheritance. She was the first woman to win an unshared Nobel Prize in this category. To sustain researchers like McClintock, annual contributions to the Carnegie Institution are essential. The McClintock Society thus recognizes generous individuals who contribute $10,000 or more in a fiscal year, as well as those individuals who have directed contributions to the Carnegie Institution at that level from private foundations and donor-advised funds.

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The Marilyn Fogel Endowed Fund for Young Scientists:

A Gift for the Future from Marilyn Fogel and Christopher Swarth

"Thirty-nine years ago in 1977, I began my scientific voyage with the Geophysical Laboratory at 2801 Upton Street in Washington, D.C. As a recent Ph.D. graduate, it was daunting to enter the august halls of the old lab. In those days, staff members, all of whom were older men, wore white shirts and ties to work every day. I was there at the right time and with the right people.

"In 1979, I was offered a position as a staff member to develop a research program in stable isotope biogeochemistry, in which different members of the same atomic family can reveal details of ancient and contemporary organic processes to understand environments, nutrient cycling, pollution sources, and whether carbon residues come from biological or nonbiological processes.

"We hope this gift will help start a life of intellectual curiosity for young students for many generations to come."

"For the next 33 1/2 years, my research was assisted and enhanced by working with young researchers—some still in high school, many in undergraduate programs—along with grad students and postdocs. I can easily say that the interactions I had with young scientists at Carnegie's Upton Street lab and the Broad Branch Road (BBR) campus were the highlight of my career at Carnegie.

"While the postdoctoral fellowship program at Carnegie remains vigorous and strong, staff members always needed to scramble to find funds for high school and undergraduate students who were spending a summer getting their feet wet in research for the very first time. Typically, a small pot of money was found somewhere, but it was a hit-or-miss proposition.

"Therefore, my husband Chris and I have donated $50,000 to an endowed Carnegie fund for supporting informal scientific research by early budding scientists—high school and undergraduate—who are working with staff members and postdocs on the BBR campus. Since the Geophysical Lab co-located with DTM in 1991, the labs have fostered a highly interdisciplinary research environment. Both departments regularly support young researchers in their laboratories.

Marilyn Fogel (right in background) is in the field with students and Carnegie colleague Andrew Steele (foreground standing).

Marilyn Fogel (right) stands with students at the Broad Branch Road campus in Washington, D.C.

Images courtesy Marilyn Fogel

"As we [husband Chris and Marilyn] reflect on Marilyn's long and prosperous career at Carnegie, we thank the institution for providing an environment with no strings attached that allowed her to pursue multiple lines of study that were never envisioned in 1977 when she first arrived. This gift is a token of thanks to the Carnegie Institution for making this happen. We hope this gift will help start a life of intellectual curiosity for young students for many generations to come."

Marilyn Fogel and Christopher Swarth

Carnegie President Matthew Scott remarked, *"We have started several new initiatives in the last year to strengthen our support and appreciation of Carnegie's postdoctoral fellows. This generous gift, to bolster the mentoring of even younger scholars, will invigorate Carnegie science and fortify the future of discovery and advancement in general. Thank you Marilyn and Chris for your very thoughtful donation."*

The Thacher Research Fund

In 2015, lifelong amateur astronomer Michael W. Thacher, with his wife Rhonda L. Rundle, established an endowed fund of $50,000 to support research projects designed by Carnegie astronomers. Thacher lives in Studio City, California, and has been engaged with nearby Mount Wilson Observatory and the Carnegie Institution for the past decade.

Thacher's passion for astronomy began as a six-year-old. One morning around 5 a.m. his mother awakened him to observe an unusually large and looming Venus. "I was amazed that something so big and bright could just appear in the morning sky," he recalls. "From then on, I was hooked."

> "I was amazed that something so big and bright could just appear in the morning sky"

With a bachelor's degree in philosophy from the George Washington University and an MBA from the University of California–Los Angeles, Thacher made his career in corporate public affairs and, as a freelance writer, has contributed to numerous publications including the *Los Angeles Times*, *Newsday*, and the *Christian Science Monitor*. In 2004, a year before he retired, he began volunteering as a tour guide at the historic Mount Wilson Observatory, which was founded by George Ellery Hale in 1904 with major Carnegie support.

At Mount Wilson, Thacher learned about the Carnegie Observatories and began to attend open houses, presentations, and dinners. In 2016, he and his wife visited Carnegie's Las Campanas Observatory in Chile, which houses the du Pont, Swope, and spectacular twin 6.5-meter Magellan telescopes. Thacher regularly interacts with Carnegie scientists, learning about their work and asking questions to clarify themes and topics he covers on his Mount Wilson tours.

Thacher's fund was inspired by the Carnegie mission to support gifted scientists in exploring questions of their own design. His gift is earmarked for Carnegie postdocs, enabling them to pursue independent research projects that would otherwise not be possible. In addition to the initial endowment, Thacher has contributed seed money to sponsor a pilot project this fiscal year, while director John Mulchaey and others establish the criteria for future awards.

Michael Thacher (left) and Observatories director John Mulchaey (right) are in the Hale Library at the Observatories on Science Day, November 3, 2016. Mulchaey is discussing the 60-inch Mount Wilson telescope using a little model. The *Hubble Atlas of the Galaxies*, by Carnegie astronomer Allan Sandage, is on the table.

Image courtesy Scott Rubel

"Everyone at Carnegie Science is extremely grateful for the Thachers' investment in the future of astronomy," said Mulchaey. "Michael and Rhonda's generous gift will allow generations of young astronomers to pursue the kind of independent research that is unique to Carnegie scientists."

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Barbara H. Zylinski

*Deceased

Members were qualified with records we believe to be accurate. If there are any questions, please call Irene Stirling at 202.939.1122.

Foundations and Corporations

$1,000,000 or more
The Cynthia and George Mitchell Foundation
Alfred P. Sloan Foundation

$100,000 to $999,999
S. D. Bechtel, Jr. Foundation
Carnegie Corporation of New York
The Lawrence Ellison Foundation
The Grantham Foundation for the Protection of the Environment
The Ambrose Monell Foundation
Gordon and Betty Moore Foundation
The David and Lucile Packard Foundation
The G. Unger Vetlesen Foundation

$10,000 to $99,999
The Abell Foundation, Inc.
Battelle Foundation Fund
The Brinson Foundation
Chesapeake Bay Trust
O.P. and W.E. Edwards Foundation
Robert and Margaret Hazen Foundation
Richard W. Higgins Foundation
The McMurtry Family Foundation
The Kenneth T. and Eileen L. Norris Foundation
The Ralph M. Parsons Foundation
T. Rowe Price Foundation, Inc.
The Rose Hills Foundation
Save the Redwoods League
The Simons Foundation
The Helen Hay Whitney Foundation

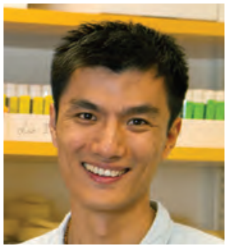
$500 to $9,999
Anonymous (2)
Atlantis Research Foundation
Craig and Barbara Barrett Foundation
The Boeing Gift Matching Program
Celerity IT, LLC
eLife
Hampton Creek, Inc.
Fred and Charlotte Hubbell Foundation
Japan Tech
The LeRoux Family Charitable Fund
Linden Trust for Conservation
Microsoft Matching Gifts Program
Northrop Grumman Corporation
The Paul & Dottie Foundation
Honey Perkins Family Foundation, Inc.
PlatinumTel Communications, LLC
Shell Oil Company Foundation
Wells Fargo

Honors & Transitions


★ Dick Meserve


★ Sandra Faber


★ Bill Kupiec


★ Zhao Zhang


★ Stephen Shectman

Honors

Trustees and Administration

Former Carnegie president and current trustee **Dick Meserve** was recognized by the Japanese government with the Order of the Rising Sun, Gold and Silver Star Award for "his contributions towards strengthening science and technology relations between Japan and the United States of America, as former Chairman of the NRC and as Chairman of the International Nuclear Safety Group (INSAG) of International Atomic Energy Agency (IAEA)." The citation noted his significant contributions towards improving Japanese nuclear safety since the Fukushima Daiichi nuclear accident in 2011. The Order of the Rising Sun is a Japanese order established in 1875. It is one of Japan's highest ranked awards and is bestowed for exemplary services to Japan by citizens or foreigners.

Trustee and former Terrestrial Magnetism postdoctoral fellow **Sandra Faber** received the Fellows Medal of the California Academy of Sciences. She also received an honorary degree from Amherst College and was the Caroline Herschel Distinguished Visitor for 2016 at the Space Telescope Science Institute.

Embryology

Bill Kupiec received one of two 2016 Service to Science Awards, created to recognize outstanding and/or unique contributions to science by Carnegie employees who work in administration, support, and technical positions. He has been the information technology manager at Embryology for over 24 years and was recognized for his efforts to go above-and-beyond the call of duty and for his tireless work on behalf of the staff.

Zhao Zhang was awarded an Early Independence Award from the National Institutes of Health (NIH). Traditionally, NIH has supported research projects, not individuals. However, "to identify scientists with ideas that have the potential for high impact, but that may be too novel, span too diverse a range of disciplines, or be at a stage too early to fare well in the traditional peer review process," they created several awards in the High-Risk, High-Reward Research Program to recognize individuals to accelerate the scientific progress.

Observatories

In October 2015, astronomer and instrumentation expert **Stephen Shectman** was awarded the Maria and Eric Muhlmann Award of the Astronomical Society of the Pacific (ASP) "for important research results based upon development of groundbreaking instruments and techniques." Shectman investigates the large-scale structure of the distribution of galaxies. He searches for ancient stars, develops novel and creative astronomical instruments, and constructs large telescopes. He was the project scientist for the 6.5-meter Magellan telescopes and is largely responsible for their superb quality.

The ASP awarded postdoctoral associate **Rachael Beaton** the 2016 Robert J. Trumpler Award for a recent Ph.D. thesis "considered unusually important to astronomy." Beaton studies the structure of galaxies to probe their evolution and formation. Beaton's dissertation, honored by the ASP, is titled "Life in the Outer Limits: Insights on Hierarchical Assembly from Stellar Halos in the Local Universe."

Observatories' Carnegie-Princeton Fellow **Eduardo Bañados** received the Otto Hahn Medal from Germany's Max Planck Society. The Otto Hahn Medal honors young researchers for outstanding scientific achievements. Bañados 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.

Plant Biology

Winslow Briggs, director emeritus and staff scientist at Plant Biology, was awarded the degree of Doctor Philosophiae Honoris Causa of the Hebrew University of Jerusalem for his "scientific leadership and groundbreaking contribution in the field of photobiology." The award letter stated that "your outstanding scientific achievements in photobiological studies on light-driven leaf movements, namely the physiology, biochemical and molecular interactions of light with plants and the control of plant development processes by plant photoreceptors gained worldwide recognition." Briggs was director of Plant Biology from 1973 to 1993 and still runs his lab.

Martin Jonikas is the 2015 recipient of NIH's New Innovator Award. NIH created several awards in the High-Risk, High-Reward Research Program to recognize individuals to accelerate the scientific progress. The NIH Director's Pioneer, New Innovator, and Transformative Research Awards encourage "outside-the-box thinkers to pursue innovative ideas . . . "

Terrestrial Magnetism

Janice Dunlap received one of two 2016 Service to Science Awards created to recognize outstanding and/or unique contributions to science by Carnegie employees who work in administration, support, and technical positions. She was recognized for her many contributions to making Terrestrial Magnetism such an efficient and enjoyable place to work during her 30-year tenure.

★ Rachael Beaton

★ Eduardo Bañados

★ Winslow Briggs

★ Martin Jonikas

★ Janice Dunlap

★ Matthew Sieber

★ Rebecca Albright

★ Johanna Teske

★ Zehra Nizami

First Four Carnegie Postdoctoral Innovation and Excellence Awards

A new program was established to recognize exceptional Carnegie postdoctoral scholars who have demonstrated both scientific accomplishments and creative endeavors beyond what is expected. Nominations for the Postdoctoral Innovation and Excellence (PIE) Awards are made through the department directors, and the award recipient is chosen by the Office of the President. Under the program, one postdoc is honored every quarter for his or her extraordinary accomplishments. 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.

Matthew Sieber, a postdoctoral fellow at the Department of Embryology, was honored for his extraordinary accomplishments as "a creative researcher, interactive colleague, and selfless mentor." Through his research, he has made substantial connections between metabolism and reproduction, an area that previously lacked serious progress.

Sieber's results have exciting implications for both basic research and medicine. He exemplified the Carnegie style of science by taking an unconventional path. His work shows that mitochondria, an energy-producing cellular organelle, are far more dynamic and responsive to external signals than expected. The finding likely applies to a broad spectrum of animals. Sieber also demonstrates a strong engagement with his department.

Rebecca Albright, a postdoc in the Caldeira lab at Global Ecology and now at the California Academy of Sciences, works on ocean acidification, specifically the effects of ocean acidification on corals and coral reef systems. She was awarded the second PIE award.

The lab had been trying to succeed with an experiment to add alkalinity to seawater flowing over a natural coral reef to buffer acidification for the past five years. Albright was the scientific leader of the third attempt at the experiment. It was the first one to succeed, in no small part due to Albright's leadership. *Nature* published a paper describing the experiment, with Albright as first author, along with an the accompanying news story "Landmark experiment confirms ocean acidification's toll on Great Barrier Reef" that featured the work.

Johanna Teske, the third PIE recipient, is the first Carnegie Origins Postdoctoral Fellow—the first fellowship that straddles two departments, the Observatories and the Department of Terrestrial Magnetism.

Teske studies the relationship between the composition of stars and their orbiting planets. She uses a clever program to make observations of binary stars that host different types of planets, or where one of the two stars is known to host a planet. She also makes detailed measurements of stars with and without planets to decipher what elements correlate with planets of different sizes in different orbits. She has been an indispensable volunteer at Carnegie's First Light Saturday Science School and is passionate about outreach in general.

Zehra Nizami, in Joe Gall's lab at Embryology, codiscovered a new class of RNA molecules called stable intronic sequence (sis) RNA. It was believed that introns—bits of DNA that scramble the sequence encoding a protein—are junk DNA and that their RNA products are typically destroyed during the unscrambling process. The discovery required exceptional skill in deep sequencing—sequencing a genomic region hundreds or even thousands of times—coupled with a thorough understanding of cell biology of the giant egg cell of the frog *Xenopus*. She also conducts structural analysis of the giant lampbrush chromosomes in amphibians and collaborates on other research projects.

Nizami was a pioneering member of the Mentoring to Inspire Diversity in Science (MInDS) initiative at the Johns Hopkins University, and she participates in the BioEYES K-12 science education program at Embryology. She was awarded the fourth PIE award in September.

Carnegie Science Venture Grants Introduced in 2015

President Matthew Scott and Science Deputy Margaret Moerchen announced six new Carnegie Science Venture Grants in 2015-2016. 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. The grants are generously supported, in part, by Michael Wilson and his wife Jane. The belief is that these projects will grow in unexpected ways with many surprises.

SWEETS

Wolf Frommer of Plant Biology and **Steve Farber** of Embryology received a grant to study the SWEET sugar transporter, identified by Frommer in plants, in the Farber lab's zebrafish. SWEET transporters play several key roles in plants, including nectar production and transporting sugars from the leaves to other tissues. This new project will observe their role in animals.

Earth's Interior

Anat Shahar of the Geophysical Lab and **Erik Hauri** of Terrestrial Magnetism with postdoctoral associate **Steve Elardo** received a grant to explore the carbon isotope ratios of Earth's mantle. Remarkably, Earth has signatures different from the other rocky planets. The team is observing the evolution of isotope ratios in a high-pressure environment and analyzing samples in the lab using the NanoSIMS instrument, a highly sensitive ion microprobe.

Coral Bleaching

Ken Caldeira's and **Greg Asner's** teams, both of Global Ecology, will use the Carnegie Airborne Observatory's unique remote-sensing capabilities to map coral bleaching off the coast of Hawaii in combination with *in situ* studies of coral biology performed by the Caldeira lab. Postdoctoral associates **Rebecca Albright** (now at the California Academy of Sciences) and **Robin Martin** are team members. The objective is to see the effect of climate change on the population and diversity of the coral.

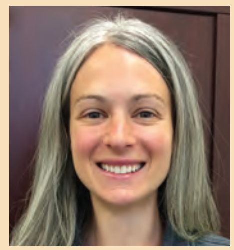
Coral Calcification

Art Grossman of Plant Biology teamed up with Global Ecology's **Rebecca Albright** and **Ken Caldeira** and others to develop a new model for understanding how coral calcification works at the cellular/molecular and community levels. The team is collaborating 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.

continued on page 58


★ Wolf Frommer


★ Steve Farber


★ Anat Shahar


★ Erik Hauri


★ Steve Elardo


★ Ken Caldeira


★ Greg Asner


★ Rebecca Albright


★ Robin Martin


★ Art Grossman

★ Yixian Zheng

★ David Ehrhardt

★ Frederick Tan

★ Zehra Nizami

★ Alan Boss

★ Sergio Dieterich

★ Johanna Teske

Carnegie Science Venture Grants *continued*

Plant Flowering

Embryology's **Yixian Zheng's** team joined forces 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, which affects carbon fixation, the timing of flowering, and more. Zheng looked at how a protein whose transition into a liquid state at physiological temperature promoted cell division. The new project will investigate another protein to determine if a similar temperature-dependent "phase transition" is required to regulate the flowering process.

Citizen Science

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

Transitions

Administration

Benjamin Aderson joined Carnegie as the institution's first General Counsel. He was Managing Director of Legal Affairs at Pew Research Center. Aderson brings more than 10 years of experience providing legal counsel to organizations and serving as a corporate secretary. At Pew Research Center, he oversaw all legal matters, including transactions, compliance, governance, and risk management.

Julie Edmonds, the codirector of the Carnegie Academy for Science Education, retired from her post in July after 16 years promoting, teaching, and mentoring science, technology, engineering, and mathematics (STEM) education.

Loronda Lee joined Carnegie as Associate Director of Human Resources after **Cady Canapp** retired. Lee brings 10 years of human resources experience. She was Human Resource Manager at CACI, an information services provider for national security missions and intelligence, defense, and federal civilian customers. Prior to that she was in human resources at the United States Institute of Peace and the Harris Corporation, among other organizations. She has an M.A. in human resource management.

Ann McElwain was appointed Carnegie's Chief Development Officer. She came from Dartmouth College where she was Executive Director of Leadership Giving. With 17 years of experience and an MBA, McElwain brings a rich portfolio to Carnegie, including 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 more.

Jessica Moore joined Carnegie as the Associate Director of Financial Planning and Budgeting. She came from the Elizabeth Glaser Pediatric AIDS Foundation where she was a team manager. She produced detailed analysis, reporting, budgeting, and forecasting for managers and program directors. She also presented financial and budgeting reports to their finance committee, among other duties. Prior to that, she was with PricewaterhouseCoopers. She has an MBA and a CPA.

Dione Rossiter was appointed Scientific Programs & Outreach Manager. She is an atmospheric scientist with a Ph.D. and B.A. in Earth and Planetary Sciences, specializing in atmospheric science. Before Carnegie she was at the American Association for the Advancement of Science (AAAS) as the project director for Education and Human Resources program and the director of the Media Science and Engineering Fellows program. She coordinated events and provided communications, presentations, and guidance to scientists and the public. She also managed all aspects of the AAAS Mass Media Fellows Program and Minority Science Writers Internship Program.

★ Benjamin Aderson

★ Julie Edmonds

★ Loronda Lee

★ Cady Canapp

★ Ann McElwain

★ Jessica Moore

★ Dione Rossiter


★ Rebecca Schwieger


★ Michael Stambaugh


★ Yixian Zheng


★ Allan Spradling


★ Andrew Newman


★ Anthony Piro


★ Gwen Rudie

Rebecca Schwieger joined Carnegie as Associate Director for Finance/Controller. She was previously at the Virginia Hospital Center where she managed a staff of eight accountants. She is a CPA with a B.S. and M.S. in accounting from Clemson University. She began her career as an auditor at Deloitte & Touche and she has nonprofit experience at three organizations, including Special Olympics.

Michael Stambaugh joined the institution as its first Chief Investment Officer. Stambaugh brings over 15 years of experience managing endowment assets. He came from the Sloan Foundation, where he drove all aspects of the investment process for their $1.8 billion endowment. He began his career in commercial banking and moved to endowment management with the Metropolitan Museum of Art in 2000, where he was part of a team managing the Met's $2.5 billion endowment and treasury function. He then moved to American University in Cairo to establish their in-house investment office before joining Sloan. He has an MBA and is a Chartered Financial Analyst (CFA).

Embryology

Yixian Zheng was appointed Acting Director of the department after the retirement of **Allan Spradling** as director. Spradling will continue his research in the lab. Zheng joined the department in 1996. She is a highly accomplished biologist who investigates cell division and the cytoskeleton. Zheng did her graduate work in molecular genetics at Ohio State University and her postdoctoral research with Bruce Alberts at the University of California-San Francisco. She has been a Pew Scholar and Howard Hughes Medical Institute Investigator, and an Ellison Medical Foundation Senior Scholar in Aging. In 2008 she was made a National Associate of the National Research Council, a lifetime appointment in recognition of extraordinary service. She is also Adjunct Professor at the Johns Hopkins University.

Observatories

Andrew Newman joined the staff in 2015. He studies extragalactic astronomy, including the distribution of dark matter in galaxies, groups of galaxies, galactic clusters, and the evolution of the structure and dynamics of early, massive galaxies. He uses a variety of techniques including gravitational lensing, stellar dynamics, and stellar population synthesis.

Anthony Piro joined the staff as the George Ellery Hale Distinguished Scholar in Theoretical Astrophysics in 2015. His interests involve compact objects, astrophysical explosions, accretion flows, and stellar dynamics. He predicts new phenomena and tries to understand the underlying physical mechanisms responsible for observations using a combination of analytic and simple numerical models.

Gwen Rudie joined the Observatories staff in 2015. Her observational research focuses on the chemical and physical properties of very distant galaxies and their surrounding circumgalactic medium. She analyzes and interprets high-resolution spectroscopy of quasi-stellar objects—highly energetic, star-like, and very distant objects and uses near-infrared and optical parts of the spectrum to study very distant galaxies.

Plant Biology

Seung Yon (Sue) Rhee succeeded **Wolf Frommer** as director. Frommer will continue his research. Rhee started as a Staff Associate from 1999-2005 and was then promoted to Staff Scientist. She received her Ph.D. from Stanford. As a staff associate, she created the Arabidopsis Information Resource, TAIR, a worldwide computational platform for integrating molecular, genomic, genetic, physiological, and other data. She applies computer science to the analysis of genes and genomes and the proteins they encode. She also explores the chemistry of plants, the network of small molecules and enzymes that form them, physiology, and responses to pathogens to understand plant evolution, origins of pharmaceutically active compounds, fragrance, and flavor.

★ Seung Yon (Sue) Rhee

★ Wolf Frommer

Terrestrial Magnetism

Peter Driscoll joined the staff as an Earth and planetary scientist. He was the planetary interiors and evolution postdoctoral fellow in the NASA Virtual Planetary Laboratory at the University of Washington in Seattle. From 2010 to 2013, he was a Bateman postdoctoral fellow in the geology and geophysics department at Yale University. He received his Ph.D. in Earth and planetary science from the Johns Hopkins University in 2010. He focuses on theories of thermal and magnetic evolution of the Earth including the thermal evolution of the interior, dynamics of the core, polarity reversals of Earth's magnetic field, the divergence of Earth and Venus, and the internal dynamics and detectability of terrestrial exoplanets.

★ Peter Driscoll

★ Peter van Keken

Peter van Keken joined the department as a staff scientist. He has been a professor at the University of Michigan. He studies the dynamics of plate tectonics. The tectonic evolution of the Earth is driven by the slow release of heat from the Earth's interior that is conducted by the slow, solid-state deformation of the Earth's mantle. The melting at mid-oceanic ridges and subsequent recycling at subduction zones, where one plate slides under another, imparts unique chemical characteristics. Van Keken develops computational models to solve the equations for this slow convection. These models are based on mineral physics and petrology and are tested using geodynamics, geochemistry, and petrology. He received his Ph.D. from the University of Utrecht, The Netherlands.

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2015-2016 YEAR BOOK

Financial Profile

for the year ending June 30, 2016

Image courtesy Matthew Scott

Reader's Note: *In this section, we present summary unaudited financial information. Each year the Carnegie Institution, through the Audit committee of its Board of Trustees, engages an independent auditor to express an opinion about the financial statements and the financial position of the institution. The complete audited financial statements are made available on the institution's website at www.CarnegieScience.edu.*

The Carnegie Institution for Science completed fiscal year 2016 in sound financial condition despite negative returns (-3.3%) on the diversified investments within its endowment; a disciplined spending policy that balances today's needs with the long-term requirements of the institution and the interests of future scientists; and the continued support of organizations and individuals who recognize the value of basic science.

The primary source of support for the institution's activities continues to be its endowment. This reliance on institutional funding provides an important degree of independence in the research activities of the institution's scientists.

As of June 30, 2016, the endowment was valued at $903 million. Over the period 2001-2016, average annual increases in endowment contributions to the budget were 5.0%. Carnegie closely controls expenses in order to ensure the continuation of a healthy scientific enterprise.

For a number of years, under the direction of the Investment committee of the board, Carnegie's endowment has been allocated among a broad spectrum of asset classes including: equities (stocks), absolute return investments, real estate partnerships, private equity, natural resources partnerships, and fixed-income instruments (bonds). The goal of this diversified approach is to generate attractive overall performance and reduce the volatility that would exist in a less diversified portfolio. Earlier this year Carnegie hired its first Chief Investment Officer to more proactively steward the endowment's assets.

The Chief Investment Officer and Investment committee regularly examine the asset allocation of the endowment and readjust the allocation, as appropriate. The institution relies upon external managers and partnerships to conduct the investment activities, and it employs a commercial bank to maintain custody. The following chart shows the allocation of the institution's endowment among asset classes as of June 30, 2016.

Asset Class	Target	Actual
Common Stock	35.0%	34.3%
Alternative Assets	57.5%	57.9%
Fixed Income and Cash	7.5%	7.9%

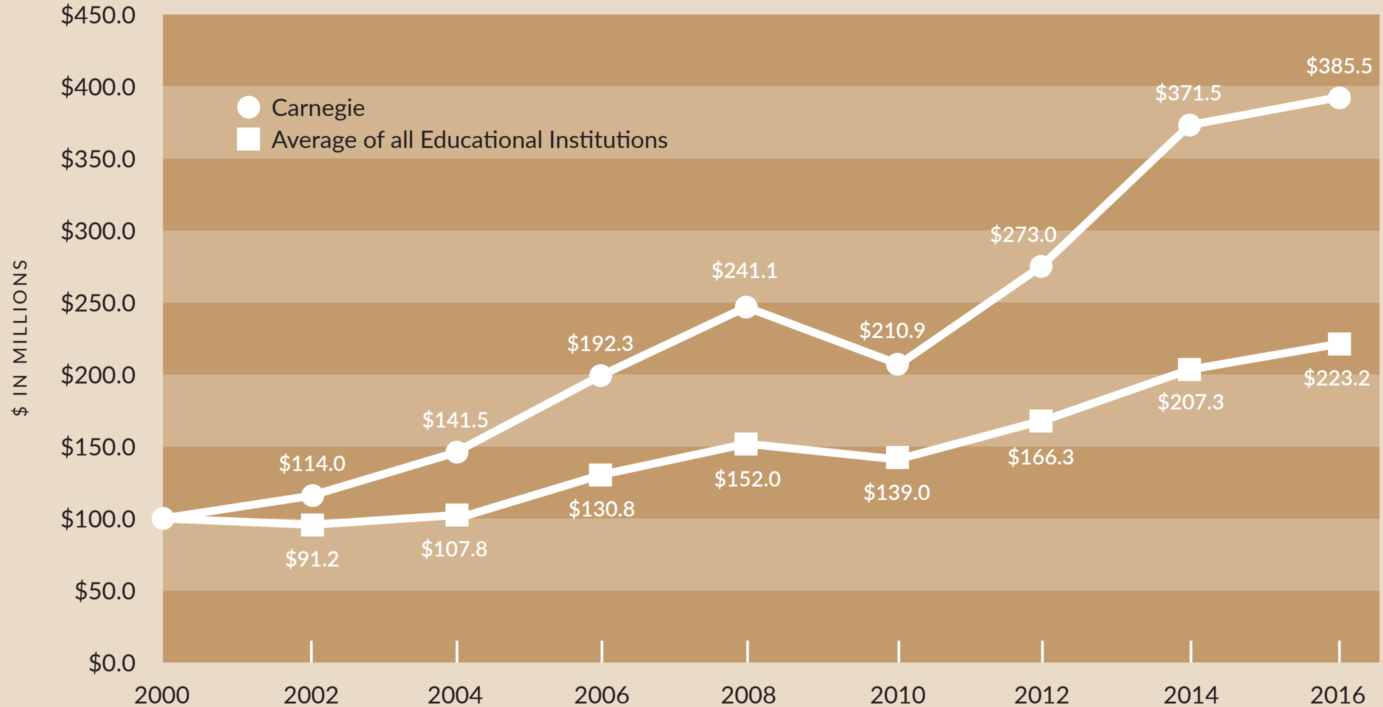
Carnegie's investment goals are to provide high levels of current support to the institution and to maintain the long-term spending power of its endowment. The success of Carnegie's investment strategy is illustrated in the following figure that compares, for a hypothetical investment of $100 million, Carnegie's investment returns with the average returns for all educational institutions for the last sixteen years.

Carnegie has pursued a long-term policy of controlling its spending rate, bringing the budgeted rate down in a gradual fashion from 6+ % in 1992 to 5% today. Carnegie employs what is known as a 70/30 hybrid spending rule. That is, the amount available from the endowment in any year is made up of 70% of the previous year's budget, adjusted for inflation, and 30% of the most recently completed year-end endowment value, multiplied by the spending rate of 5% and adjusted for inflation and debt. This method reduces volatility from year-to-year. The second figure depicts actual spending as a percentage of ending market value for the last 19 years.

In fiscal year 2016, Carnegie benefitted from continuing federal support. Carnegie's received $30 million in new/additional federal grants in 2016. This is a testament to the high quality of Carnegie scientists and their ability to compete successfully for federal funds in this period of fiscal restraint.

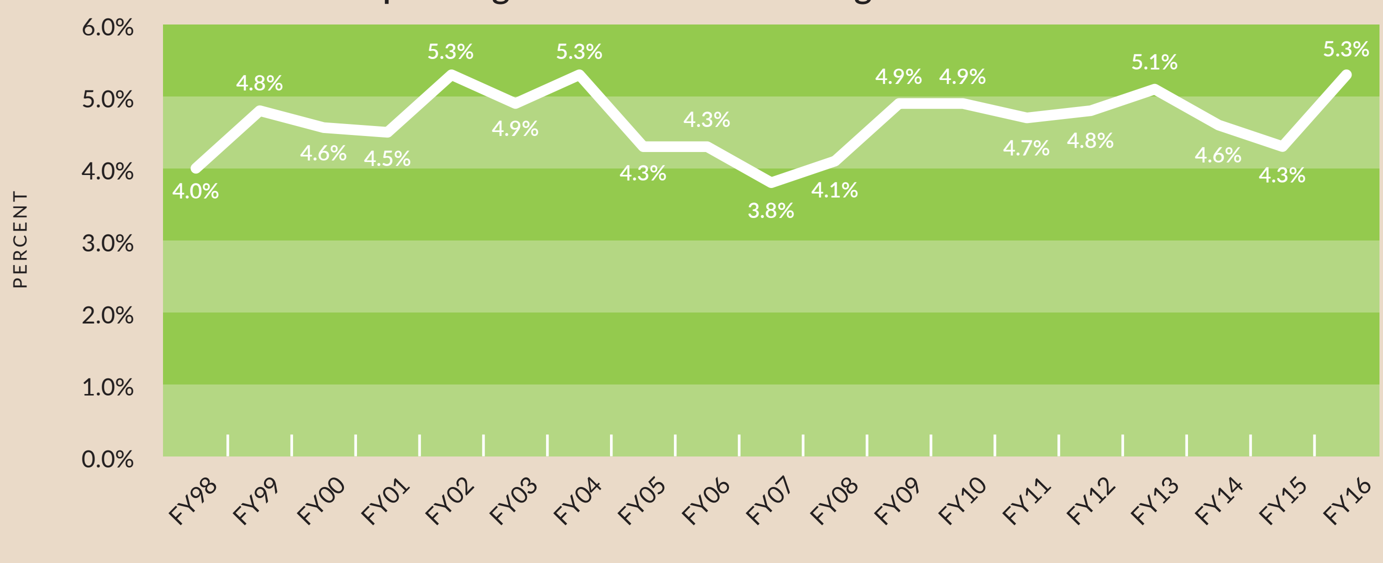
Carnegie also benefits from generous support from foundations and individuals. Funding from foundations has grown from an average of about $3 million/year in the period from 2000 to 2004 to $8.9 million in 2016. Within Carnegie's endowment, there are a number of "funds" that provide support either in a general way or targeted to a specific purpose. The largest of these is the Andrew Carnegie Fund, begun with the original gift of $10 million. Mr. Carnegie later made additional gifts totaling another $12 million during his lifetime. This tradition of generous support for Carnegie's scientific mission has continued throughout our history and a list of donors in fiscal year 2016 appears in an earlier section of this year book. In addition, Carnegie receives important private grants for specific research purposes, including support from the Howard Hughes Medical Institute for researchers at the Department of Embryology.

Illustration of $100 Million Investment — Carnegie Returns vs. Average Returns for All Educational Institutions (2000-2016)



Average returns for education institutions are taken from commonfund reports on endowment performance

Endowment Spending as a Percent of Ending Endowment Value



Statements of Financial Position

June 30, 2016, and 2015

	2016	2015
Assets		
Current assets:		
Cash and cash equivalents	$ 29,525,260	$ 16,120,426
Accrued investment income	8,990	73,772
Contributions receivable	4,165,123	7,077,572
Accounts receivable and other assets	8,073,777	8,966,680
Bond proceeds held by Trustee	25,799,872	49,434,798
Total current assets	67,575,022	81,673,248
Noncurrent assets:		
Investments	877,972,420	983,996,467
Property and equipment, net	133,823,031	137,996,467
Long term deferred assets	56,676,701	21,992,598
Total noncurrent assets	$1,068,472,152	$1,143,605,259
Total assets	$1,136,045,174	$1,225,278,507
Liabilities and Net Assets		
Accounts payable and accrued expenses	$ 8,204,479	$ 10,145,114
Deferred revenues	28,929,144	27,431,440
Bonds payable	115,051,346	115,057,854
Accrued postretirement benefits	27,674,751	25,923,865
Total liabilities	$ 179,859,720	$ 178,558,273
Net assets		
Unrestricted	$ 288,925,810	$ 310,287,147
Temporarily restricted	612,103,681	681,328,124
Permanently restricted	55,155,963	55,104,963
Total net assets	$956,185,454	$1,046,720,234
Total liabilities and net assets	$1,136,045,174	$1,225,278,507

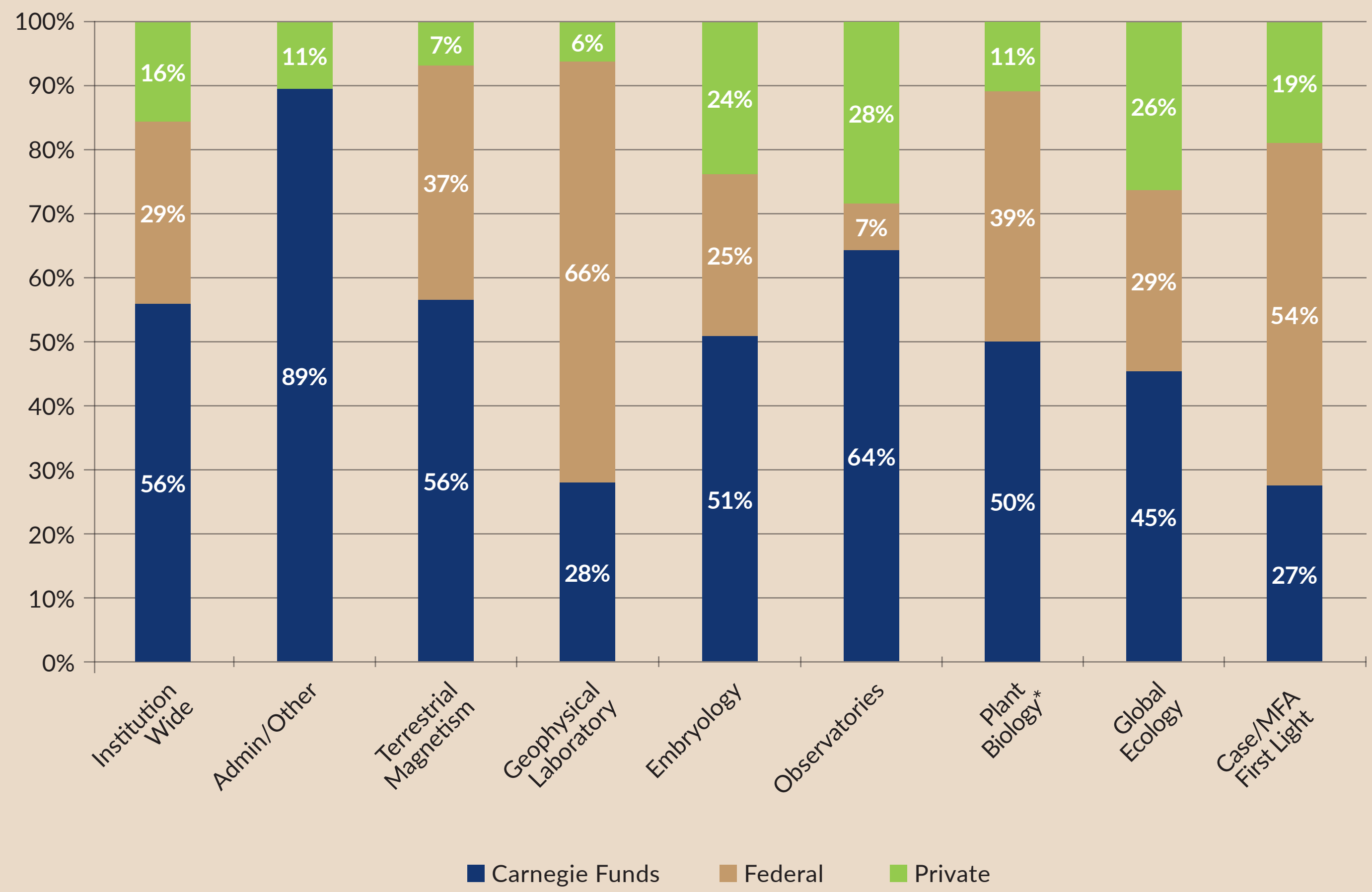
Statements of Activities[1]

Periods ended June 30, 2016, and 2015

	2016	2015
Revenue and support:		
Grants and contracts	$ 34,549,397	$ 37,738,760
Contributions, gifts	7,950,687	10,610,849
Other income	3,999,462	6,213,102
Net external revenue	$ 46,499,546	$ 54,562,711
Investment income and unrealized gains (losses)	$ (33,749,526)	$ 58,482,948
Total revenues, gains, other support	$ 12,750,020	$ 113,045,659
Program and supporting services:		
Terrestrial Magnetism	$ 11,936,953	$ 11,769,589
Observatories	17,496,682	18,318,574
Geophysical Laboratory	19,651,283	22,714,496
Embryology	13,463,956	12,269,662
Plant Biology	11,492,430	11,402,502
Global Ecology	8,588,883	7,563,559
Other programs	934,806	1,046,000
Administration and general expenses	19,099,189	17,975,643
Total expenses	$ 102,664,182	$ 103,060,025
Change in net assets before pension related changes	$ (89,914,162)	$ 9,985,634
Pension related changes	(620,618)	(1,275,370)
Net assets at the beginning of the period	$ 1,046,720,264	$ 1,038,009,970
Net assets at the end of the period	$ 956,185,454	$ 1,046,720,234

[1] Includes restricted, temporarily restricted, and permanently restricted revenues, gains, and other support.

Funding Sources by Department



*Please note this allocation has been corrected from the printed version.

Small Size, Big Impact

Some 65 senior Carnegie investigators, with postdoctoral fellows and other colleagues, machinists, business administrators, facilities staff, and more contributed to about 700 papers published in the most prestigious, peer-reviewed scientific journals during the last year. Many discoveries were widely covered by the media and had extensive social media reach.

For a full listing of personnel and publications see https://CarnegieScience.edu/yearbooks

Carnegie Investigators IN THE NEWS

"New research suggests sun's magnetic field may soon change."

JENNIFER VAN SADERS IN UPI

"The unexpected realization that this 1917 plate from our archive contains the earliest recorded evidence of a polluted white dwarf system is just incredible."

JOHN MULCHAEY IN SMITHSONIAN

"They found that the parts of the planet with higher concentrations of carbon were also the darkest."

LARRY NITTLER IN THE WASHINGTON POST

"Our work provides the first strong evidence…on a natural ecosystem that ocean acidification is already slowing coral reef growth."

REBECCA ALBRIGHT IN USA TODAY

"Human actions not only are emitting greenhouse gases based on our own activities, but also are causing plants and animals and microbes to be net emitters of greenhouse gases as well."

ANNA MICHALAK IN THE WASHINGTON POST

“Scientists have so far tracked down 5,000 mineral species and it turns out that fewer than a 100 constitute almost all of Earth’s crust.”

ROBERT HAZEN IN THE BBC

“This dark hydrogen layer was unexpected and inconsistent with what modelling… had led us to believe about the change from hydrogen gas to metallic hydrogen inside of celestial objects.”

ALEXANDER GONCHAROV IN THE DAILY MAIL

“…the researchers say that restless volcanoes go quiet just before they erupt.”

DIANA ROMAN IN POPULAR SCIENCE

“…our results show that aged muscle stem cells with compromised β1-integrin activity and aged muscles with insufficient amount of fibronectin [are] both root causes of muscle aging.”

CHEN-MING FAN IN GENETIC ENGINEERING AND BIOTECHNOLOGY NEWS

“A team of scientists…has now discovered that a sugar-transport protein…is both necessary for successful seed filling and shows genome changes that indicate domestication…”

WOLF FROMMER IN AG PROFESSIONAL

“the fact that the resulting cell could be injected into an egg and produce a viable animal is a stringent test.”

ALLAN SPRADLING IN THE HUFFINGTON POST

Carnegie Investigators

Staff Scientists

- GEORGE D. CODY, Acting Director
- RONALD E. COHEN
- YINGWEI FEI
- ALEXANDER F. GONCHAROV
- ROBERT M. HAZEN
- RUSSELL J. HEMLEY[1]
- HO-KWANG MAO
- BJØRN O. MYSEN
- DOUGLAS RUMBLE III
- ANAT SHAHAR
- ANDREW STEELE
- TIMOTHY A. STROBEL
- VIKTOR V. STRUZHKIN

[1] To January 31, 2016

THE GEOPHYSICAL LABORATORY »

Matter at Extreme States, Earth/Planetary Science

Front row (left to right): Robert Hazen, Bjørn Mysen, Anat Shahar, George Cody, Ronald Cohen, Alexander Goncharov, Timothy Strobel, Andrew Steele. Second row: Adelio Contreras, Otta Medina, Michael Guerette, Asmaa Boujibar, Craig Schiffries, Maceo Bacote, Andrew Needham, Rajasekarakumar Vadapoo, Marilyn (Helen) Venzon, Aline Niyonkuru, Qianqian Wang, Hiroyuki Takenaka, Ivvan Naumov, Chang-Sheng Zha, Stephen Gramsch. Third Row: Quintin Miller, Matthew Ward, Bill Key, Michael B. Meyer, Joseph Lai, Nick Holtgrewe (visitor), Seth Wagner, Zachary Gabelle, Jeff Lightfield, Michael Ackerson, Dyanne Furtado, Merri Wolf, Gary Bors, Shi Liu, Hanyu Liu, Daniel Eldridge, Chao Liu. Forth row: Sergey Lobanov, Dionysis Foustoukos, Gefie Gian, Emma Bullock, Morgan Phillips Hoople, Michelle Hoon-Starr, Wu Ye (visitor), Xiao-Miao Zhao (visitor), Renbiao Tao, Gabor Szilagyi, Li Zhu, Colin Jackson, Zhixue Du, Xiaowei Sun (visitor), Haijun Huang (visitor), Megan Duncan, Michelle Scholtes.

« THE DEPARTMENT OF EMBRYOLOGY

Genetics/Developmental Biology

Front row (left to right): Ed Hirschmugl, Sonya Bajwa, Kevin Smolenski. Second row: Leon Lin, Sungjin Moon, Mahmud Siddiqi, Steve Farber, Jean-Michael Chanchu, Carmen Tull, Allan Spradling. Third row: Alex Bortvin, Luxin Pei, Elizabeth Urban, Joseph Gall, Christoph Lepper, Chen-Ming Fan, Eugenia Dikovskaia, Siew-Hui Low, Sheryl Southard, Zehra Nizami, Michelle Macurak, David Neal, Pat Cammon, Glenese Johnson. Fourth row: James Thierer, Jui-Ko Chang, Jessica Otis, Gaelle Tallhouarne, Sveta Deryusheva, Ona Martin, Lynne Hugendubler, Marla Tharp, Chiara De Luca, Safia Malki, Matt Sieber, Neta Shwartz, Joseph Tran, Maggie Shen, Vanessa Quinlivan-Repasi, Kyle Joynes. Fifth row: Chandra Harvey, Rob Vary, Meredith Wilson, Valerie Butler, Sibiao Yue, Dianne Williams, Ming-Chia Lee, Allison Pinder, Carol Davenport, Megha Ghildiyal, Steve DeLuca, Ethan Greenblatt, Jiabiao Hu, Lin Lin, Zhao Zhang. Sixth row: Gennadiy Klimachev, Rebecca Obniski, Lu Wang, Huijie Zhao, Shusheng Wang, Han Xiao, Mike Sepanski, Chenhui Wang, Kun Dou, Gugu Pang, Ebrahim Darvish, Wilber Ramos, Eric Duboué, Kathryn Daly, Monica Hensley. Seventh row: Kirti Prakash, Xiaobin Zheng, Wenbin Liu, Yuejia Huang, Sarina Raman, Christine Pratt, Brandie Dobson, Sara Roberson, Jung-Hwa Choi, Amanda Chicoli, Dolly Chin, Liangji Li, Tyler Harvey, Samantha Satchell.

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ANDREW MCWILLIAM
JOHN MULCHAEY, Director
ANDREW NEWMAN[4]
AUGUSTUS OEMLER, JR., Director Emeritus
ERIC PERSSON
MARK PHILLIPS, Director, Las Campanas Observatory
GEORGE PRESTON, Director Emeritus
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GWEN RUDIE[4]
FRANÇOIS SÇHWEIZER, Staff Member Emeritus
STEPHEN SHECTMAN
JOSHUA SIMON
IAN THOMPSON
RAY WEYMANN, Director Emeritus

Research Associates

CHRISTOPHER BURNS, Research Associate[5]
JEFFREY CRANE, Staff Associate[5]
DAN KELSON, Staff Associate
BARRY MADORE, Senior Research Associate
ANTHONY PIRO, Staff Associate[6]

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[1] From July 1, 2015, to Staff Astronomer; formerly Staff Associate, George Ellery Hale Distinguished Scholar in Theoretical Astrophysics
[2] To December, 31, 2015; now Staff Member Emeritus
[3] To June 30, 2016
[4] From August 1, 2015, to Staff Astronomer; formerly Carnegie Fellow, listed in Postdoctoral Fellows and Associates
[5] Formerly listed in Postdoctoral Fellows and Associates
[6] From August 1, 2015, George Ellery Hale Distinguished Scholar in Theoretical Astrophysics; formerly Postdoctoral Associate, listed in Postdoctoral Fellows and Associates

THE OBSERVATORIES »

Astronomy

Front row (left to right): Christoph Birk, Ian Thompson, Andrew McWilliam, Charlie Hull, Jeffrey Crane, Christopher Burns, Daniel Kelson, Eric Persson, Becky Lynn, Beverly Fink, Stephanie Tonnesen, John Grula. Second row sitting: Alan Uomoto, Eduardo Bañados, Marja Seidel, Janet Colucci, Katey Alatalo. Third row: Jerson Castillo, Greg Ortiz, Sung-Ri Sok, Irina Strelnik, Cynthia Hunt, Gwen Rudi, Sharon Kelly, Gillian Tong, Kristi Macklin, Erica Clark, Alan Dressler, Vgee Ramiah, John Mulchaey. Fourth row: Luis Ochoa, Yu Lu, Jeffery Rich, Robert Storts, Jennifer van Saders, Rachael Beaton, Andrew Benson, Earl Harris, Barry Madore, François Schweizer, Juna Kollmeier, Anthony Piro, Scott Rubel.

Image courtesy Andy Monson

Global Ecology

Front row (left to right): Patrick Freeman, Ismael Villa, Angelica Vasquez, Eva Sinha, Kathi Bump, Geeta Persad, Tarin Paz-Kagan, Joe Berry. Second row: Anna Possner, Seth Lalonde, Rong Wang, Anna Michalak, Susan Cortinas, Jennifer Scerri, Leander Anderegg, Sandra Skowronek, Matthew Shultz. Third row: Dario del Giudice, Peter Turner, Daniel Sanchez, Kathleen Denniston, Dana Chadwick, Ken Caldeira, Nick Vaughn, Dave Knapp, Jennifer Johnson, Dave Koweek. Fourth row: Maria Rugenstein, Theo van de Sande, Min Chen, Matthew Shaner, Scot Miller, Loreli Carranza-Jíminez, Michael Mastrandrea, Yoichi Shiga, Jessamy Barker, Grayson Badgley, Daniel Cullenward, Freddie Draper.

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JOSEPH A. BERRY
KENNETH CALDEIRA
CHRISTOPHER B. FIELD, Director
ANNA MICHALAK

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ALAN P. BOSS
R. PAUL BUTLER
RICHARD W. CARLSON, Director
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PETER E. DRISCOLL[1]
JOHN A. GRAHAM, Emeritus
ERIK H. HAURI
ALAN T. LINDE, Emeritus[2]
LARRY R. NITTLER
DIANA C. ROMAN
I. SELWYN SACKS, Emeritus
SCOTT S. SHEPPARD
STEVEN B. SHIREY
SEAN C. SOLOMON, Director Emeritus[3]
FOUAD TERA, Emeritus
PETER E. VAN KEKEN[4]
LARA S. WAGNER
ALYCIA J. WEINBERGER

THE DEPARTMENT OF TERRESTRIAL MAGNETISM »

Earth/Planetary Science and Astronomy

Front row (left to right): Janice Dunlap, Jonathan Gagné, Steven Golden, Casey Leffue, Tri Astraatmadja, Winston (dog), Lara Wagner, Wan Kim, Alycia Weinberger. Second row: Timothy (T.J.) Rodigas, Adelio Contreras, Otto Medina, Fouad Tera, Daniela Power, Gary Bors, Myriam Telus, Maggie Thompson, Hélène Le Mével, Merri Wolf, My Riebe, Peter Driscoll, Christopher Thissen, Stephan Lachowycz, Cian Wilson. Back row: Quintin Miller, Alan Boss, Bill Key, Maceo Bacote, Tyler Bartholomew, Brian Schleigh, Kevin Johnson, Rick Carlson, Diana Roman, Steve Shirey, Erika Nesvold, Robin Dienel, Tim Mock, Jianhua Wang, Stephen Richardson, Liyan Tian, M.A. O'Donnell.

Image courtesy Stephanie Clark

Merle A. Tuve Senior Fellow

JACQUELINE DIXON, Dean, College of Marine Science at University of South Florida[5]

[1] From August 1, 2015
[2] From July 31, 2015
[3] On leave of absence
[4] From January 1, 2016
[5] From March 3, 2016, to April 22, 2016

Plant Science

First row (left to right): Theo van de Sande. Second row: Ronald Halim, Devaki Bhaya, Wei-Feng, unnamed intern, Sue Rhee, Vivian Chen, Jiaying Zhu, Nina Ivanova, Xiaobo Li, Chris Chen, Xuelian Yang. Third row: Lina Duan, José Sebastian, Jebasingh Selvanayagam, Liz Freeman, Kathryn Barton, Matt Evans, Kathi Bump, XiaoQing Qu, Wolf Frommer, Wenqiang Yang. Fourth row: Yuval Kaye, Cheng-Hsun Ho, Jessica Foret, Vanessa Castro-Rodríguez, Aurelie Grimault, Evana Lee, Veder Garcia, Martin Jonikas, Dahlia Wist, Robert Jinkerson, Ted Raab, Shixuan Li. Fifth row: Sarah Fajon, Shai Saroussi, Lily Cheung, Heike Lindner, Joëlle Sasse-Schläpfer, Masayoshi Nakamura, Pascal Schlapfer, Susan Cortinas, Naoia Williams, Josep Vilarasa-Blasi, Tingting Xiang, José Dinneny, Alan Itakura, Ismael Villa. Sixth row: Friedrich Fauser, Tyler Wittkopp, Diane Chermk, Taylor Marie, Yan Gong, Matt Prior, Joon-Seob Eom, Man Ao, Peifen Zhang, Ankit Walia, M.C. Yee, Heather Cartwright, Wei-Chuan Kao, Thomas Hartwig, Arthur Grossman. Seventh row: Haojie Jin, Anchal Chandra, Adam Iodine, Sophia Xu, Hong Bo Ye, Jitze Jelmer Lindeboom, Antony Chettoor, Jacob Robertson, Neil Robbins, Michelle Davison, Eunkyoo Oh, Flavia Bossi, Jennifer Scerri, I Lin, Rick Kim, Bi Yang, Sunita Patil, Michael Banf, Chuan Wang, Chanho Park. Last row: Tuai Williams, Maria Slade.

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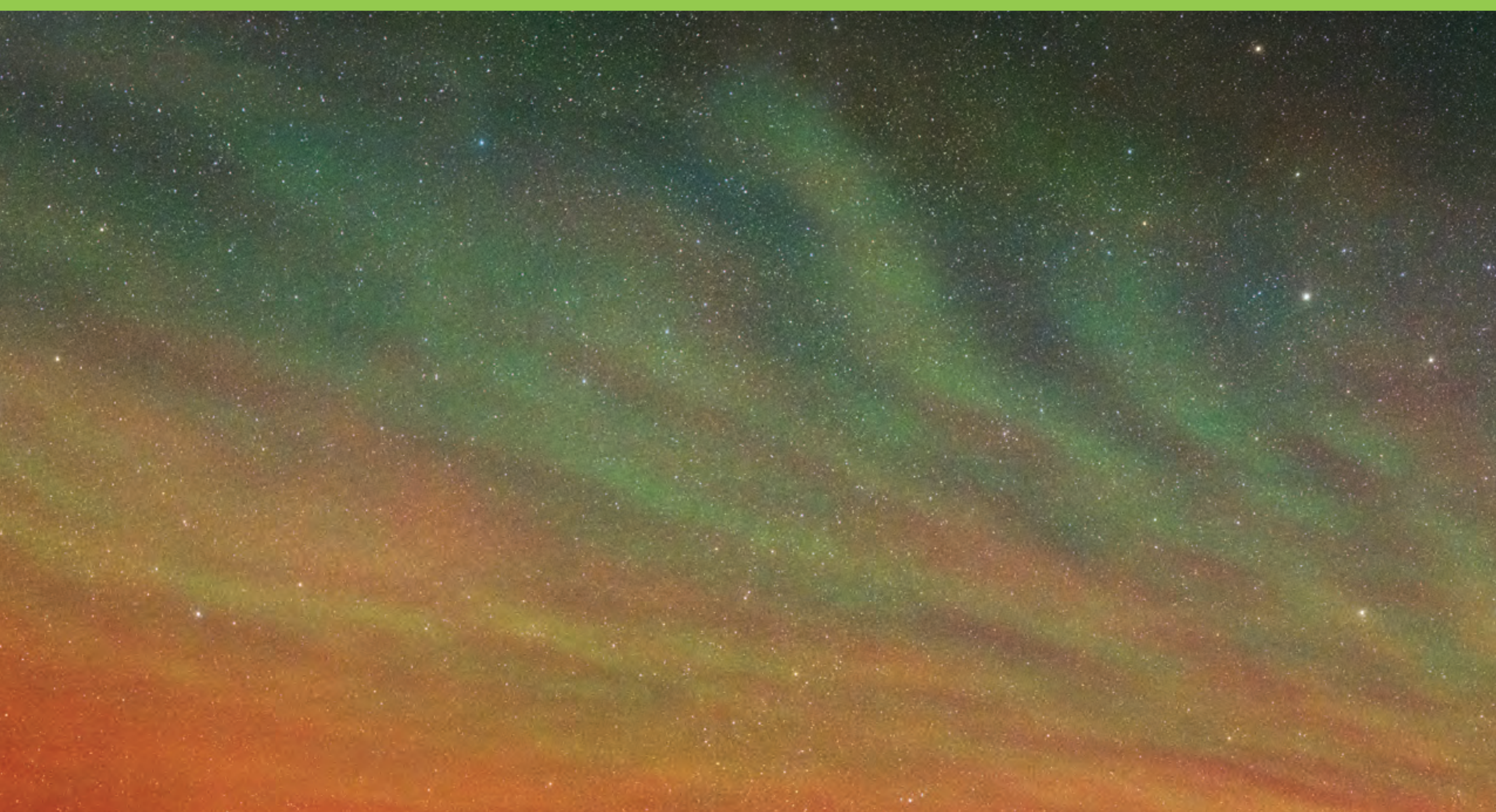
- ZHI-YONG WANG

Adjunct Staff
- DEVAKI BHAYA
- MATTHEW EVANS

Young Investigator
- MARTIN JONIKAS

Senior Investigator
- THEODORE RAAB



« CARNEGIE SCIENCE

Administration

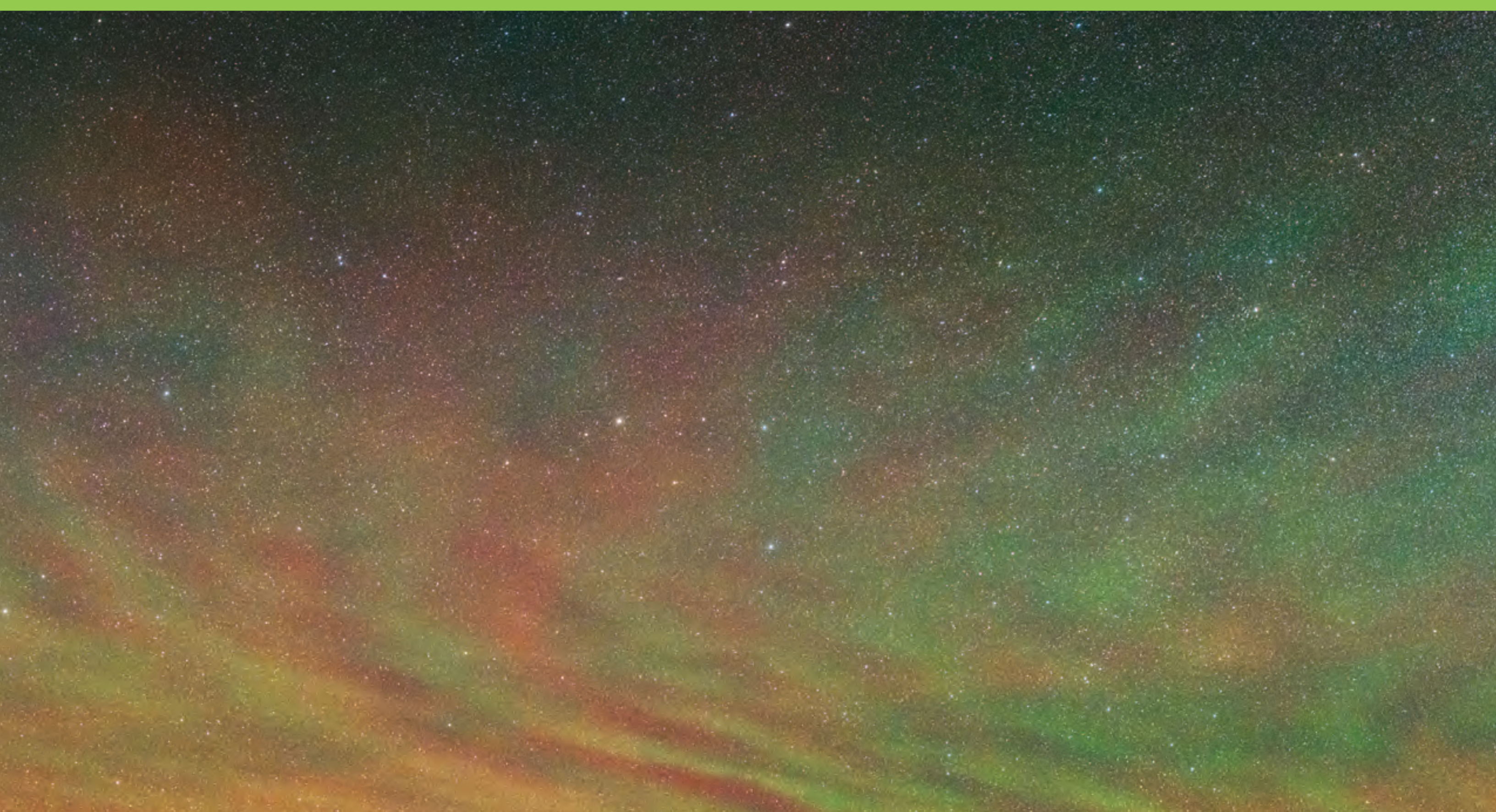
Front row (left to right): Dione Rossiter, June Napoco-Soriente, Dina Freydin, Jessica Moore, Shaun Beavan, Rosi Vela, Jackie Williams, Ana Lojanica, Alexis Fleming, Tamar Lolua, Abby Sevcik, Lara Budeit, Nibret Daba, Shanique Washington, Natasha Metzler, Jessica Cima, Yulonda White, Loronda Lee, Matthew Scott. Back row: Don Brooks, Harminder Singh, Ann McElwain, Timothy Doyle, Tom McDonaugh, Benjamin Aderson, Yang Kim, Michael Pimenov, John Strom, Benjamin Barbin, Michael Stambaugh, Brian Loretz, Susanne Garvey, Tina McDowell, Brady Stovall, Alicia North.

Image courtesy Matthew Scott

Senior Administrative Staff

MATTHEW P. SCOTT, President
TIMOTHY DOYLE, Chief Operating Officer
ANN MCELWAIN, Chief Development Officer[1]
MICHAEL STAMBAUGH, Chief Investment Officer[2]
BENJAMIN ADERSON, General Counsel[3]

[1] From July 1, 2016
[2] From March 28, 2016
[3] From August 15, 2016



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