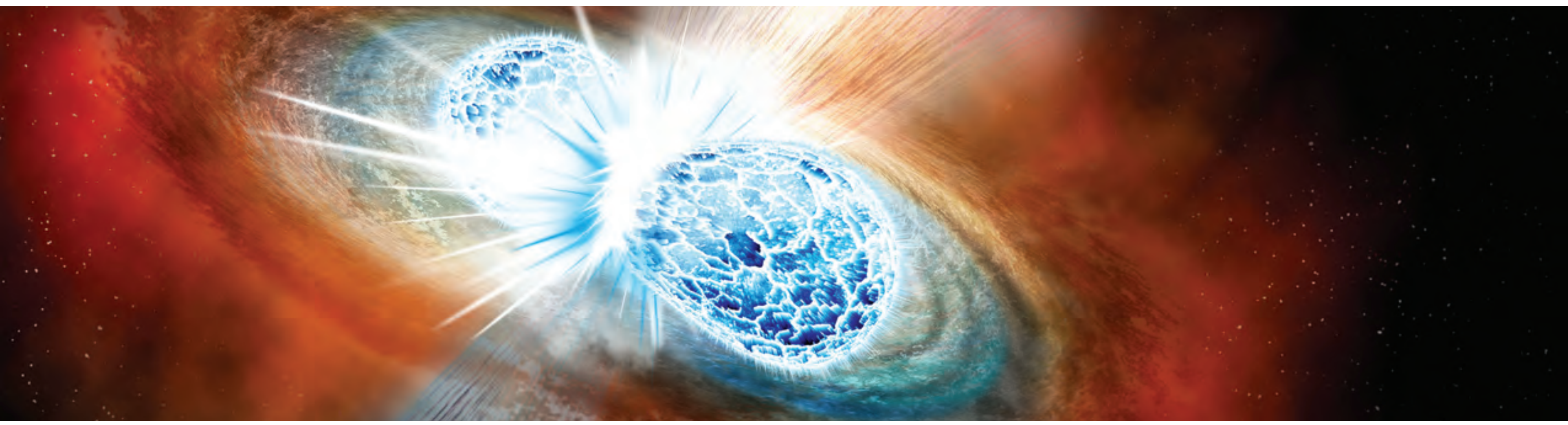
Carnegie Science

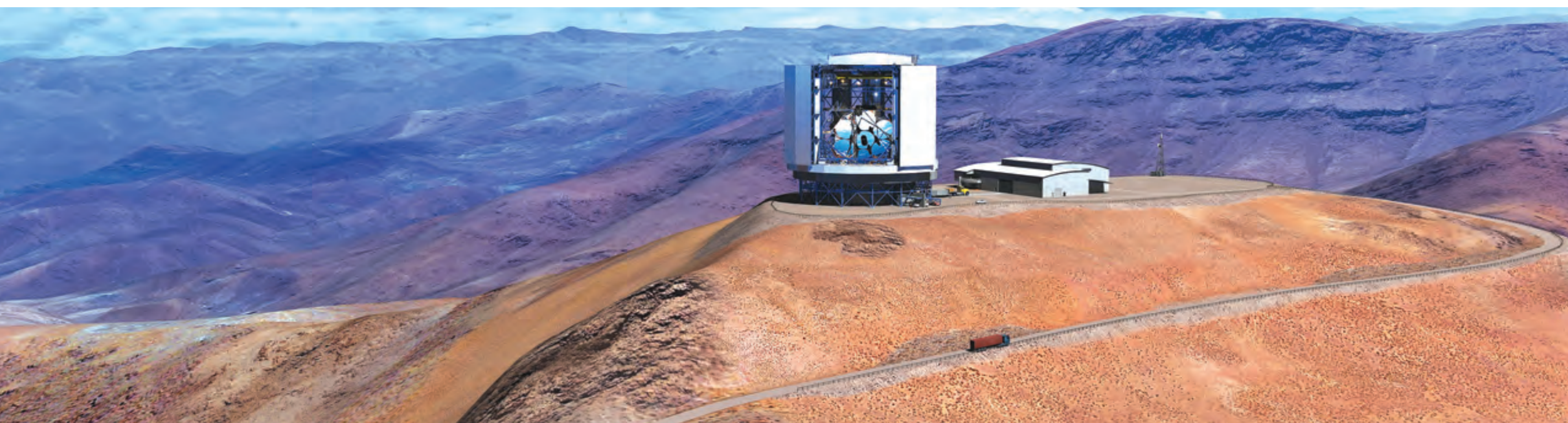
The Newsletter of the Carnegie Institution for Science

SPRING 2018

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



On the Inside



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1530 P Street, NW
Washington, D.C. 20005-1910
202.387.6400

LETTER FROM INTERIM CO-PRESIDENTS

John Mulchaey and Yixian Zheng

As many of you know, the Carnegie Board of Trustees announced that we would serve together as Carnegie interim co-presidents starting January 1, 2018, after the retirement of Carnegie President Matthew Scott. We will also continue to serve as department directors of the Observatories and the Department of Embryology, respectively.

In addition to our service as co-presidents, we are members of the search committee for the new Carnegie president. We are honored to be serving in these new capacities both to provide continuity in institutional leadership and management and to ensure that the candidates for the next Carnegie president meet the highest scientific and managerial standards.

Although we have only been serving for a short time, both of us have been particularly delighted by the in-depth education we are experiencing with our immersion into the wide range of Carnegie science and the inner business workings of the institution. Our own research 'bookends' Carnegie science, from genetics and molecular biology to the large-scale workings of the universe. But there is much we do not know in between, and we view our education as vital to better understand the role of the next president.

Some of the exciting studies that we have learned more about include the high-pressure, high-temperature experiments at the Geophysical Laboratory, which—with modeling at Terrestrial Magnetism—are yielding insights into the dynamics and evolution of deep planetary interiors, including massive super-Earths. Other similar experiments could lead to the creation of new materials, with applications ranging from aerospace engineering and military armor to much more.

The spectranomics database at Global Ecology is another example. It has just celebrated its 10th anniversary and represents a new pathway for science and conservation mapping. Spectranomics is a technique to map the biodiversity and functioning of forests using the fixed-wing Carnegie Airborne Observatory in breathtaking detail. It senses canopy chemistry and functional properties to understand species' interactions, among other things. The new database now includes about half of the world's known tropical canopy species, and its advanced system will integrate into future satellite mapping missions.

Another fascinating project that crosses disciplines, from remote ecological mapping to genetics, is about corals. The objective is to better understand how corals—vital to the world's food chain—are faring and how they can survive, adapt, and evolve with increasing environmental onslaughts. This is just the kind of work that the institution is likely to pursue more: cross-disciplinary investigations that delve deep into understanding the biological and physical world around us.

In addition to our ongoing education, we are advancing the work of the president's search committee. The committee, including five trustees, has elicited input from the other department directors, the scientific staff, postdocs and students, and support personnel by holding meetings at all the departments, among other activities. Our objective is to ensure that the qualities of the next president are the best possible fit with our science and culture and that the individual possesses a scientific vision for our future, has strong management abilities and interpersonal skills, and exceptional enthusiasm for Carnegie science to expand our support network.

With only 10 former presidents in our 116-year history, we take this task very seriously. We all have the same goal—to conduct the best unfettered science possible so that we flourish as our second century unfolds. We all want to advance our mission of improving humankind through discovery.

John Mulchaey and Yixian Zheng
Interim Co-presidents

Image courtesy Juna Kollmeier and Hans-Walter Rix, SDSS-V

New Survey to Map the Entire Sky!

Carnegie's Juna Kollmeier will direct the next generation of the Sloan Digital Sky Survey (SDSS-V) to map the entire sky, following a $16-million grant from the Alfred P. Sloan Foundation. The grant will kick-start a groundbreaking all-sky spectroscopic survey, anticipated to start in 2020.

This artist's impression shows a cutaway view of the parts of the universe that the Sloan Digital Sky Survey-V (SDSS-V) will study. SDSS-V will study millions of stars to create a map of the entire Milky Way. Farther out, the survey will get the most detailed view yet of the largest nearby galaxies like Andromeda in the Northern Hemisphere and the Large Magellanic Cloud in the Southern Hemisphere. Even farther out, the survey will measure quasars—superbright objects powered by matter falling into giant black holes.

Image courtesy Robin Dienel/Carnegie Institution for Science/SDSS

Theoretical astrophysicist Juna Kollmeier will lead the next generation Sloan Digital Sky Survey (SDSS-V) to map the entire sky.

Image courtesy Cindy Hunt

The Sloan Digital Sky Survey series has been one of the most successful and influential surveys in the history of astronomy, creating the most detailed three-dimensional maps of the universe ever made, with deep multicolor images of one-third of the sky and spectra for more than three million astronomical objects. The spectra of light hold information on celestial object chemistry, composition, age, and more.

Under Kollmeier's leadership, the survey's fifth generation will build off the earlier surveys and pioneer all-sky observations and monitor changes in a million objects. "With observations in both hemispheres, no part of the sky will be hidden from SDSS-V," Kollmeier said.

In the tradition of previous Sloan Survey generations, SDSS-V will make its data publicly available for all to use.

SDSS-V will make use of both optical and infrared spectroscopy, observing in two hemispheres of light. The survey operates out of Apache Point Observatory in New Mexico, home of the survey's original 2.5-meter telescope, and Carnegie's Las Campanas Observatory in Chile, where it uses Carnegie's du Pont telescope.

"Las Campanas Observatory will channel its best resources to enable outstanding science from SDSS-V," remarked Leopoldo Infante, director of the observatory.

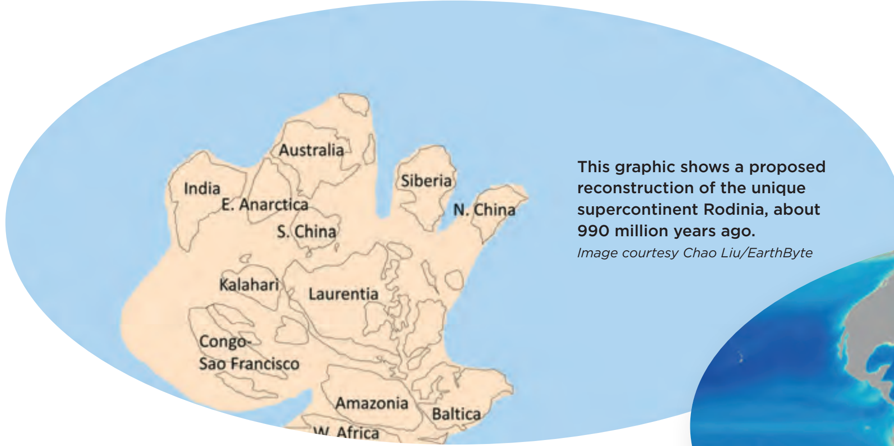
The survey will take advantage of the recently installed second APOGEE spectrograph on Carnegie's du Pont telescope. Both it and its twin on Apache Point penetrate the dust that confounds optical spectrographs to obtain high-resolution spectra for hundreds of stars at infrared wavelengths. In the optical wavelengths, the survey's twin BOSS spectrographs can obtain simultaneous spectra for 500 stars and quasars. A newly envisioned pair of integral field unit spectrographs can each obtain nearly 2,000 spectra contiguously across objects in the sky.

SDSS-V will consist of three projects, each mapping different components of the universe: the Milky Way Mapper, the Black Hole Mapper, and the Local Volume Mapper. The first focuses on the formation of the Milky Way and its stars and planets. The second will study the formation, growth, and ultimate sizes of the supermassive black holes at galaxy centers, while the third will create the first complete spectroscopic maps of the most iconic nearby galaxies. ■

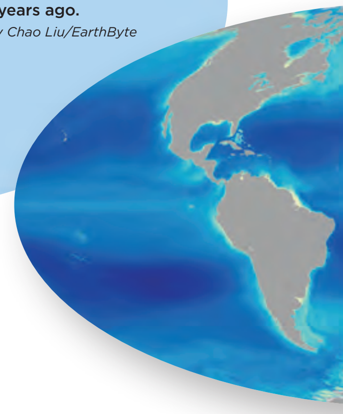
SUPPORT AND COLLABORATORS:
Funding for the Sloan Digital Sky Survey (SDSS)-IV has been provided by the Alfred P. Sloan Foundation, the U.S. Department of Energy Office of Science, and the SDSS Participating Institutions. SDSS acknowledges support and resources from the Center for High-Performance Computing at the University of Utah. The SDSS web site is www.sdss.org.

SDSS is managed by the Astrophysical Research Consortium for the Participating Institutions of the SDSS Collaboration.

The project's fifth generation is building its consortium, but it already has support from 18 institutions including Carnegie Institution for Science, Max Planck Institute for Astronomy, Max Planck Institute for Extraterrestrial Physics, the University of Utah, Israeli Centers of Research Excellence, the Kavli Institute for Astronomy and Astrophysics at Peking University, Harvard University, the Ohio State University, the Pennsylvania State University, Georgia State University, University of Wisconsin, the California Institute of Technology, New Mexico State University, Space Telescope Science Institute, University of Washington, Vanderbilt University, University of Warwick, Leibniz-Institut für Astrophysik Potsdam, KU Leuven, Monash University, and Yale University, with additional partnership agreements underway.



This graphic shows a proposed reconstruction of the unique supercontinent Rodinia, about 990 million years ago.
Image courtesy Chao Liu/EarthByte



RODINIA

A SUPERCONTINENT THAT'S DIFFERENT

Pangaea, a well-known supercontinent that included all continents on Earth, began to break up about 175 million years ago. But the cycle of Earth's landmasses ripping apart and colliding had been occurring for the 3 billion years before, affecting the planet's geography, climate, and carbon cycles.

Each supercontinent has its quirks, but Rodinia, which assembled 1.3 to 0.9 billion years ago and then broke up about 0.75 billion years ago, is particularly odd. A study led by Carnegie's Chao Liu and Robert Hazen (also Deep Carbon Observatory Executive Director), and Harvard University's Andrew Knoll, described why Rodinia is so unusual in *Nature Communications*.

When looking for evidence of past supercontinents, geologists love grains of zircon, a diamond-resembling, durable mineral from melted rocks at high temperatures.

ENTER ZIRCON

"Zircons are so robust that they survive most geologic events," said Liu. Like other supercontinents, the number of zircon grains increased during formation and decreased during breakup of Rodinia. "However, zircon is only one of more than 5,000 different kinds of Earth minerals. We thought, maybe we can look at the distribution of other minerals through time to see if they're different from zircon."

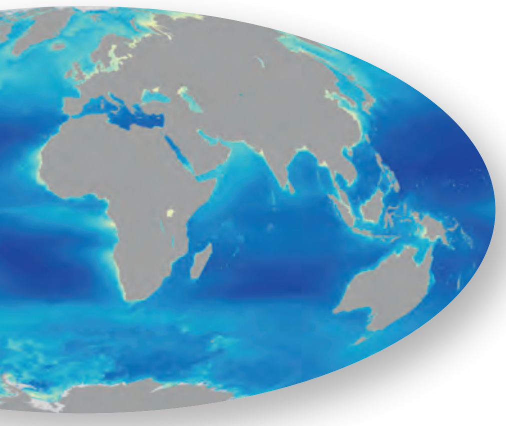
Liu and colleagues compiled global records of high-temperature minerals, going back 3 billion years. They also analyzed data of trace element concentrations in magmatic rocks—rocks from melted magma—to identify how mineral distribution changes over time. The mineral data revealed patterns that were similar to zircon, with peaks associated with supercontinent assembly. However, the one exception—Rodinia—had fewer total mineral occurrences compared to the others.

The research showed that Rodinian minerals bearing niobium and yttrium showed similarly high peaks to zircons. These peaks nicely couple with higher global concentrations of yttrium, niobium, and zirconium in magmatic rocks of Rodinia, when compared to all other supercontinents.

POSSIBLE FORMATION

The researchers propose that during its formation, Rodinia may have experienced limited arc magmatism—a type of volcanic activity typical during supercontinent assembly. This is associated with subduction, where one tectonic plate sinks beneath another and creates volcanic arcs across the Earth, like the Aleutian Islands and mountains like the Himalayas. Such tectonic events usually carry signatures of very little zirconium, yttrium, and niobium. Instead, Rodinian geochemistry, mineralogy, and petrology all point to widespread non-arc magmatism.

To explain the dwarfed mineral records for Rodinia, the researchers speculate that there might have been extensive



This NASA SeaWiFS image shows the Earth's continents today.
Image courtesy Robert Simmon/ SeaWiFS/NASA

erosion of the Rodinian volcanic arcs and mountain belts, which could be due to the style in which Rodinia was formed, a process called extrovert assembly. After a supercontinent splits apart, the pieces can come together through either introvert or extrovert assembly. In introvert assembly, the tectonic plates drift back and merge again. With extrovert assembly, the continents drift farther apart and meet up on the other side of the planet. Longer travel distance during extrovert assembly may have led to greater erosion of plate margins. The extrovert assembly of Rodinia may also have included two-sided subduction, where both colliding plates sink into the mantle, further dooming mineral preservation.

The speculated enhanced erosion of Rodinia would have significantly affected global carbon cycling, because weathering is a major sink of atmospheric carbon dioxide.

NEXT STEPS

The researchers, with ore geologist Simone Runyon, a Carnegie postdoctoral researcher, will examine the enhanced erosion speculation carefully. "We're trying to find out the formation temperature, pressure, and depth of all the Rodinian minerals and compare that with minerals formed during the formation of other supercontinents," said Liu. "I think that's going to be very interesting." ■

Carnegie's postdoctoral associate Chao Liu was lead author on the study.
Image courtesy Michelle Scholtes

Miki Nakajima Receives Postdoctoral Innovation and Excellence Award

Carnegie's Miki Nakajima

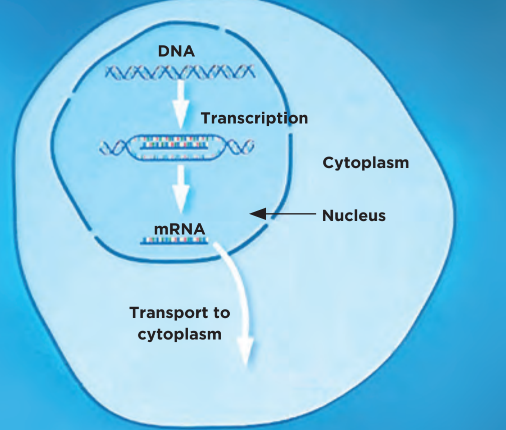
Department of Terrestrial Magnetism (DTM) postdoctoral researcher Miki Nakajima was awarded the eighth Postdoctoral Innovation and Excellence Award (PIE). These awards are made through nominations from the departments and are chosen by the Office of the President. The recipients receive a cash prize for their particularly creative approaches to science, mentoring, and contributing to the sense of campus community.

Nakajima is a planetary geophysicist who joined Carnegie in 2015 with her Ph.D. from the California Institute of Technology. She uses computational approaches to study the formation of planets and their satellites to predict the dynamics of planetary impacts and how these impacts affect the young planetary objects across traditional disciplines.

Nakajima is an innovative modeler, adopting multiple methods and developing benchmarks for accuracy tests. She enhances modeling with new techniques for planet formation and internal planetary evolution.

Her work on the large, Moon-forming impact predicts that afterward the Earth was mostly stratified, important to the initial evolution and dynamic mixing of the Earth's mantle and core. She demonstrated that volatile loss was inefficient after the impact. This helps to resolve the dilemma that, even though the impact should have boiled off all vapor, DTM measurements of lunar rocks show they retained water.

Nakajima organizes activities that range from annual poster sessions to interdisciplinary reading groups. She also serves as a postdoctoral representative and hosts international visitors. She received her M.S. and B.S. in Earth and planetary sciences from the Tokyo Institute of Technology, and she will be an assistant professor at the University of Rochester in the fall of 2018. ■



The first step of gene expression—turning a gene on—is transcription. It occurs in the cell nucleus (above) where a segment of DNA is copied into a complementary bit of RNA, which in turn forms a specific protein.
Image courtesy National Library of Medicine (adapted)

Research scientist Jennifer Anderson (left) with Steve Farber and team used the model organism zebrafish (above) to understand why expected physical changes induced by the CRISPR/Cas9 mutation technique do not always occur.
Left image courtesy Jennifer Anderson and Miriam Alexander-Kearns, above image courtesy the Halpern lab

Zebrafish Teach Us About Mutation and Survival

Not long ago, biologists would induce mutations in an entire genome, identify an organism with a disease or abnormality, and then work backward to determine which gene was responsible for the defect. This process often took years for definitive results.

Now, thanks to the CRISPR/Cas9 genome-editing tool, biologists can first target specific genes for mutation, then see how an induced mutation manifests in an organism—tackling the problem from the other direction, more directly. But they are finding that the expected physical changes don't always occur.

Carnegie's Steven Farber and Jennifer Anderson asked why. They looked at how to circumnavigate one kind of resistance to harmful mutations that's found in the vertebrate zebrafish.

Sometimes an organism compensates for a mutation in a gene by changing how it regulates the expression of other related genes. Other times, cells skirt errors in the process by which a gene is transcribed from DNA into RNA—the first step in gene expression—and is then translated from RNA into a protein to compensate for a mutation.

For example, Anderson and her colleagues described cases wherein cells were able to generate RNAs that survived by splicing out a harmful mutation. These cells would be expected to produce a protein that is missing a small piece.

"The result may not be perfect, but these compensating measures mean that the organisms can get some of the job done with a less-than-perfect protein," Farber said. "These work-arounds show that from an evolutionary perspective, we have some pretty robust mechanisms in place to keep surviving despite mutations."

This raises questions about how to best generate mutations to understand the genetic basis of disease—keeping the efficiency of modern methods but find a way to account for some of an organism's own work-arounds, which can interfere with scientists' ability to induce a mutation.

The team found that a good way to hunt out these kinds of genomic work-arounds is to look at the RNA phase, which is the intermediary between gene and protein.

"Our work shows that conducting analysis on the RNA level can help us better understand how to not only interpret but also design targeted mutations," Farber added. "We provide guidelines to increase chances that a researcher will disrupt a gene of interest and ultimately characterize its function. This type of approach accelerates the development of diagnostics and therapeutics for a host of human diseases and disorders."

The research team also included Carnegie's Timothy Mulligan and Meng-Chieh Shen, as well as collaborators from the Du lab (University of Maryland School of Medicine) and the Busch-Nentwich lab (Wellcome Sanger Institute). ■

SUPPORT:
The National Institute of Diabetes and Digestive and Kidney Diseases; the National Institute of General Medical Sciences; the Wellcome Sanger Institute; a research fund from the University of Maryland, Baltimore; a Shandong Provincial Education Company for International Exchange visiting professorship; the Carnegie Institution for Science Endowment; and the G. Harold and Leila Y. Mathers Charitable Foundation supported this research and researchers in part.

Water Plus Iron Created Life?

Reservoirs of oxygen-rich iron between the Earth's core and mantle could have played a major role in Earth's history, including the breakup of supercontinents, drastic changes in Earth's atmosphere, and the creation of life, according to recent work from an international research team published in *National Science Review.*

The team—including scientists from Carnegie, Stanford University, the Center for High Pressure Science and Technology Advanced Research in China, and the University of Chicago—probed the chemistry of iron and water under the extreme temperatures and pressures of the Earth's core-mantle boundary.

When the action of plate tectonics draws water-containing minerals down deep enough to meet the Earth's iron core, the extreme conditions cause the iron to grab oxygen atoms from the water molecules, setting the hydrogen atoms free. The hydrogen escapes to the surface, but the oxygen gets trapped into crystalline iron dioxide, which can only exist under such intense pressures and temperatures.

Using theoretical calculations and laboratory experiments to recreate the intense environment, the team determined that iron dioxide can be created under pressures between about 950 and 1 million times normal atmospheric pressure and more than 3500°F. They used a laser-heated diamond anvil cell to create these conditions.

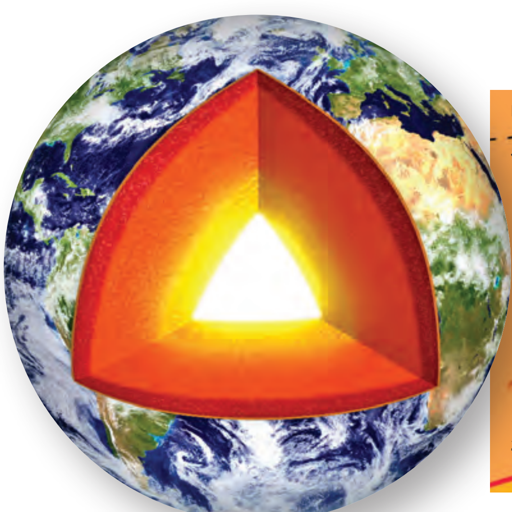
"Based on our knowledge of the chemical makeup of the slabs that are drawn into the Earth's deep interior by plate tectonics, we think 300 million tons of water could be carried down to meet iron in the core and generate massive iron dioxide rocks each year," said lead author Carnegie's Ho-kwang "Dave" Mao.

These extremely oxygen-rich solid rocks may accumulate steadily year-by-year above the core, growing into gigantic, continent-like sizes. A geological event that heated up these iron dioxide rocks could cause a massive eruption, suddenly releasing extensive oxygen to the surface.

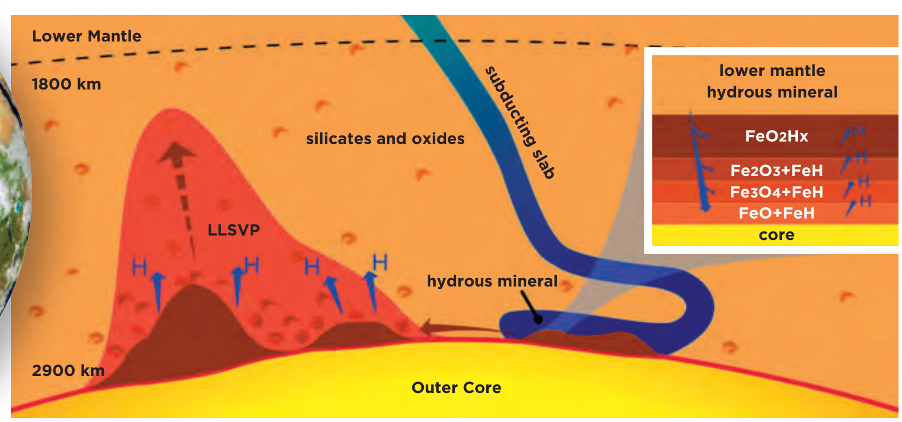
The authors hypothesize that such an oxygen explosion could put a tremendous amount of the gas into the Earth's atmosphere—enough to cause the so-called Great Oxygenation Event, which occurred about 2.5 billion years ago and created our oxygen-rich atmosphere that kick-started the rise of oxygen-dependent life.

"This newly discovered high-temperature and intense-pressure water-splitting reaction affects geochemistry from the deep interior to the atmosphere," said Mao. "Many previous theories need to be re-examined now." ■

Carnegie's Dave Mao, a pioneer in high-pressure/high-temperature research, was lead author on this international study.
Image courtesy Dave Mao

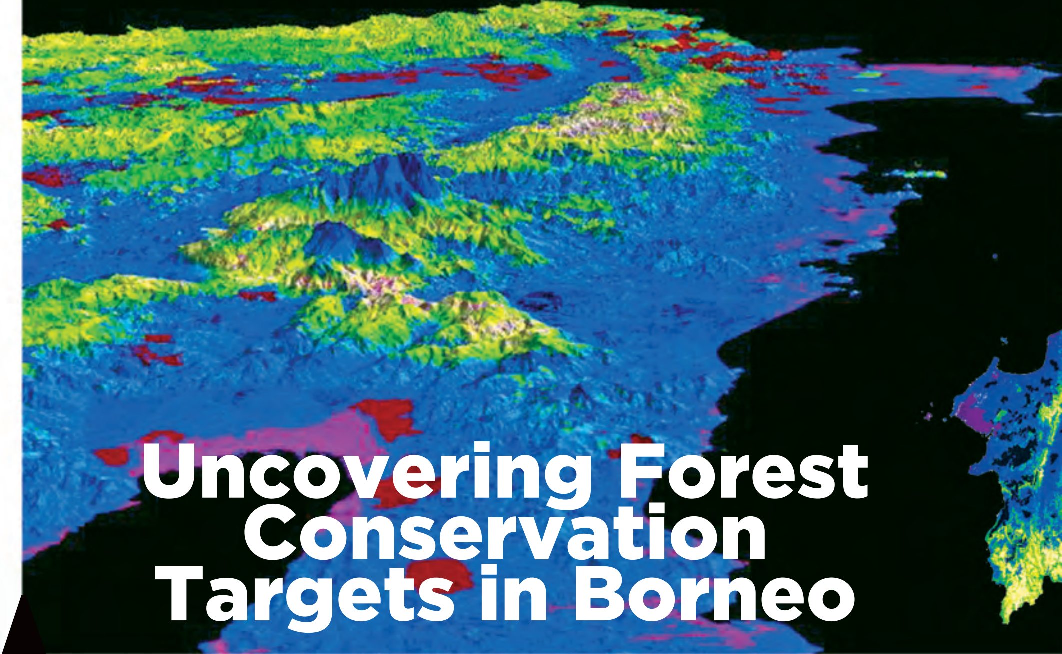


The team used theoretical calculations and laboratory experiments to recreate the environment of the core-mantle boundary (yellow to orange) in Earth's interior.
Image courtesy NASA



This diagram shows oxygen and hydrogen cycling in the deep Earth, as described in the paper.
Image courtesy Mao, et al., National Science Review

SUPPORT:
The National Science Foundation of China, the U.S. Department of Energy, and the U.S. National Science Foundation funded this work.



Uncovering Forest Conservation Targets in Borneo

The island of Borneo (red) is located in Southeast Asia and is home to Indonesia and Malaysia.
Image courtesy Free World Maps

Carnegie's Greg Asner leads the Carnegie Airborne Observatory project.
Image courtesy Robin Kempster

About 40% of northern Malaysian Borneo's carbon stocks exist in forests that are not designated for maximum protection, according to new remote sensing and satellite mapping from Carnegie's Greg Asner and colleagues.

Asner's flying laboratory, the Carnegie Airborne Observatory (CAO), mapped carbon stocks that—together with satellite imaging and other geospatial data—will guide conservation efforts undertaken by the Sabah Forestry Department in Malaysian Borneo, the South East Asia Rainforest Research Partnership (SEARRP), the PACOS Trust, BC Initiative, and other organizations.

"We are proud to be part of this groundbreaking endeavor in the state of Sabah, which sets us apart in accelerating the quest and capacity to protect, restore, and conserve more high-conservation and high-carbon forests in this country," said Sam Mannan, Chief Conservator of Forests. "This project is of immense value to tropical forest management."

Why is measuring carbon stocks so important? Because tropical forests like those in the Sabah have converted large quantities of atmospheric carbon into organic material, and they accomplish more of this than any other terrestrial ecosystem on Earth. But when this forest land undergoes agriculture, logging, or mining, carbon is released into the atmosphere, contributing to climate change. Tropical deforestation and forest degradation account for about a tenth of the world's carbon emissions each year.

So, figuring out which segments of Sabah's forests contain the most carbon in the form of biomass is an important first step in helping the government meet its goal of increasing protected forests from 1.8 to 2.2 million hectares.

"The nearly 4 million hectares of Sabah's forests are a kaleidoscope of many different habitats and management histories, which required a wall-to-wall mapping effort to truly quantify the amount of carbon they contain," Asner explained.

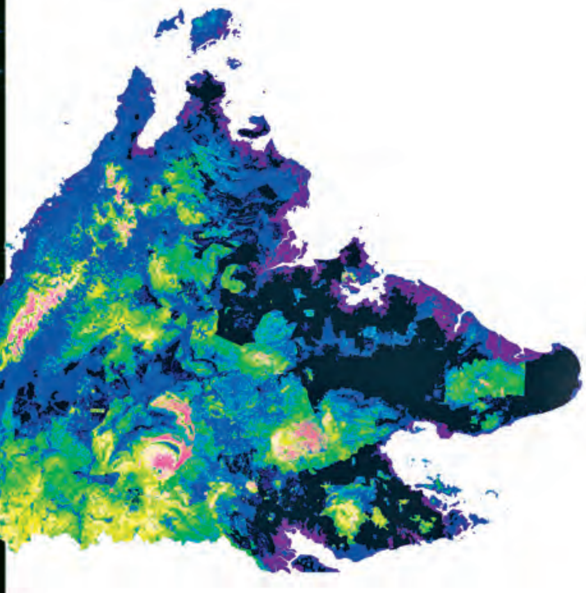
Using the CAO's signature technique—airborne laser-guided imaging spectroscopy—integrated with satellite imaging and other geospatial data, Asner and his team provided high-resolution maps of Sabah's forests. In addition to finding 50 of the tallest tropical trees ever measured, the CAO team pinpointed important targets for conservation.

They found that about 40% of the state's carbon is contained in forests that are not protected at the highest designation. What's more, they discovered that Sabah could double carbon stocks by allowing previously logged forests to regenerate—a process estimated to take about a century.

SEARRP's Glen Reynolds said, "It's a rare opportunity to work with state-wide datasets of this quality. By integrating the CAO maps with ground-based biodiversity data and information on the use of forests by local people, we should be uniquely well placed to identify hundreds of thousands of new conservation areas in Sabah that not only protect key habitats, but also the livelihoods of forest-dependent communities."

"Forest carbon is an important factor in locating places where conservation efforts could make the greatest impact," Asner added. "But other data on canopy biodiversity and animal habitats, such as our work on Bornean orangutans, will also help inform decision makers." ■

SUPPORT:
The United Nations Development Programme, Avatar Alliance Foundation, Roundtable on Sustainable Palm Oil, World Wide Fund for Nature, Morgan Family Foundation, Natural Environment Research Council, and the Rainforest Trust supported this study.



The aboveground carbon density (ACD) is shown throughout the state of Sabah in Malaysian Borneo. The spatial resolution is at about 100 feet (30 meters, 0.09 hectares). The areas with mangrove and oil palm plantation are masked out. Mapping forest carbon is an important step in identifying areas for conservation, but is tremendously difficult to accomplish without airborne and satellite technology.

Images courtesy Greg Asner CAO

Carnegie ecologist Greg Asner was awarded the 22nd Heinz Award in the Environment category on September 14, 2017, by the Heinz Family Foundation. Asner was recognized for developing and using airborne and space-borne ultra-high-resolution imaging technology to reveal in unprecedented detail the health and biodiversity of the world's forests and coral reefs. In addition, his work has detailed the extent of deforestation, land degradation, and climate change throughout many regions of the world. "His findings are helping to empower government agencies and nongovernment organizations, and to drive land use and environmental policy decisions in the United States and globally." An unrestricted award of $250,000 was part of this prestigious recognition. ■

Arizona State University Joins the Giant Magellan Telescope Organization

This artist's rendition shows the Giant Magellan Telescope at Carnegie's Las Campanas Observatory.

Image courtesy GMTO

EFFECTIVE APERTURE 24.5 METERS IN DIAMETER

Arizona State University (ASU) joined the Giant Magellan Telescope Organization (GMTO), to build the world's largest telescope, the GMT. The project's partnership with ASU will aid in GMT's mission of discovery and its quest to answer some of the most fundamental questions: where did we come from, and are we alone in the universe? The GMT will probe the atmospheres of planets around other stars for signs of biochemistry, and look back to understand how the first stars and galaxies formed.

"ASU's research expertise in the study of planets will be a great asset to the GMT project going forward," said Robert N. Shelton, president of GMTO. "The involvement of the ASU team with the James Webb Space Telescope and with the investigation of the early universe is also a critical addition to the knowledge base of the project."

ASU's School of Earth and Space Exploration (SESE) has established itself as a leading voice in the fields of exoplanets and space exploration by combining the strengths of science, engineering, and education.

"Major scientific advances are created by new instrumentation, and to be serious about studying our universe we need to join in these partnerships," said Linda Elkins-Tanton, director of SESE. "I'm excited that ASU has taken this leap institutionally to be a part of what's going to be a beautiful and transformational instrument."

The GMT will combine the light from seven 8.4-meter mirrors to create a telescope with an effective aperture 24.5 meters in diameter (80 feet) to produce images that are 10 times sharper than those from the Hubble Space telescope. The GMT is expected to be operational in 2023. ■

PARTNERS:
GMTO's partner institutions are Arizona State University, Astronomy Australia Ltd., Australian National University, Carnegie Institution for Science, Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), Harvard University, Korea Astronomy and Space Science Institute, Smithsonian Institution, Texas A&M University, the University of Texas at Austin, the University of Arizona, and the University of Chicago.

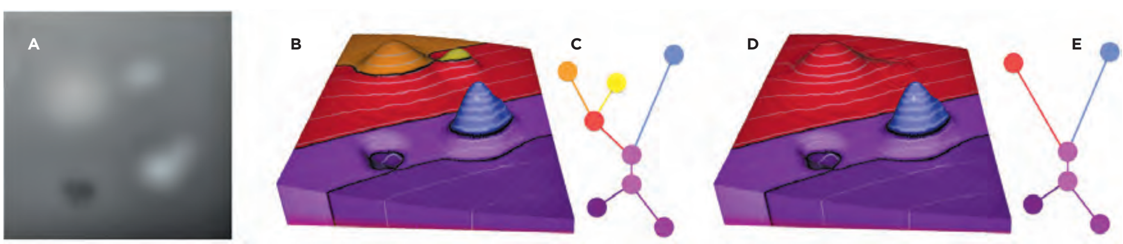
Venture Grants for Astrophysics and Geophysics

Carnegie Science Venture Grants, debuting in 2015, foster projects that ignore conventional boundaries and bring together researchers from different backgrounds with fresh eyes to explore novel questions. These projects are expected to yield surprising results. Each Venture Grant provides $100,000 support for two years. Trustee Michael Wilson, his wife Jane, and the Monell Foundation generously support these grants in part.

Astrophysical Data Extraction

One Venture Grant was awarded to Juna Kollmeier and Guillermo Blanc of the Observatories, who are collaborating to apply a new astronomical data extraction technique to optical astronomy data sets, which are currently inaccessible. The new techniques will produce superior visuals and analysis of distant astronomical objects.

Juna Kollmeier (left) and Guillermo Blanc (right), with others, will apply a new astronomical data extraction technique to optical astronomy to render superb visuals with rich data.



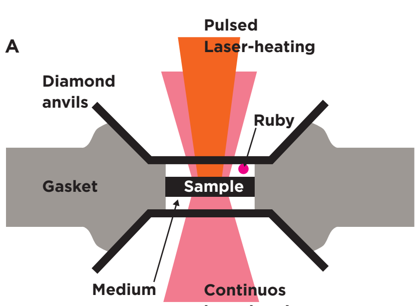
The images left show a 2-dimensional observation (A), which could be rendered using the new mathematical technique as a 2-D projection (C and E) of a 3-D structure (B and D) with much finer resolution.

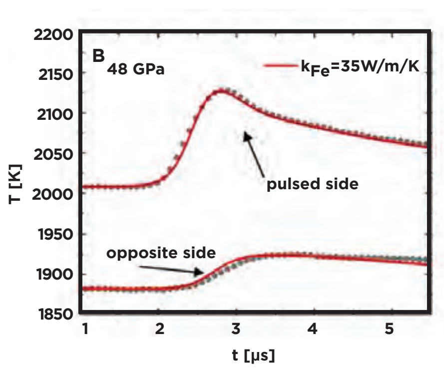
Images courtesy Juna Kollmeier and Guillermo Blanc

New Experiments to Model Mars' Thermal Evolution

A second Venture Grant was awarded to the Geophysical Lab's Alex Goncharov and Terrestrial Magnetism's Peter van Keken to apply a new flash-heating method for high-pressure/high-temperature experiments to measure the thermal conductivity of Mars. They will then develop new models to understand why that planet cooled so fast and early.

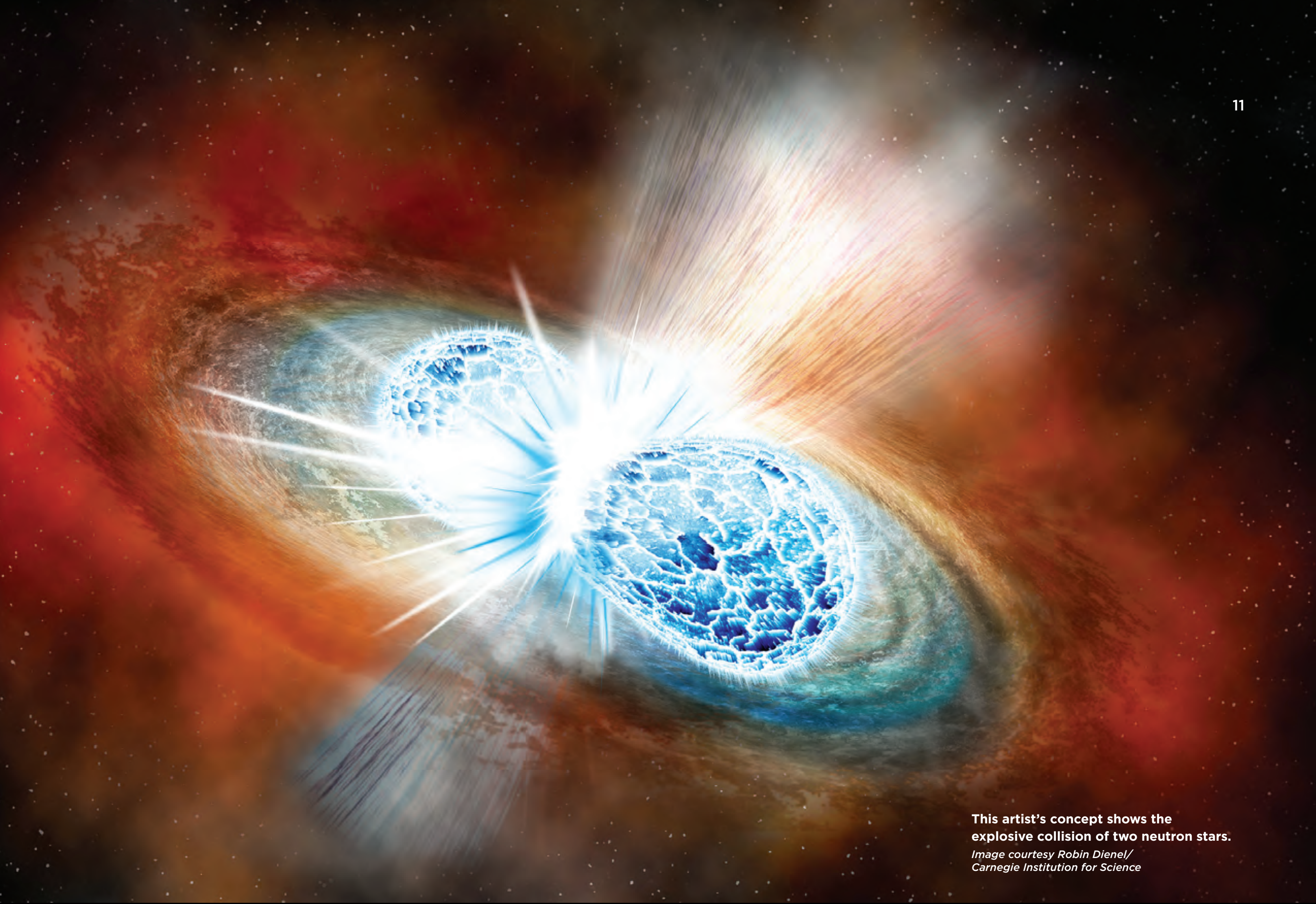
Alex Goncharov (left) and Peter van Keken (right) joined forces in experimentation and modeling to understand why Mars' geologic activity stopped so early.





The schematic far left shows the flash-heating method in a diamond anvil cell to measure thermal conductivity (left).

Images courtesy Alex Goncharov and Peter van Keken



This artist's concept shows the explosive collision of two neutron stars.
Image courtesy Robin Dienel/ Carnegie Institution for Science

WE SAW IT FIRST! TWO NEUTRON STARS COLLIDE

Carnegie Scientists Help Usher in New Era of Astronomy

On August 17, 2017, a team of four Carnegie astronomers provided the first-ever glimpse of two neutron stars colliding, opening the door to a new era of astronomy.

Along with colleagues at U.C.-Santa Cruz, the team used the Swope telescope at Carnegie's Las Campanas Observatory to detect the light produced by the merger, pinpointing the origin of a gravitational wave signal less than 11 hours after it was detected. They also obtained the earliest spectra of the collision, which may allow them to explain how many of the universe's heavy elements were created—a decades-old question for astrophysicists.

A quartet of *Science* papers published their discovery, named Swope Supernova Survey 2017a (or SSS17a).

Neutron stars are the incredibly dense remnants left behind after supernova explosions. Theoretical astrophysicists have speculated for years about what happens when two of them merge, but until now the phenomenon had never been witnessed.

"They are as close as you can get to a black hole without actually being a black hole," explained Carnegie's Tony Piro, the Carnegie team's leader. "Just one teaspoon of a neutron star weighs as much as all the people on Earth combined," he added.

Carnegie's scientists were alerted to the event by the Laser Interferometer Gravitational-Wave Observatory (LIGO), which detects gravitational waves, ripples in space-time, caused by distant cosmic events. In February of last year, the project announced the first detection of gravitational waves caused by two black holes merging—a discovery that was awarded the Nobel Prize in Physics last October.

While the LIGO black hole discovery marked an important

[CONTINUED ON PAGE 12]

This comparison of images shows the Swope Supernova Survey 2017a (or SSS17a) from the night of discovery, August 17, 2017, and four nights later, August 21.

Image courtesy Tony Piro

milestone, black hole mergers do not emit light and are therefore invisible to telescopes. Neutron star mergers, however, have long been expected to produce both light and gravitational waves, so the detection of these events was eagerly anticipated.

"The ability to study the same event with both gravitational waves and light is a real revolution in astronomy," Piro said. "We can now study the universe with two completely different probes, which teach us things we could never know with only one or the other."

On August 17, LIGO sent alerts for a gravitational wave detection from colliding neutron stars to observatories around the world, firing a "starter's pistol" in the race to spot the source of the space-time ripples.

Working with David Coulter, Charles Kilpatrick, and Ryan Foley of U.C.-Santa Cruz, the team began combing the night sky for evidence of a never-before-seen collision of neutron stars.

"We knew we only had about an hour at the beginning of the night to find the source before it set," explained Carnegie-Dunlap Fellow Maria Drout, who helped guide the discovery, "so we had to act fast."

Despite many large teams across the world working feverishly to find the event, it was the Carnegie and U.C.-Santa Cruz astronomers—a small, young group of researchers—who made the first discovery of SSS17a.

"We saw a bright blue source of light in a nearby galaxy, the first time the glowing debris from a neutron star merger had ever been observed," recalled Josh Simon, one of the Carnegie leaders on this discovery. "It was definitely a thrilling moment."

Because they were the first to find the event, Simon and Carnegie-Hubble Fellow Ben Shappee had time for additional observations. They quickly set up spectrographs at the observatory's two Magellan telescopes to obtain several spectra of the merger.

No other observatory in the world made comparable observations during that first night.

Spectra separate the light from a celestial object into its component wavelengths, just as a prism spreads sunlight into the colors of the rainbow. The light helps astronomers measure the speed and chemical composition of cosmic sources.

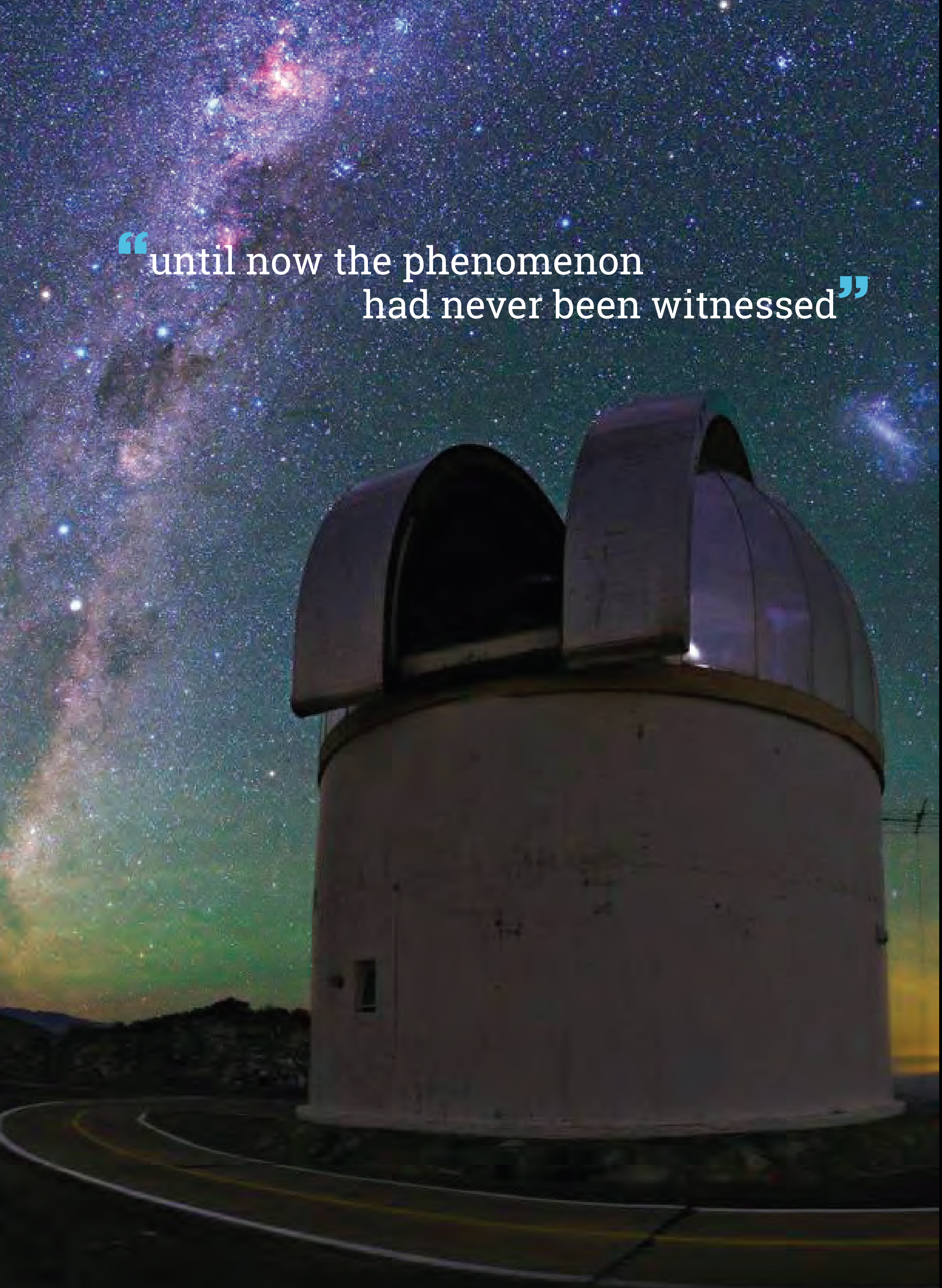
Scientists think that neutron star mergers create many heavy elements, such as gold, platinum, and uranium. But until now it has been impossible to confirm that idea.

"As we followed the glow of the explosion over the next few weeks, it showed some key characteristics of the radioactive decay of these heavy elements," Drout explained. "This strongly suggests that these elements were synthesized following the merger, solving a 70-year-old mystery."

"These first spectra are completely unique data and will lead to a lot of science down the road," added Shappee. "They will be extremely important for our understanding of neutron star mergers for years to come." ■

The Carnegie discovery team, with Observatories director John Mulchaey and theoretical astrophysicist Juna Kollmeier, held a panel discussion about the discovery of the neutron star collision during a dinner that accompanied the Carnegie Board of Trustees meetings in Pasadena in November. The researchers from left to right are John Mulchaey, Tony Piro, Ben Shappee, Maria Drout, and Juna Kollmeier.

Image courtesy Cindy Hunt



The Swope telescope, at Carnegie's Las Campanas Observatory, was where the collision of two neutron stars was seen for the first time ever on the night of August 17, 2017.

Image courtesy Yuri Beletsky

SUPPORT AND COLLABORATORS: Authors on this suite of papers were supported by the National Science Foundation; the Gordon & Betty Moore Foundation; the Heising-Simons Foundation; a U.C.-Santa Cruz Giving Day grant; the Alfred P. Sloan Foundation; the David and Lucile Packard Foundation; the Niels Bohr Professorship; UCMEXUS-CONACYT; the Dunlap Institute at the University of Toronto; NASA Hubble Fellowships, which are awarded by the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy Inc. for NASA; FONDECYT; the Ministry of Economy, Development, and Tourism's Millennium Science Initiative through a grant awarded to The Millennium Institute of Astrophysics; the Department of Energy; and the Kavli Summer Program in Astrophysics.

These papers include data gathered with the 6.5-meter Magellan Telescopes located at Las Campanas Observatory, Chile; data obtained from the ESO Science Archive Facility; observations made with the NASA/ESA Hubble Space Telescope, obtained from the Data Archive at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy; data from the NASA/IPAC Extragalactic Database (NED), which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with NASA; observations collected at the European Organisation for Astronomical Research in the Southern Hemisphere, Chile, as part of PESSTO (the Public ESO Spectroscopic Survey for Transient Objects Survey) through ESO programs 199.D-0143; and data obtained at the W. M. Keck Observatory, which is operated as a scientific partnership among the California Institute of Technology, the University of California, and NASA and made possible by the generous financial support of the W. M. Keck Foundation.

Climate-change Predictions and Solutions

Global Ecology's Ken Caldeira has been a Carnegie staff scientist since 2005. His lab investigates issues about climate, carbon, and energy systems. He and his colleagues use climate and the carbon cycle models to understand different scenarios, and he conducts fieldwork related to ocean acidification, particularly how it affects coral reefs.

More-severe Climate Predictions Could be the Most Accurate

The climate models that project greater amounts of warming this century are the ones that best align with observations of the current climate, according to research from postdoctoral researcher Patrick Brown and Ken Caldeira published by *Nature*. Their findings suggest that the models used by the Intergovernmental Panel on Climate Change, on average, may be underestimating future warming.

Climate model simulations predict how much warming should be expected for a given increase in the atmospheric concentration of carbon dioxide and other greenhouse gases.

"There are dozens of prominent global climate models, and they all project different amounts of global warming for a given change in greenhouse gas concentrations, primarily because there is not a consensus on how to best model some key aspects of the climate system," Brown explained.

Raw climate model results for a business-as-usual scenario indicate that we can expect global temperatures to increase anywhere in the range of 5.8 to 10.6°F (3.2 to 5.9°C) over preindustrial levels by the end of the century—a factor of two difference between the most and least severe projections.

Brown and Caldeira looked at what part of this range is more likely to prove accurate. They pursued the idea that the best model projections of future warming should be best in contexts, such as simulating the recent past. The new study eliminates the range's lower end, finding that the most likely warming is about 0.9°F (0.5°C) greater than what the raw model suggests.

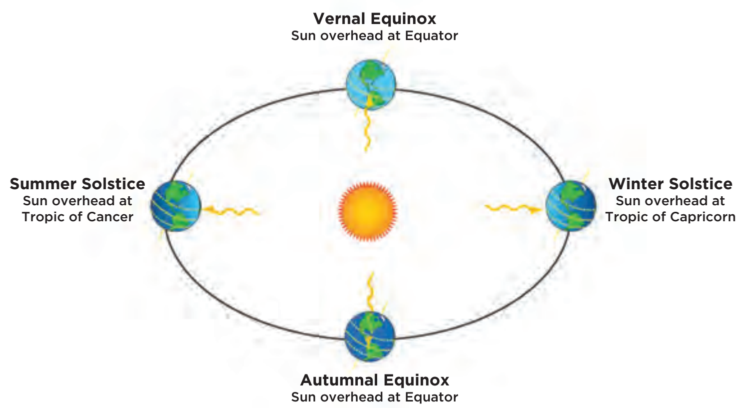
They focused on comparing model projections and observations of seasonal patterns of how energy flows from Earth to space. The models that best simulate the recent past of these energy exchanges tend to project greater-than-average future warming.

"Our results suggest that it doesn't make sense to dismiss the most severe global warming projections because climate models are imperfect in their simulation of the current climate," Brown said. "On the contrary, if anything, we are showing that model shortcomings can be used to dismiss the least severe projections."

The uncertainty in the range of future warming is mostly due to how models simulate changes in clouds. Some models suggest that the cooling effect caused by clouds reflecting the Sun's energy back to space could increase in the future while other models suggest that this cooling might decrease.

"The models that are best able to recreate current conditions are the ones that simulate a reduction in cloud cooling in the future, and thus these are the models that predict the greatest future warming," Brown explained.

Caldeira added, "Our study indicates that if emissions follow a commonly used business-as-usual scenario, there is a 93% chance that global warming will exceed 7.2°F (4°C) by the end of this century. Previous studies had put this likelihood at 62%."



The work by Brown and Caldeira focused on comparing model projections and observations of seasonal patterns of energy as it flows to and from Earth and space. As the Earth makes its annual journey around the Sun, the flow of energy differs depending on the seasons, among other factors.
Image courtesy NOAA/NASA

Patrick Brown (left) and Ken Caldeira (center) found that the models used by the Intergovernmental Panel on Climate Change, on average, may be underestimating future warming.

(Far right) Carnegie's Anna Possner was lead author on the ocean wind study.
Images courtesy Ken Caldeira

SUPPORT:
The Fund for Innovative Climate and Energy Research and the Carnegie Institution for Science endowment supported this study.

Possner and Caldeira compared the productivity of large Kansas wind farms to theoretical open-ocean wind farms and found that, in some areas, ocean-based wind farms could generate at least three times more power than those on land. These two floating wind turbines are off the coast of Aberdeenshire, Scotland.
Image courtesy of Terje Aase/Shutterstock.com

Huge Potential for Wind Farms in the Open North Atlantic

There is considerable opportunity for generating wind power in the open ocean, particularly the North Atlantic, according to research from Carnegie's Anna Possner and Ken Caldeira published by the *Proceedings of the National Academy of Sciences*.

Wind speeds are higher on average over ocean than over land, so wind turbines in the open ocean could in theory intercept more than five times as much energy as land turbines—an enticing opportunity for generating renewable energy. But it was unknown whether these faster winds could be converted to increased amounts of electricity.

Caldeira asked, "Are the winds so fast just because there is nothing out there to slow them down? Will sticking giant wind farms out there just slow down the winds so much that it is no better than over land?"

Most of the energy captured by large wind farms originates high in the atmosphere and flows to the surface and turbines. Other studies have estimated that there is a maximum rate of electricity generation for land-based wind farms and concluded that this maximum rate is limited by the rate at which energy is moved down from faster, higher-up winds.

"The real question is," Caldeira said, "can the atmosphere over the ocean move more energy downward than the atmosphere over land?"

Possner and Caldeira's sophisticated modeling tools compared the productivity of large Kansas wind farms to massive, theoretical open-ocean wind farms and found that in some areas ocean-based wind farms could generate at least three times more power than those on land.

Particularly in the North Atlantic, the drag introduced by wind turbines would not slow down winds as much as they would on land, they found. This is largely due to heat pouring out of the North Atlantic Ocean and into the atmosphere, especially during the winter. This contrast in surface warming along the U.S. coast drives the generation of low-pressure systems that cross the Atlantic and are very efficient in drawing the upper atmosphere's energy down to turbine height.

"We found that giant ocean-based wind farms tap into the energy of the winds throughout much of the atmosphere, whereas wind farms onshore remain constrained by the near-surface wind resources," Possner explained.

However, this tremendous wind power is very seasonal. While in the winter, North Atlantic wind farms could provide sufficient energy to meet all of civilization's current needs, in the summer they could merely generate enough power to cover the electricity demand of Europe, or possibly the United States alone.

Wind power production in the deep waters of the open ocean is in its commercialization infancy. The huge wind power resources identified by the study provide strong incentives to develop lower-cost technologies for the open-ocean environment. ■

SUPPORT:
The Fund for Innovative Climate and Energy Research and the Carnegie Institution for Science endowment supported this study.

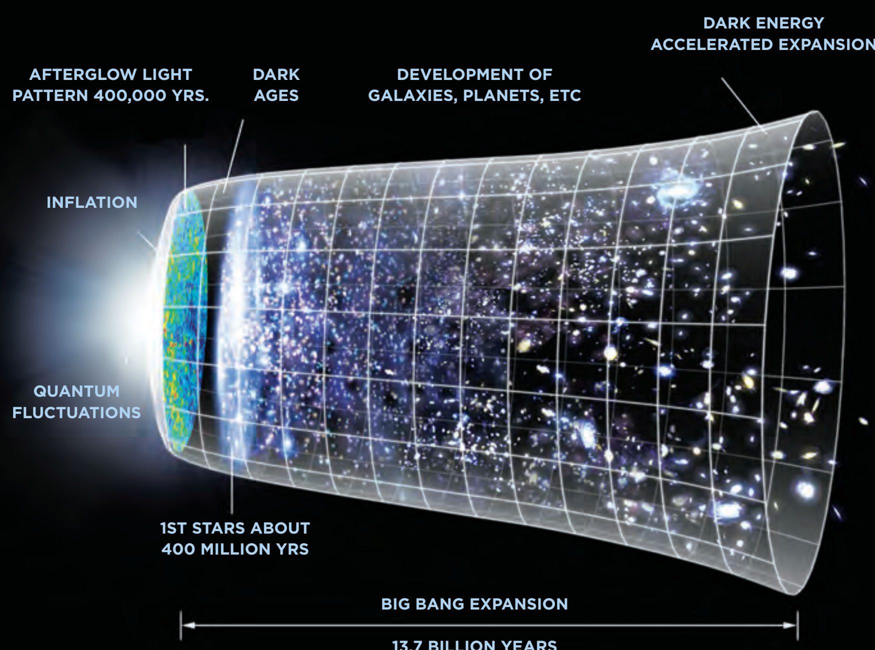
FOUND

Above (orange disk) is an artist's concept of the most distant supermassive black hole ever discovered, part of a quasar from just 690 million years after the Big Bang. The quasar is surrounded by neutral hydrogen, indicating that it is from the period called the epoch of reionization, when the universe's first light sources turned on. The object was detected by Carnegie's Magellan telescope at the Las Campanas Observatory.

Top image courtesy Robin Dienel Carnegie Institution for Science

Eduardo Bañados is the Carnegie-Princeton Fellow at the Carnegie Observatories who led the research.

Image courtesy Cindy Hunt



The universe began with the Big Bang over 13.5 billion years ago as a hot, murky soup of highly energetic particles, which expanded rapidly and cooled. About 400,000 years later, the cooled particles combined into neutral hydrogen gas. The universe stayed dark until gravity condensed matter into the first stars and galaxies.

Image courtesy NASA/WMAP Science Team

THE MOST DISTANT SUPERMASSIVE BLACK HOLE EVER

THIS BLACK HOLE IS 800 MILLION TIMES THE MASS OF OUR SUN

A team of astronomers led by Carnegie's Eduardo Bañados used Carnegie's Magellan telescopes to discover the most distant supermassive black hole ever observed. It's in a distant, luminous quasar from when the universe was only 5% of its current age—690 million years after the Big Bang. *Nature* published the findings, which were covered widely by the media.

Quasars are tremendously bright objects comprised of enormous black holes accreting matter at massive galaxy centers. This black hole is 800 million times the mass of our Sun.

"Gathering all this mass in fewer than 690 million years is an enormous challenge for theories of supermassive black hole growth," Bañados explained. Black holes in the present-day universe rarely exceed a few dozen solar masses. To grow black holes that big so soon, astronomers have speculated that the early universe might have had conditions to create very large black holes with masses reaching 100,000 times the mass of the Sun.

This new quasar is especially interesting, because it is from the time known as the epoch of reionization, when the universe emerged from its dark ages.

The Big Bang started the universe as a hot, murky soup of energetic particles that rapidly expanded. About 400,000 years later, the particles cooled and coalesced into neutral hydrogen gas. The universe stayed dark until gravity condensed matter into the first stars and galaxies. The energy released by these ancient galaxies caused the neutral hydrogen to excite and lose electrons; this ionized state is how the gas has remained since. Once the universe became reionzed, photons could travel freely and the universe became transparent to light.

In the newly found quasar, a large fraction of the surrounding hydrogen is neutral, indicating a source in the epoch of reionization, before the first stars and galaxies turned on enough to reionize the universe.

"It was the universe's last major transition and one of the current frontiers of astrophysics," Bañados said.

A quasar's distance from Earth is determined by its redshift, a measurement of the wavelength of its light stretched by the expansion of the universe; the higher the redshift, the greater the distance and the farther back in time. This quasar has a redshift of 7.54, based on ionized carbon from the host galaxy. The light took more than 13 billion years to reach us. The characterization of the quasar host galaxy was carried out with the IRAM/NOEMA and VLA interferometers and is reported in a companion article in *The Astrophysical Journal Letters* led by Bram Venemans of the Max Planck Institute for Astronomy in Germany.

"This great distance makes objects extremely faint. Early quasars are also very rare. Only one quasar was known to exist at a redshift greater than seven before now, despite extensive searching," said Xiaohui Fan of the University of Arizona's Steward Observatory.

Between 20 and 100 quasars as bright and as distant as the quasar discovered by Bañados and team are predicted to exist over the whole sky, so this major discovery will provide fundamental information about the young universe.

The discovery used NASA's orbiting Wide-field Infrared Survey Explorer and ground-based telescopes in Chile and Hawaii. The team used two Magellan telescope instruments to observe the supermassive black hole: FIRE, which made the discovery, and FourStar, which was used for additional images.

"This important discovery, together with the detection of distant galaxies, is elucidating the conditions of the universe during the reionization epoch. While we wait for the construction of the new generation of giant telescopes, such as the Giant Magellan Telescope, telescopes such as the Magellans at Las Campanas Observatory in Chile will continue to play a crucial role in the study of the early universe," added Las Campanas Director Leopoldo Infante. ■

COLLABORATORS:
This work is based on data collected with the Magellan Baade telescope, the Gemini North telescope (program GN-2017A-DD-4), the Large Binocular Telescope, and the IRAM/NOEMA interferometer.

Washington Nationals Celebrated DC STEM Fair Winners

As part of the Washington Nationals team's commitment to using baseball as a tool for science, technology, engineering, and mathematics (STEM) learning, they recognized and celebrated the Grand Award winners of the DC STEM Fairs on the field at Nationals Park last September.

The Nationals provided free tickets for the winners, their families, and select guests to the game, in addition to sponsoring the Grand Award and Category winners for the Elementary STEM Fair. During the pregame ceremony, the Grand Award winners of the Senior, Junior, and Elementary Divisions were celebrated and were joined on the field by Marlena Jones, director of the DC STEM Fair and acting director of the Carnegie Academy of Science Education (CASE), and Hanseul Kang, the D.C. state superintendent of education.

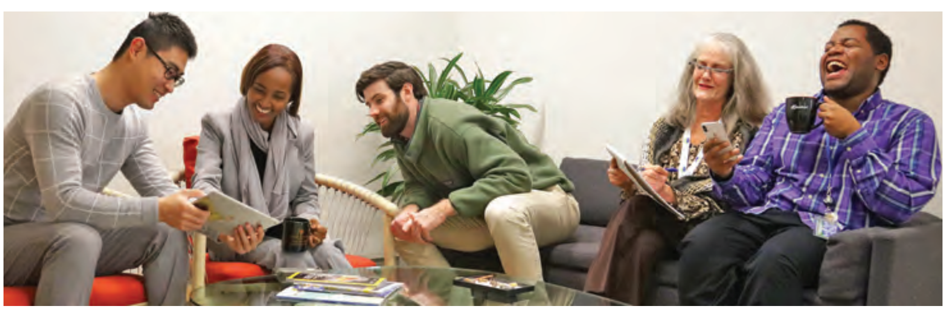
The DC STEM Network has managed the DC STEM Fair since the fall of 2015. The Network started as a partnership between Carnegie Institution's CASE and the D.C. Office of the State Superintendent of Education in late 2014. The Network unites more than 150 community partners in a collective effort to help inspire and prepare all D.C. youth to succeed, lead, and innovate in STEM fields and beyond.

"We are elated that these hard working STEM students are getting this recognition," remarked Jones. "Not only is it a thrill for the kids, but it shows how important science, technology, engineering, and mathematics education is to D.C." ■

The Washington Nationals baseball team celebrated DC STEM Fair winners in September at a pregame ceremony. The team is committed to using baseball as a tool for science, technology, engineering, and mathematics (STEM) learning.

Image courtesy Washington Nationals

Uniting Carnegie's Business Functions



Last year, members of the Administrative Working Group (AWG) conducted a technology assessment of its business systems that support all administrative functions at the P Street headquarters and the department business offices. This assessment was led by Tony DiGiorgio, of IT. One of the biggest needs identified in the assessment was a unified human resources (HR) and payroll system.

To facilitate the process of selecting a new system, P Street staff and the department business managers identified and inventoried 115 business requirements for Carnegie's HR and payroll processes. After reviewing several different products, Carnegie selected Dayforce from Ceridian https://www.ceridian.com/products/dayforce.

Dayforce is a singular cloud-based application where HR, payroll, benefits, workforce management, time and attendance, and recruitment data will reside. This system will unify Carnegie's core human resources and payroll services and is the first step in the institution's digital transformation initiative. Once implemented, employees will have continuous access to an online self-service portal. This new portal will allow employees to onboard online, submit address changes, add or remove dependents, change tax exemptions, update benefits, and review pay statements online.

Human resources and finance teams, working with IT, started implementing the first phase of the project in February 2018. The plan is to migrate the current payroll services to Ceridian by the end of summer 2018, with all departments and staff participating in open enrollment in fall 2018. The second phase of the project will be completed toward the end of this calendar year and will include performance management, compensation management, and dashboard data for HR teams.

Tim Doyle, COO, remarked, "The implementation of Dayforce is the first step in modernizing our administrative technology and moving towards a paperless, self-service environment. It also eliminates the need to maintain dual HR and pay data in different systems." More information will be provided by HR and the local business office as implementation continues. ■

BIG GRANT for Sorghum Bioenergy

Carnegie plant scientists Sue Rhee and José Dinneny, with their labs, are part of a research effort led by the Donald Danforth Plant Science Center, one of the world's largest independent plant science institutes. The effort is a five-year, $16-million grant from the U.S. Department of Energy (DOE). The objective is to identify new genes and pathways that are involved with photosynthesis and water-use efficiency in sorghum.

Sorghum is a grass grown worldwide. It is very resilient to drought and heat stress. Natural genetic diversity in sorghum makes it a promising system for identifying stress-resistance mechanisms in grasses that may have been lost during the domestication of related cereal crops. Sorghum is among the most efficient crops in converting solar energy and water use, making it an ideal crop for a bioenergy feedstock.

Building on earlier research using the model grass green foxtail (*Setaria viridis)*, this project will identify new genes and pathways that contribute to photosynthesis and enhanced water use. The team will then deploy these genes using synthetic biology, a science that combines biology and engineering to build new biological systems. The goal is to accelerate the development of sorghum varieties, in marginal environments, that could be used as biofuels.

"Understanding the network of genes involved in photosynthesis and drought tolerance will provide targets for plant breeders and genetic engineers to redesign sorghum specifically as a high-value bioenergy feedstock to be grown on marginal soils and thus not compete with food crops," said Thomas Brutnell, lead principal investigator and director of the Enterprise Institute for Renewable Fuels at the Danforth Center.

This project aims to produce stress-tolerant sorghum lines. The development of a low-input, environmentally safe, and highly productive sorghum germplasm, such as seed, will help establish a plant biomass energy economy that could provide jobs to rural communities, ensure energy security, and benefit the environment.

The project's strength lies within the multidisciplinary team spanning plant physiology, genetics, molecular biology, informatics, computational biology, and genetic engineering from scientists at Washington State University, the University of Rhode Island, the University of Illinois, and the University of Minnesota, in addition to Danforth and Carnegie.

"We're excited to use our computational modeling approaches to find key genes and pathways that will enable sorghum to grow with low input," Rhee said. "This research program will contribute to sustainable agriculture." ■

Sue Rhee (left), with José Dinneny and colleagues, received a Department of Energy grant to investigate new genes and pathways that are involved with photosynthesis and water-use efficiency in sorghum to use as an effective biofuel.
Images courtesy Robin Kempster

Sorghum, a member of the grass family, is resilient to drought and heat stress, making it an ideal crop for a bioenergy feedstock.
Image courtesy Public Domain

SUPPORT:
Founded in 1998, the Donald Danforth Plant Science Center is a not-for-profit research institute with a mission to improve the human condition through plant science. Research, education, and outreach aim to have impact at the nexus of food security and the environment and position the St. Louis region as a world center for plant science. The Center's work is funded through competitive grants from many sources, including the National Institutes of Health, U.S. Department of Energy, National Science Foundation, and the Bill & Melinda Gates Foundation. Follow on Twitter at @DanforthCenter.

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SPRING 2018

Capital Science Evening Lectures

Live Streaming, Live Tweets, and Archived for Later Viewing!

The Washington, D.C., Capital Science Evening Lectures are all free and open to the public. They feature some of the most extraordinary researchers of our time. Many of our events are webcast live and/or recorded. Registration is required. The lectures are held at 1530 P St., NW, and are listed at right.

For details see https://carnegiescience.edu/events

THURSDAY, MARCH 29, 2018 - 6:30PM

Dr. Julia Clarke - The Secret Lives of Dinosaurs
How do we go beyond the bones to bring dinosaurs to life? Dr. Clarke will explain the new toolkits she uses to study what dinosaurs might have sounded or looked like when they roamed.

Registration opens March 1, 2018 **#DINOSAURBONES**

WEDNESDAY, APRIL 25, 2018 - 6:30PM

Dr. Jane Lubchenco - Hope for People and the Ocean
Can we use the ocean without using it up? The task is daunting given current trajectories in fisheries, plastics, and other pollutants, and the impacts of climate change and ocean acidification.

Registration opens March 25, 2018 **#OCEANHOPE**

WEDNESDAY, MAY 9, 2018 - 6:30PM

Dr. Michael Walter - Deep Earth Through a Diamond Looking Glass
Looking upward, the vastness of the heavens is accessible through giant telescopes that collect light from the beginning of time. Learn how diamonds, those translucent rarities, illuminate the depths of our planet.

Registration opens April 9, 2018 **#DIAMONDSCIENCE**

WEDNESDAY, MAY 23, 2018 - 6:30PM

Ray Rothrock - The Future of Cybersecurity: Winning the War

The new reality is that all digitally networked enterprises and organizations will fall under cyberattack and be breached. RedSeal CEO Ray Rothrock will be speaking about his new book.

Registration opens April 23, 2018 **#DIGITALRESILIENCE**

TUESDAY, JUNE 12, 2018 - 6:30PM

Dr. Rainer Weiss - Probing the Universe with Gravitational Waves
The direct measurement of gravitational waves predicted by Albert Einstein 100 years ago has open a new field of science – gravitational wave astrophysics and astronomy. He will discuss recent discoveries.

Cohosted by the Carnegie Institution for Science, the Kavli Foundation, the Royal Embassy of Norway, and the Norwegian Academy of Science and Letters

Registration opens May 12, 2018 **#GRAVITATIONALWAVES**