

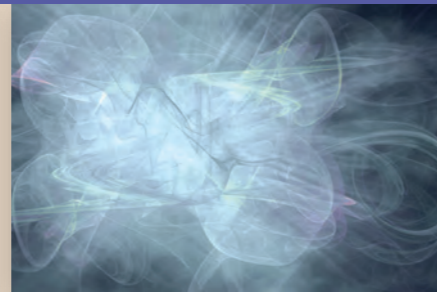
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2012-2013 YEAR BOOK

# The President's Report

*July 1, 2012 - June 30, 2013*

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*“ . . . 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.

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*Image courtesy Yuri Beletsky*



2012-2013 YEAR BOOK

# The President's Commentary

6





Carnegie president  
Richard A. Meserve  
*Image courtesy Jim Johnson*

I recently had the opportunity to participate in the centennial of Carnegie's Department of Embryology. About 200 alumni—former postdocs, fellows, and staff members—attended and the common theme of their comments was the formative effect of their time at Carnegie in shaping their careers.<sup>1</sup> Their enthusiasm was a reassuring endorsement of Carnegie's impact. The event was capped by insightful commentary by Allan Spradling, the director of the department, as to what has allowed Carnegie to thrive. Spradling's talk and the stimulating discussion through the day prompt me to articulate the special role that Carnegie has played and will continue to play in the pursuit of scientific knowledge.

As I have emphasized in these pages in prior years, the pursuit of basic science is essential for our future.<sup>2</sup> As shown by numerous studies, investments in scientific research serve as an engine for productivity, growth, and economic advance. Moreover, research driven solely by scientific curiosity may have impacts that are completely unanticipated, as evidenced, for example, by the role of scientific research in quantum mechanics in enabling the microelectronics, communications, and computer developments that have fundamentally changed our lives. And, of course, the benefits from scientific research extend far beyond its direct economic impacts. Science leads the way for improving healthcare, advancing national security, enhancing energy supply, assuring environmental protection, providing food supply for a growing world population, understanding and responding to climate change, achieving sustainable societies, and more. Perhaps most fundamentally, scientific research satisfies a deep-seated human desire to *know*—to understand the universe and our place in it.

Fortunately for our nation, we have many institutions that contribute in powerful ways to our scientific output. Foremost among them, of course, are the research universities, which contribute across the entire spectrum of the scientific enterprise. They legitimately are the envy of the world. But this raises a question about what Carnegie adds. We are tiny in comparison with the prominent research universities. Are we simply one contributor—a small one—among many exceptional performers? I will argue that Carnegie is uniquely productive in this important sphere.

<sup>1</sup> R. Meserve, "Embryology Turns 100," *CarnegieScience* newsletter fall 2013 (Washington, D.C.: Carnegie Institution for Science) p. 2.

<sup>2</sup> R. Meserve, "The President's Commentary," *Year Book 11/12* (Washington, D.C.: Carnegie Institution for Science, 2012) pp. 7-9.



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The Embryology Centennial reinforced the reality that Carnegie provides scientific output that is disproportionate to our size and that often is the prelude to scientific paradigm shifts. Over its entire century of work, the department has had a small staff—no more than 10 individuals of professorial rank at any one time—but the discussions emphasized that we have had exceptional impact across biology, both through our direct scientific output and through our role in training and stimulating individuals who are now scientific stars at other places.

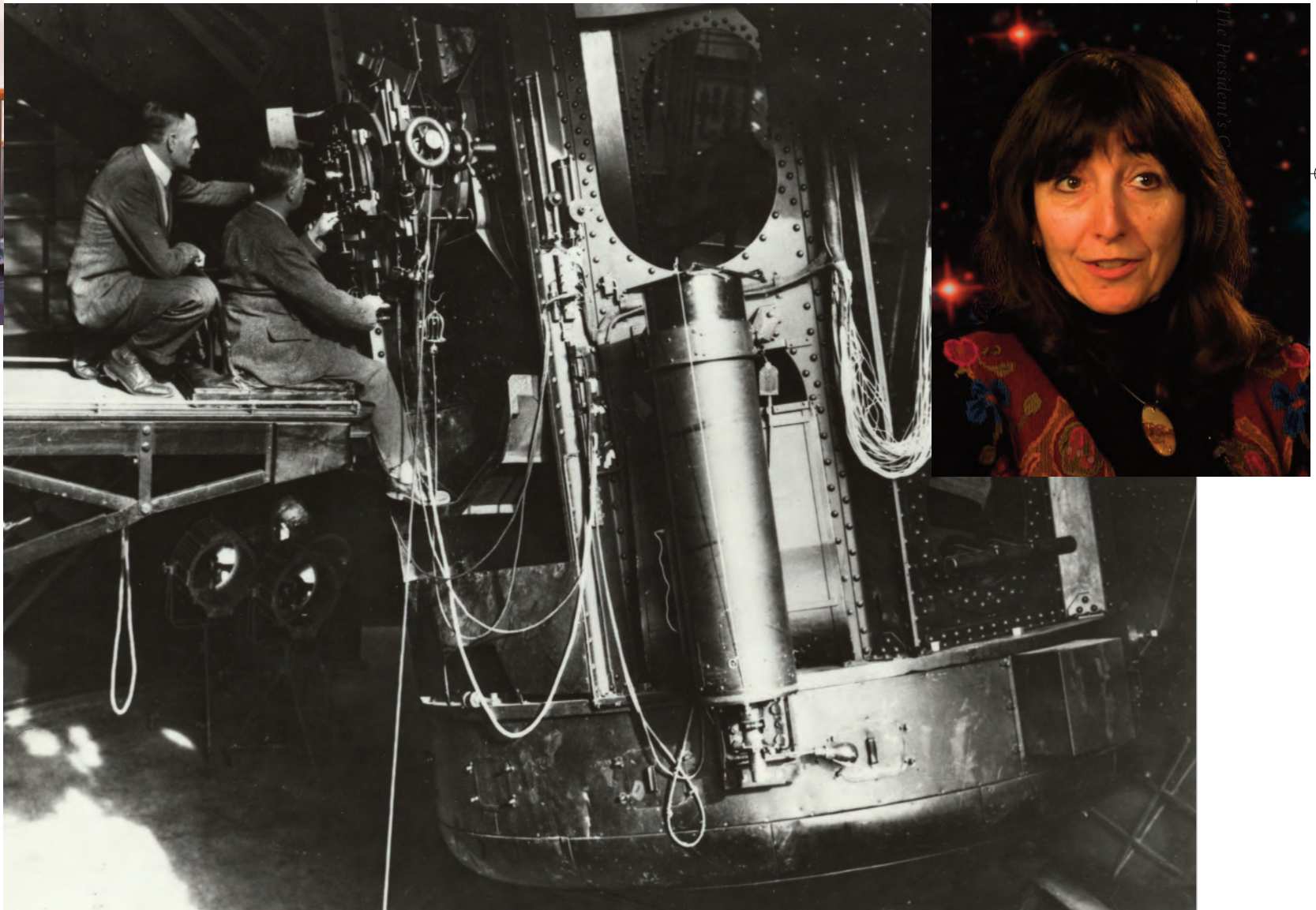
There is a similar history of striking accomplishment in our other departments. As shown by the discussion in the subsequent pages, exciting advances are being pursued across all our departments to this day. A few examples reinforce the point.

The Department of Embryology has changed dramatically from its early days (above left) to its state-of-the-art Singer Building, where it is housed today (above). But its commitment to excellence and its study of questions that others do not has remained true throughout its 100-year history.

*“What is the ‘secret sauce’ that accounts for our success?”*

In the 1920s, Carnegie's Edwin Hubble (below on left) redefined what we thought we knew about the universe. He discovered that the universe contains many galaxies in addition to our Milky Way and that it is expanding. Today, Carnegie's Wendy Freedman (far right) continues research on the rate of expansion. With her team, she recently reduced the uncertainty in the expansion rate, called the Hubble constant, to just three percent. This value is fundamental for determining of the age and size of the universe.

Carnegie Astronomer Edwin Hubble's discovery in the 1920s that the universe is expanding provides the foundation for the research of Wendy Freedman, the director of the Observatories. With an international team of scientists, Freedman has recently reduced the uncertainty in the expansion rate, the Hubble constant, to just three percent. This is perhaps the most fundamental and important measurement in cosmology because it governs the determination of the age of the universe. Today, through Freedman's role as chair of the board for the Giant Magellan Telescope Organization (GMTO), Carnegie is leading an international effort to build the largest, most powerful telescope in the world. The GMT not only will help solve current scientific mysteries, but also will simultaneously reveal many others.





Ecologist Greg Asner's recent work uncovering the true extent of legal and illegal gold mining taking place in the biologically diverse region of Madre de Dios in the Peruvian Amazon is an outgrowth of his creation of a one-of-a-kind airborne Earth-mapping system. He and his team have "mapped" the carbon content in the entire country of Panama and have completed numerous missions mapping ecosystems in Colombia, Costa Rica, Madagascar, and South Africa, among others.

Understanding the chain of events that lead to volcanic eruptions has long been an area of research for Carnegie scientists. The Sacks-Evertson strainmeter, codeveloped by Carnegie's Selwyn Sacks, has played a key role in our understanding of Earth dynamics since its development in the late 1960s. Diana Roman's current research in seismology and volcanology builds on this foundation. With her team, Roman studies the relationships among magma flow, seismicity, and localized stresses by analyzing minute amounts of deformation deep in the Earth. She is currently analyzing

Carnegie's Greg Asner works on the Carnegie Airborne Observatory (above). It flew over the gold-mining ravaged Madre de Dios region of the Peruvian Amazon (top) to determine the extent of ecological damage.

*Images courtesy Robin Kempster and Greg Asner, Carnegie Airborne Observatory*

Carnegie's Diana Roman (below) continues Carnegie's long tradition of studying seismology and volcanology, but with new methods that are improving our understanding of the causes of eruptions. Her work could lead to improved prediction capability.

Martin Jonikas (right) and colleagues have found that the unicellular green algae *Chlamydomonas* (bottom right) is able to increase the concentration of carbon dioxide and dramatically improve the efficiency of photosynthesis. If this capacity can be transferred to food crops, it could improve food production around the world.

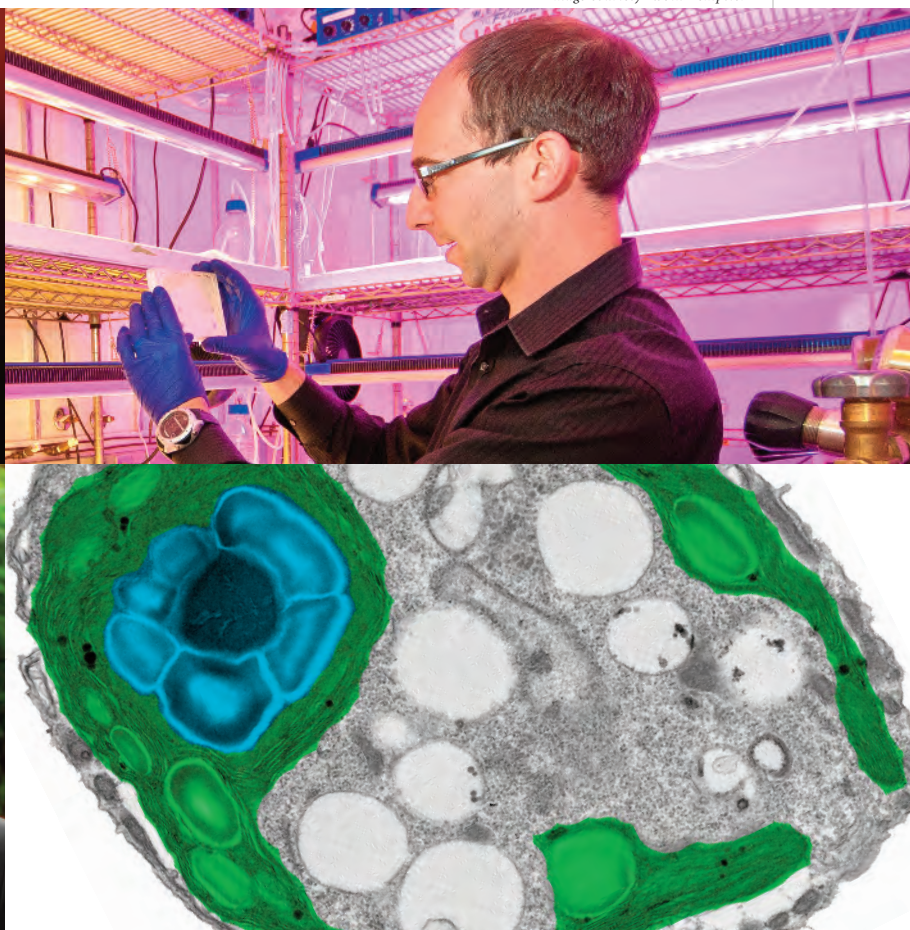
data from a dozen active volcanoes in the United States, Nicaragua, New Zealand, and Iceland. Her research will improve our understanding of the causes of volcanic eruptions and could lead to improved prediction capability.

When photosynthesis first evolved, the atmosphere contained much higher concentrations of carbon dioxide, with the result that the photosynthetic machinery in plants is not optimized for today's environment. Although the protein responsible for fixing carbon dioxide—called Rubisco—functions extremely slowly in low concentrations of carbon dioxide, plant scientist Martin Jonikas and his colleagues have found that the unicellular green algae *Chlamydomonas* is able to increase the concentration of carbon dioxide in the vicinity of Rubisco and thereby dramatically improve the efficiency of photosynthesis. If they are able to transfer this ability to food crops, they could find a way to improve food production around the world.

Image courtesy Robin Kempster



Image courtesy Diana Roman



Images courtesy Robin Kempster and Moritz Meyer

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In sum, although the continuing record of accomplishment is undeniable, there remains the question of what makes Carnegie different. What is the “secret sauce” that accounts for our success?

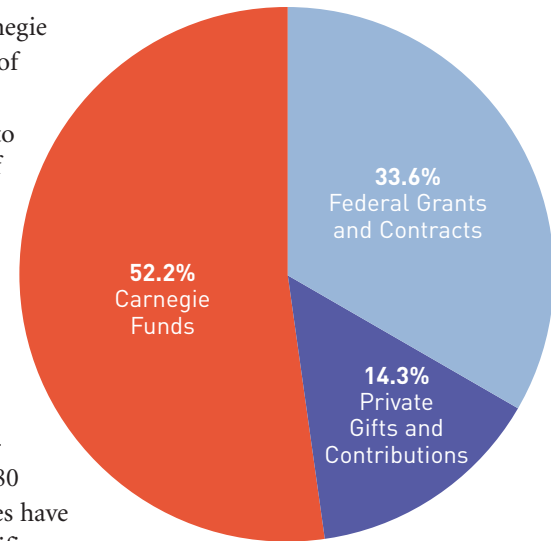
I believe that the answer starts with the foresight of our founder. Andrew Carnegie directed the institution to “discover the exceptional man in every department of study whenever and wherever found . . . and enable him to make the work for which he seems specially designed his life work.”<sup>3</sup> Carnegie’s aim was grand: “to secure if possible for the United States of America leadership in the domain of discovery and the utilization of new forces for the benefit of man.”<sup>4</sup> We have strived throughout our history to fulfill the Carnegie vision, albeit our researchers always have included many prominent women.

We seek to recruit promising scientists, nearly always at the beginning of their careers, and to free them as much as possible from obligations other than the pursuit of science. As one scientist put it, “Carnegie buys my time and then gives it back to me.” The productivity of our staff may be traced in part to freedom from distraction. Indeed, our productivity is astonishing; we have about 80 Carnegie investigators across our six departments and they and their colleagues have published over 795 papers in the past year, many in the most prestigious scientific journals. (*See p. 61*) But there are other factors beyond the avoidance of non-research tasks that account for our scientific productivity.

Thanks to the generosity of our founder, support from a variety of foundations and individuals over the years, and the careful stewardship of our endowment by the Finance Committee, we are able to support a significant portion of our budget from institutional funds. Although Carnegie has continued to fare well in the receipt of federal grants, we are able to support about 50% of our budget from our endowment. By contrast, only about 20 percent of academic research in the United States benefits from such internal support.<sup>5</sup> Most other research enterprises are highly dependent on federal funds for their scientific work.

As the availability of federal funds for research has been constrained by tight budgets in recent years, the character of the research that is supported has been affected. Many have observed the growing tendency of federal agencies to be more conservative in funding decisions, to the disadvantage of path-breaking research that departs from conventional wisdom.<sup>6</sup> That is, it is easier to find support for work that promises to validate or extend what is already known. Carnegie prides itself in providing our staff with the freedom to take chances and to pursue novel concepts, even though such fresh ideas may not initially benefit from federal grants. We encourage our scientists to explore those areas that are not currently in fashion.

### 2013 Expenses by Funding Source (\$99.8 Million)



*“We seek to encourage a culture in which it is safe—even expected—to challenge conventional wisdom.”*

Our board becomes concerned if federal support grows too large for fear that we might then follow the herd mentality of the scientific mainstream.

I hasten to add that the Carnegie approach of providing significant independence to its researchers does *not* reflect a criticism of peer review. While it is true that peer review can tend to reinforce and favor scientific orthodoxy, it is an important safeguard to ensure that seriously aberrant work or wasteful expenditures are avoided. Carnegie’s approach, while providing short-term to mid-term independence, is coupled with a careful review of each scientist’s contributions at roughly five-year intervals. Those reviews seek to assure that scientists are using the independence that Carnegie provides to good effect. The time interval is established with

an awareness that some truly path-breaking approaches may require the development of an instrument or the conduct of studies that may take years—longer than contemplated by the typical federal grant—to complete. Of course, allowance also has to be made for the reality that the pursuit of a novel idea necessarily

involves a certain likelihood of failure; the review should protect—even reward—the scientist who takes an adventurous wrong turn. Fortunately, we have been blessed with scientists with the insight or intuition that has enabled them often to succeed in pursuit of novel approaches.

A somewhat less obvious benefit of the availability of Carnegie funds is the capacity and willingness to provide independence to researchers early in their scientific careers. Many have observed that the demand for funds and conservatism in their allocation have served to favor established researchers. This has led to a decreased availability of grants for young scientists. Thus, the average age of a researcher receiving his or her first major research grant from the National Institutes of Health is now well over 40 years.<sup>7</sup> It is paradoxical that radical transformations often come from those who are not burdened by “knowing” too much—from outsiders who bring fresh perspectives and even naiveté.<sup>8</sup> Professor Mildred Dresselhaus, the MIT professor who won the most recent Kavli Prize in nanotechnology, recently gave her laureate lecture at Carnegie in which she noted that she benefited at the start of her career by working on a problem that no one else was pursuing and about which she, at least at the outset, knew little, thereby avoiding the restrictions imposed by a crowded field and accepted wisdom. Carnegie seeks to provide young researchers with the capacity to strike out into unmapped scientific territory. Early support enabled Andrew Fire, a staff associate and then a former Carnegie staff member in

<sup>3</sup> Carnegie Institution of Washington, *Articles of Incorporation, Deed of Trust* (Washington, D.C., 1902) p. xiii–xiv.

<sup>4</sup> *Ibid.*

<sup>5</sup> National Science Board, *Science and Engineering Indicators 2012* (Washington, D.C.: National Science Foundation, 2012) Figure 5-2.

<sup>6</sup> S.L. McKnight, “Unconventional Wisdom,” *Cell* 138, 817–819, 2009.

<sup>7</sup> *New Investigator Data* 1980–2011, <http://report.nih.gov/FileLink.aspx?rid=826>

<sup>8</sup> See *supra* note 6, 817.

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the Department of Embryology, to start his research on RNA interference, work that ultimately resulted in a Nobel Prize.

We seek to encourage a culture in which it is safe—even expected—to challenge conventional wisdom. As Spradling noted at the centennial celebration, a healthy disbelief of what is accepted can rescue a field from the blockage that can arise from a widely accepted but fundamentally wrong idea. Challenging orthodoxy can be dangerous business, but it is the foundation for significant advances. Moreover, such advances are encouraged by an environment in which scientists with different scientific backgrounds work together. The eclectic group of researchers in each of our departments has nurtured exactly the mixture of challenge and cooperation that facilitates advance.

Although the science we undertake today would doubtless not be recognizable to our researchers in our early years, there is one fundamental constant. We have a scientific staff that is dedicated to the pursuit of scientific truth as their first and highest calling. Perhaps the enduring character of our staff was captured best by the comments of Allan Spradling in discussing his career with Carnegie at the centennial:

Having the opportunity to do science for a living anywhere must already be considered a great fortune. To search for truth, to immerse oneself in the beauty of biological forms, to look for new knowledge that is potentially of great benefit to mankind, all while working with and mentoring exceptionally smart, creative and fascinating people is to live without truly working at all. Indeed it is profoundly satisfying to join the line of humans throughout the ages who searched to understand the universe by applying skepticism and reason rather than remaining satisfied with myth. Working at Carnegie has provided these satisfactions in a highly enriched form.

The Carnegie Institution is a special place.

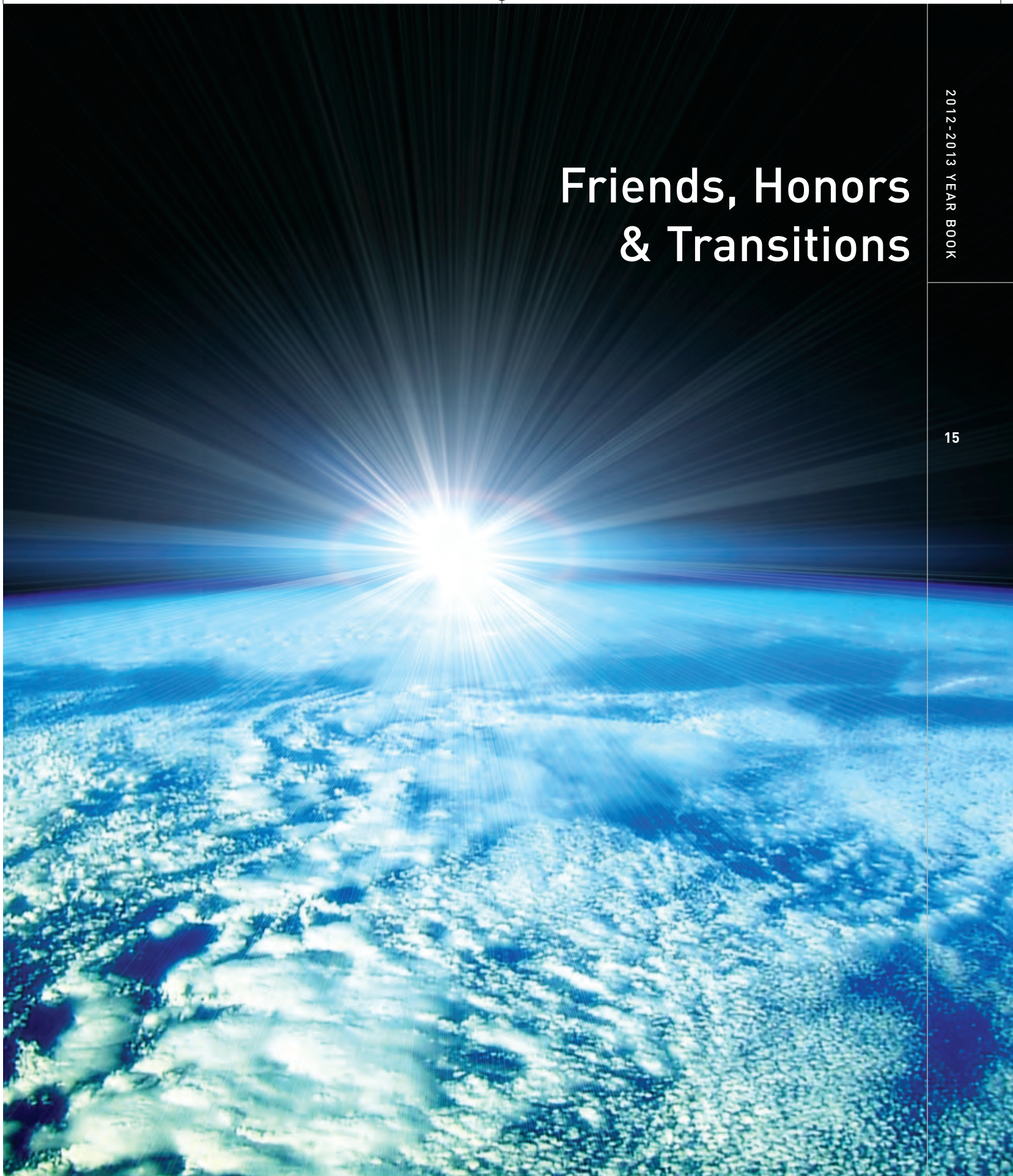


Richard A. Meserve, *President*

# Friends, Honors & Transitions

2012-2013 YEAR BOOK

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*Carnegie Institution for Science*

# Carnegie Friends

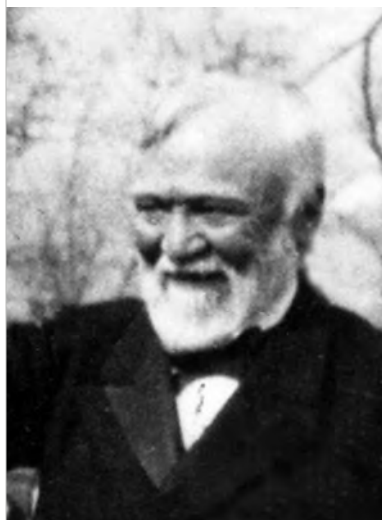
## Lifetime Giving Societies

### The Carnegie Founders Society

Andrew Carnegie, the founder of the Carnegie Institution, established it with a gift of \$10 million. Although he ultimately gave a total of \$22 million to the institution, his initial \$10 million gift represents a special level of giving. In acknowledgment of the significance of this initial contribution, individuals who support Carnegie’s scientific mission 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\*



### The Edwin Hubble Society

The most famous astronomer of the 20th century, Edwin Hubble, joined the Carnegie Institution in 1919. Hubble’s observations shattered our old concept of the universe. He proved that the universe is made of collections of galaxies and is not just limited to our own Milky Way—and that it is expanding. This work redefined the science of cosmology. Science typically requires years of work before major discoveries like these can be made. The Edwin Hubble Society honors those whose lifetime support has enabled the institution to continue fostering such long-term, paradigm-changing research by recognizing those who have contributed between \$1,000,000 and \$9,999,999.

.....

- Anonymous
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- Michael and Mary Gellert
- Robert G. and Alexandra C. Goelet
- William T. Golden\*
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- Deborah Rose, Ph.D.
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- Thomas and Mary Urban
- Sidney J. Weinberg, Jr.\*



### 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 wrote in 1950, "It was Andrew Carnegie's conviction that an institution which sought out the unusual scientist, and rendered it possible for him to create to the utmost, would be worthwhile . . ." He further said that "the scientists of the institution . . . seek to extend the horizons of man's knowledge of his environment and of himself, in 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 and \$999,999.



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 G. Leonard Baker Jr.  
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### 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 have supported the institution through other forms of planned giving.

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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, making it possible to pursue the highly original research for which Carnegie is known.



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# Honors & Transitions

## Honors

### Trustees/Administration

President Obama awarded the National Medal of Science to former Carnegie postdoctoral researcher and current trustee **Sandra Faber** in December 2012.

### Embryology

Director Emeritus **Donald Brown** received the prestigious 2012 Lasker-Koshland Special Achievement Award in Medical Science.

### Geophysical Laboratory

Instrument shop supervisor **Stephen Coley** received Carnegie's 2012 Service to Science award.

### Global Ecology

Staff scientist **Greg Asner** was elected to the National Academy of Sciences in April 2013.

### Observatories

Director **Wendy Freedman** was elected a fellow of the American Physical Society and was selected to receive a NASA Honor Award, the Exceptional Scientific Achievement Medal.

### Plant Biology/Global Ecology

Business manager **Kathi Bump** received Carnegie's 2012 Service to Science award. She manages both Plant Biology and Global Ecology's business operations.

### Terrestrial Magnetism

The American Physical Society designated the Department of Terrestrial Magnetism as a historic site in recognition of **Vera Rubin's** and **Kent Ford's** pioneering research on dark matter.



★ *Sandra Faber*



★ *Donald Brown*



★ *Stephen Coley*



★ *Greg Asner*



★ *Wendy Freedman*



★ *Kathi Bump*



★ *Vera Rubin*



★ *Kent Ford*



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# Honors & Transitions

## Transitions

### Trustees/Administration

**Michael Gellert** stepped down in May 2013 as chairman of the Carnegie Board of Trustees, a position he held for the last ten years. He remains an active board member.

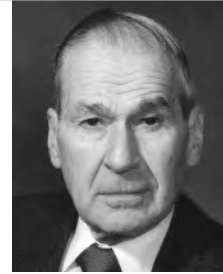
**Stephen Fodor** and **Suzanne Nora Johnson** were elected to serve as cochairs at the May 2013 Carnegie board meetings. **Bruce Ferguson** was elected to serve as vice chair.

**Samuel Bodman** became a trustee emeritus.

Senior trustee **Jaylee Mead** died September 14, 2012.

### Geophysical Laboratory

Staff scientist **Marilyn Fogel** left Carnegie to join the faculty at UC-Merced.



★ *Michael Gellert*



★ *Stephen Fodor*



★ *Suzanne Nora Johnson*



★ *Bruce Ferguson*



★ *Samuel Bodman*



★ *Jaylee Mead*



★ *Marilyn Fogel*



# Research Highlights

Kenneth Schneider takes seawater samples from around One Tree Island to measure their carbon dioxide concentration.

*Image courtesy Ken Caldeira*



# Astronomy

*Investigating the Birth, Structure, and Fate of the Universe*



## New Theory for Old Ellipticals

The traditional understanding of elliptical galaxies is that they are fairly uniform blobs made up of older, low-mass stars, with little star formation. Some might say they are boring. But Ph.D. student Song Huang and staff astronomer Luis Ho have discovered elliptical galaxies are both complicated and interesting. They have a more complex structure than previously believed and likely evolved in two phases, rather than forming via a huge collapse and major galactic merger.

The astronomers' analyses used highly accurate photometric devices to measure the brightness of the light in the galaxies and a two-dimensional image processing method, which is more powerful than the standard one-dimensional process. These capabilities enabled more detailed analyses than have occurred before.

They sampled 94 nearby massive ellipticals from the Carnegie-Irvine Galaxy Survey. They found that 70 of them have three subcomponents—compact cores with radii of about 3,200 light-years (1 kiloparsec, or kpc), middle components with radii stretching about 8,000 light-years (2.5 kpc), and extended outer envelopes with radii of 33,000 light-years (10 kpc).

Then, to see if the substructures of the nearby ellipticals related to much younger early-type galaxies farther away, the astronomers then looked at the stellar masses and plotted radii of over 1,300 early types.

The team found that the radii of the nearby inner components were like compact, distant red galaxies called red nuggets, which came into existence 2½ to 3 billion years after the Big Bang (which occurred 13.7 billion years ago). However, the masses of the nearby galaxy stars are about two times larger than those of the red nuggets and they are four to five times larger in size. These observations suggest the red nuggets are likely a younger version of the inner components of present-day ellipticals.

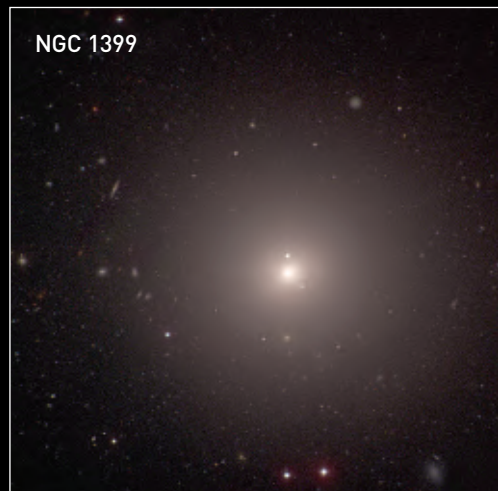
The researchers believe that red nuggets had to grow quickly to be so compact and massive, probably through the mergers of gas-rich galaxies forming the two inner components in phase one. In phase two, minor mergers between gas-poor galaxies could have built up the present-day outer envelopes. The astronomers plan to further study the mechanisms and timing of this evolution.



Staff astronomer Luis Ho (left) and his Ph.D. student Song Huang are finding that elliptical galaxies are not so boring after all.

*Image courtesy Meng Gu*

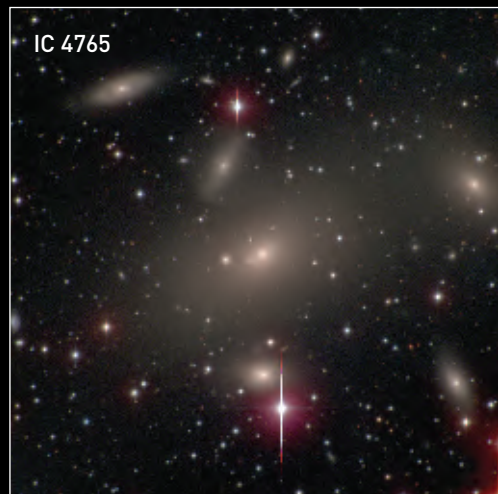
NGC 1399



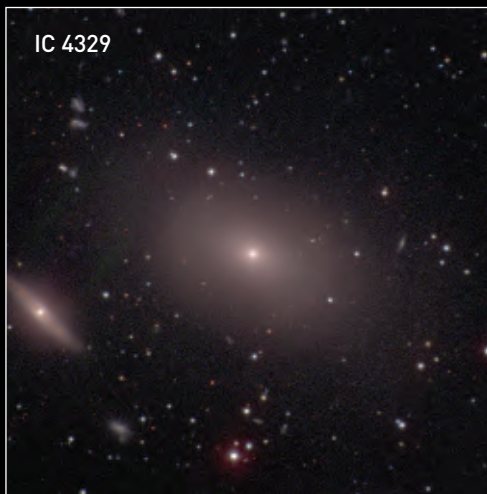
NGC 720



IC 4765



IC 4329



Until recently astronomers thought that elliptical galaxies, shown here, were fairly uniform with older, low-mass stars and little interstellar medium or star formation. The work of Huang and Ho is changing this view: Elliptical galaxies are far more complex than previously believed. From top left counterclockwise are NGC 1399, IC 4765, IC 4329, and NGC 720. The scale is 30 arcseconds, which is 1/3600 of a degree. There are 360 degrees in a circle.

*Image courtesy Carnegie-Irvine Galaxy Survey*

# Astronomy

*Continued*

## Rare Galactic Outliers

All of the elements are processed in successive generations of stars and are released to the cosmos via spectacular explosions called supernovae. There are several varieties of supernovae, depending on chemical makeup, light intensity over time, and other features. Astronomers recently found that there is more calcium than expected within some clusters of galaxies, so John Mulchaey, Mansi Kasliwal, and Juna Kollmeier looked at two common supernova types and a new, rare type to see what could be the cause.

The two regular types of supernovae are Type I and Type II, each with several sub-varieties, depending on their chemistry. Type I are produced when sufficient matter causes atomic nuclei to fuse in the core, creating an explosion. Type II explode when their dense cores gravitationally collapse in on themselves. The newly found rare type is calcium rich and tends to reside in odd locales, such as at the outskirts of galaxies. Until now, astronomers thought that Type Ia and Type II supernovae may have been sufficient to explain the elements found within galaxy clusters, because they explain the abundances of most of the elements. But recent observations suggest that the models underproduce calcium.

John Mulchaey, Juna Kollmeier, and Mansi Kasliwal (left to right) looked at two common supernova types and a new rare one to see which could be the cause of more calcium than expected within some clusters of galaxies.

*Image courtesy Scott Rubel*



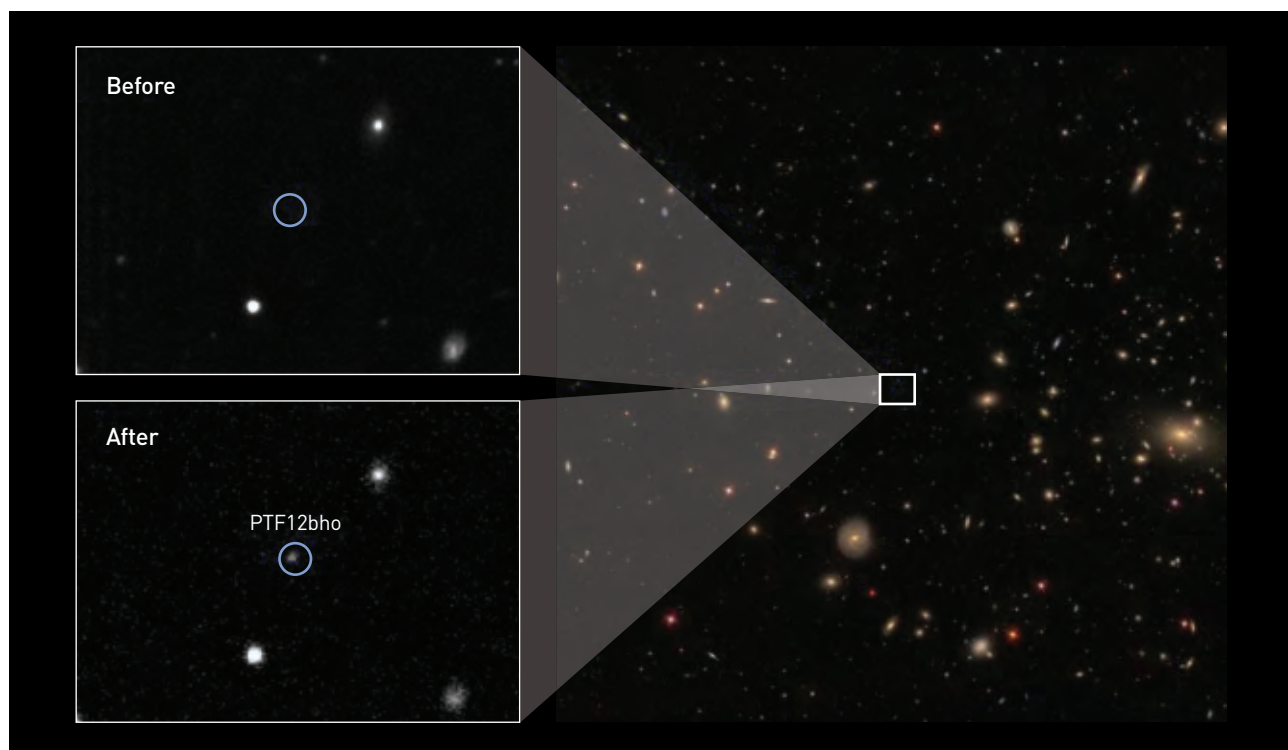


**BELOW:** Recently a new class of calcium-rich transient objects was discovered in the luminosity gap between novae and supernovae. This gap is a factor of 1000 between the brightest nova and faintest supernova. These transients tend to reside in the middle of nowhere, in the far outskirts of their putative host galaxies. At right in the image below is an image of the dense Coma galaxy cluster. At left is a zoom in on the location of one such calcium-rich gap transient named PTF12bho before explosion (left top) and after explosion (left bottom). PTF12bho is at the same distance as the Coma cluster but very far from any host galaxy.

*Image courtesy Mansi Kasliwal/Palomar Transient Factory Collaboration*

The Carnegie astronomers modeled the three supernovae types. They based the calcium yield for a calcium-rich type on supernova 2005E, whose ejected mass was nearly 50% calcium, some five to 10 times greater than that of other supernovae. They then compared the model results to measurements of the intracluster medium taken from a 22-cluster sample. In addition to yields, they also considered the rate of supernovae events. They found that the calcium-rich supernovae fit well with the actual calcium abundances, with little effect on the abundances of other elements. This result suggests that the newly found type of supernovae is responsible for the high calcium observations.

The astronomers were additionally interested in the role these calcium-rich supernovae have in circulating material throughout galaxy clusters. They believe that their locations in the outskirts of galaxies would allow the elements to be stripped off more easily from the drag of galaxies falling into the cluster than would happen if the supernovae occurred near the center of the galaxy where gas is more concentrated. This points to the possibility that these rare objects are also important to material distribution. ■



# Earth/Planetary Science

*Understanding Earth, Other Planets, and Their Place in the Cosmos*



## Where Did Earth's Water Come From?

Identifying the source of Earth's so-called volatile elements, such as hydrogen, nitrogen, and carbon, is crucial for determining the origins of both water and life on our planet. It has long been believed that comets and/or a type of very primitive meteorite called carbonaceous chondrites were the sources of early Earth's volatile elements and possibly of prebiotic organic material. Research from Carnegie's Conel Alexander and Larry Nittler suggest that meteorites and their parent asteroids—not comets—are the most likely sources of Earth's water.

The team focused on water contained in carbonaceous chondrites. Water ice would have been distributed throughout much of the early Solar System, but it probably was not present in the materials that initially aggregated to form Earth. This primordial ice is preserved in the outer Solar System, in comets and the icy moons of the giant planets, as well as in water-bearing minerals—such as clays—found in carbonaceous chondrites.

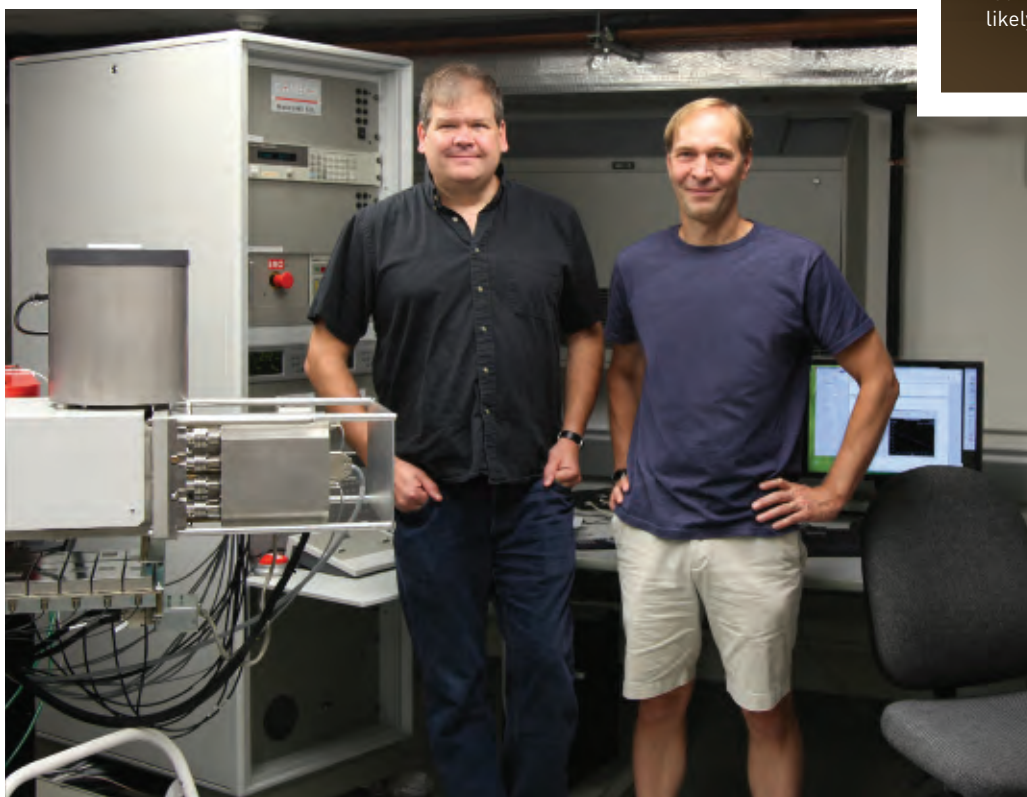
By examining the ice's ratio of hydrogen to its heavy isotope deuterium, scientists can get an idea of the relative distance from the Sun at which water-bearing objects were formed. Objects that formed farther out should generally have higher deuterium concentrations in their ice than those that formed closer to the Sun. Objects that formed in the same regions should have similar hydrogen isotopic compositions. By comparing the deuterium content of water in carbonaceous chondrites to the deuterium content of comets, and to Saturn's icy moon Enceladus, it is possible to tell if they formed in similar reaches of the Solar System.

One popular model suggests that both comets and the parent asteroids of carbonaceous chondrites formed beyond the orbit of Jupiter, perhaps even at the edges of our Solar System, and were then scattered inwards by the orbital migration of the giant planets, eventually bringing volatiles and organic material to Earth. If this were true, then the ice found in comets, Enceladus, and the remnants of ice preserved in carbonaceous chondrites would have similar isotopic compositions.

The team analyzed samples from 85 carbonaceous chondrites and showed that carbonaceous chondrites likely did not form in the same regions of the Solar System as comets and Enceladus. Rather, carbonaceous chondrites formed in the asteroid belt between the orbits of Mars and Jupiter. What's more, most of the volatile elements on Earth were delivered by one or two particular varieties of carbonaceous chondrite, not from comets, as is often proposed.



This photo shows a cross section of a chondritic meteorite. Nittler and Alexander found that this type of meteorite is most likely the source of Earth's water.



**ABOVE LEFT:** An image montage of the Saturnian system shows the icy moon Enceladus off to the left. Nittler and Alexander compared the isotopic composition of the ice from this moon to the ice from distant comets and from chondritic meteorites, to pinpoint the source of the water.

*Image courtesy NASA's Jet Propulsion Laboratory*

**LEFT:** Larry Nittler (left) and Conel Alexander are in the lab.







This artist's conception shows a gas giant planet forming from the disk of dust surrounding a young star.

*Image courtesy L. Calçada, European Southern Observatory*

## From Pebbles to Planets

According to one theory, giant planets like Jupiter are formed when dust and grains from a protoplanetary disk aggregate into a core. When this core reaches a critical mass—between one and 10 times Earth's mass—it is able to accrete gas from the surrounding disk. However, scientists have had difficulty figuring out how the protoplanet has enough time to undergo both of these developmental stages before the disk disperses. This has presented a real problem to modelers because most disks only last for a few million years. Yet despite this limitation, gas giants are numerous. So they must be able to form relatively quickly for their size.

Carnegie's John Chambers developed new simulations to predict how gas giants form quickly enough to harvest gas from the protoplanetary disk before it disappears. He focused on one particular phase of gas giant formation called oligarchic growth.

During oligarchic growth an embryonic giant-planet core gets larger as it sweeps up smaller asteroid-sized particles called planetesimals. During this process, high-speed collisions between the planetesimals form fragments of various sizes, referred to as pebbles. Chambers determined that smaller planetesimals resulted in more frequent collisions and thus a larger number of pebbles.

Chambers also showed that the sizes of these pebbles determine the speed of giant planet formation. Larger pebbles experience drag in the rotating gas disk and move toward the core, increasing their probability of capture. But smaller pebbles are more likely to be caught up in the movement of the gas and be swept right past the aggregating core, without being captured.



This photo shows Jupiter and its moon Io. Chambers is trying to determine how gas giant planets like Jupiter formed.

*Image courtesy NASA*



John Chambers

What's more, Chambers found that the turbulence of the rotating gas and pebbles play a role in the rate of accretion. Strong turbulence resulted in a slower growth rate for the embryonic planet.

The result of the simulations indicated that a giant planet core with a mass of about 10 times that of Earth will take 3 million or fewer years to form, if it is at a distance of about five times that between the Earth and the Sun. The simulations provide a possible means to reconcile how giant planets can form before the disk disperses. ■



# Genetics/Developmental Biology

*Deciphering the Complexity of Cellular, Developmental, and Genetic Biology*

## Is Premature Egg Loss the Price of Quality?

Integrity of hereditary material—the genome—is critical for species survival. Genomes need protection from environmental and cellular agents that can cause mutations affecting DNA coding, regulatory functions, and duplication during cell division. DNA sequences called transposons (discovered by Carnegie’s Barbara McClintock) can multiply and randomly jump around the genome and cause mutations. RNA interference (RNAi, codiscovered by Carnegie’s Andy Fire) and related processes are central to transposon control, particularly in egg and sperm precursor cells. Previously, Alex Bortvin’s group showed the critical role of transposon “silencing” for normal fertility of male mice. But the impact of transposons on the mammalian egg precursor—an oocyte—has remained elusive.

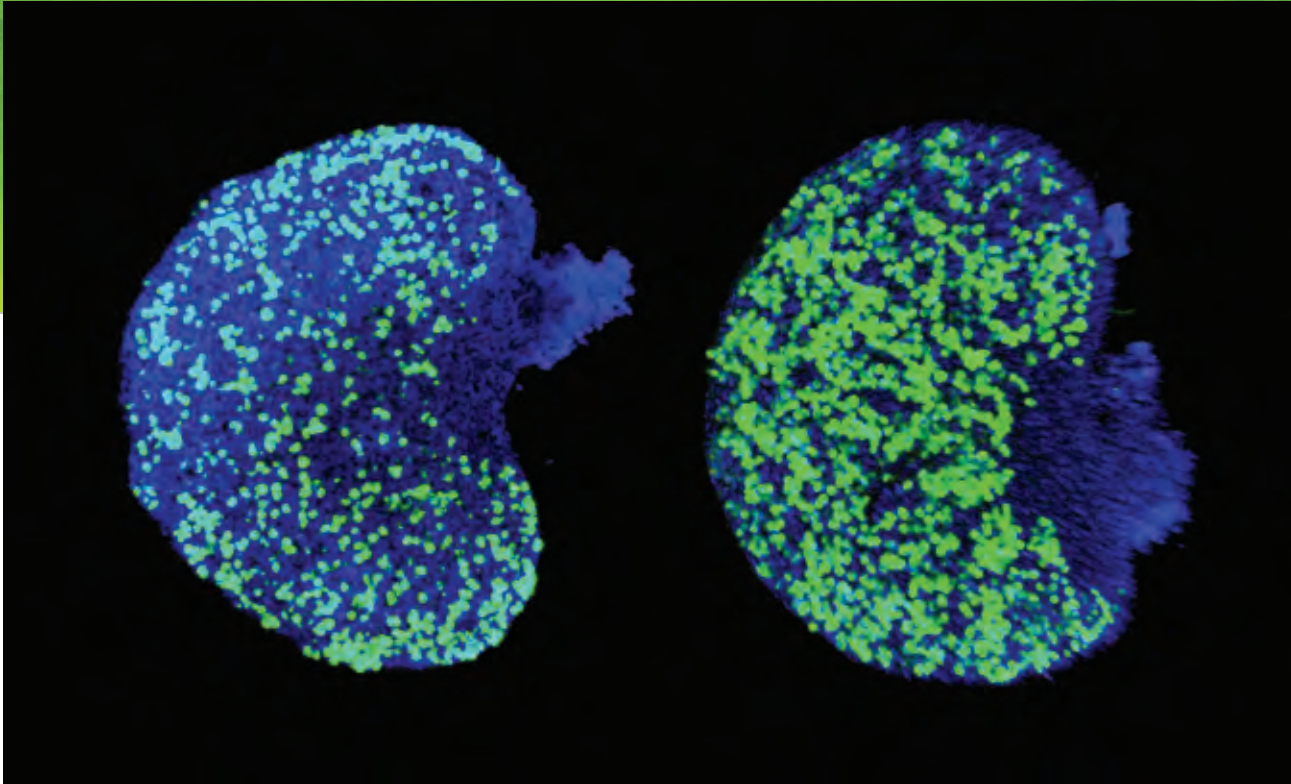
Carnegie postdoctoral fellow Safia Malki in the Bortvin group found that mouse oocytes repress transposons inefficiently. Because of this poor transposon silencing, every oocyte accumulates this potent mutagen. Malki correlated transposon abundance with oocyte viability and oocyte cell division reliability, which are critical for normal chromosome content. She found that a burst of activity of a single transposon in transgenic mice increased oocyte death. Most strikingly, Malki improved oocyte viability and prevented errors in chromosome segregation by blocking the ability of the transposon to copy itself using a drug that blocks multiplication of HIV, the AIDS-causing virus.

This unique mode of transposon control in mouse oocytes sheds light on two puzzles—prenatal death of most oocytes and the age-related increase in chromosome errors, such as those that cause Down syndrome. Malki and Bortvin speculate that the lax control of transposons in mice, and perhaps human oocytes, causes the elimination of oocytes with either highly active transposons or those incapable of more stringent transposon control.

The surviving oocytes may prevent excessive transposon alterations to the genomes and be better suited to support the healthy development of the next generation. The Malki and Bortvin findings also suggest that an ovary of a newborn girl already contains “good” oocytes as well as those predisposed for chromosomal errors. It may be the case that “good” oocytes are ovulated during first two decades of a female’s reproductive life, while “bad” ones are ovulated later.

**RIGHT:** Safia Malki and Alex Bortvin look at a monitor showing mouse ovaries.

*Image courtesy Alex Bortvin*



A normal (untreated) mouse ovary is at left. The ovary at right has been treated to prevent transposons—genes that jump around the genome—from killing oocytes (green) and causing chromosome abnormalities. Genomic DNA (blue) is in all cells of the organ.

*Image courtesy Alex Bortvin*



# Genetics/Developmental Biology

*Continued*

## New Class of RNA Discovered

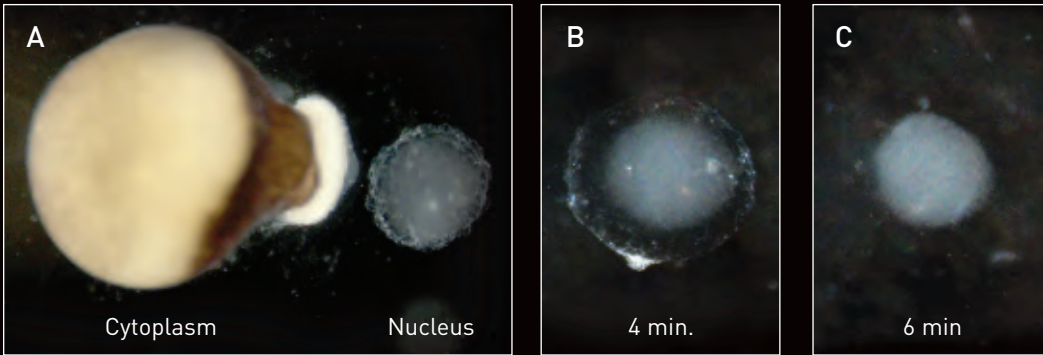
For genes to make proteins, information from a strand of DNA is first copied (transcribed) to a strand of RNA. This RNA then travels out of the cell nucleus to the cytoplasm, where the information it carries is translated into a protein. The process is complicated by the fact that each gene consists of alternating segments that code for the protein (exons) interspersed with segments that don't code at all (introns). The RNA transcribed from a gene initially contains both the exons and introns. Normally the non-coding introns are spliced out and then degrade quickly in the nucleus, and the resulting messenger RNA (mRNA) is exported to the cytoplasm.

To study this process in more detail the Gall lab decided to analyze nuclear and cytoplasmic RNA separately. They took advantage of the immature egg cell (oocyte) of the frog *Xenopus tropicalis*. The oocyte in this species is a giant cell nearly 1 millimeter in diameter containing a correspondingly giant nucleus. By manually separating nuclear and cytoplasmic fractions, they could study pure nuclear and cytoplasmic RNAs for the first time.

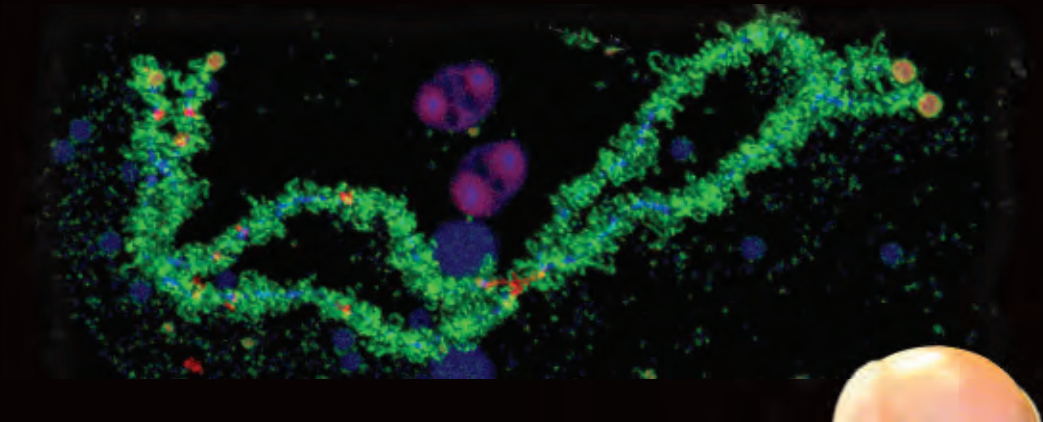
As expected, the cytoplasm contained spliced mRNA consisting solely of the coding exons. But the scientists were surprised by the nuclear RNA, which consisted of numerous stable fragments derived from the non-coding introns. The Gall team, including Eugene Gardner, Zehra Nizami, and Conover Talbot, named them stable intronic sequence (sis) RNA. Even more surprising, the sisRNA was transmitted intact to the embryo, suggesting that these tiny fragments may play previously unanticipated regulatory roles in egg and/or embryonic development.

These Gall lab studies grew out of a long-standing interest in the giant chromosomes found in the oocytes of frogs and other amphibians. These chromosomes are larger than chromosomes from any other source. They were named "lampbrush" chromosomes in the 19<sup>th</sup> century because of their resemblance to the brushes used to clean lamp chimneys. Lampbrush chromosomes transcribe RNA at an incredibly high rate, which may be necessary to accumulate all the RNAs needed within the large eggs of these animals, but many aspects of lampbrush chromosome structure and function remain a mystery. The scientists hope to extend their study of sisRNA to find out exactly how chromosomal RNA is transcribed and processed. ■

**RIGHT:** Information from a strand of DNA is first copied (transcribed) to a strand of RNA. This RNA then travels out of the cell nucleus to the cytoplasm, where the information it carries is translated into a protein. Each gene consists of segments that code for the protein (exons) and segments that do not code at all (introns). Initially, the RNA transcribed from a gene contains both the exons and introns. The non-coding introns are normally spliced out and then degrade quickly in the nucleus; the resulting messenger RNA (mRNA) travels to the cytoplasm.

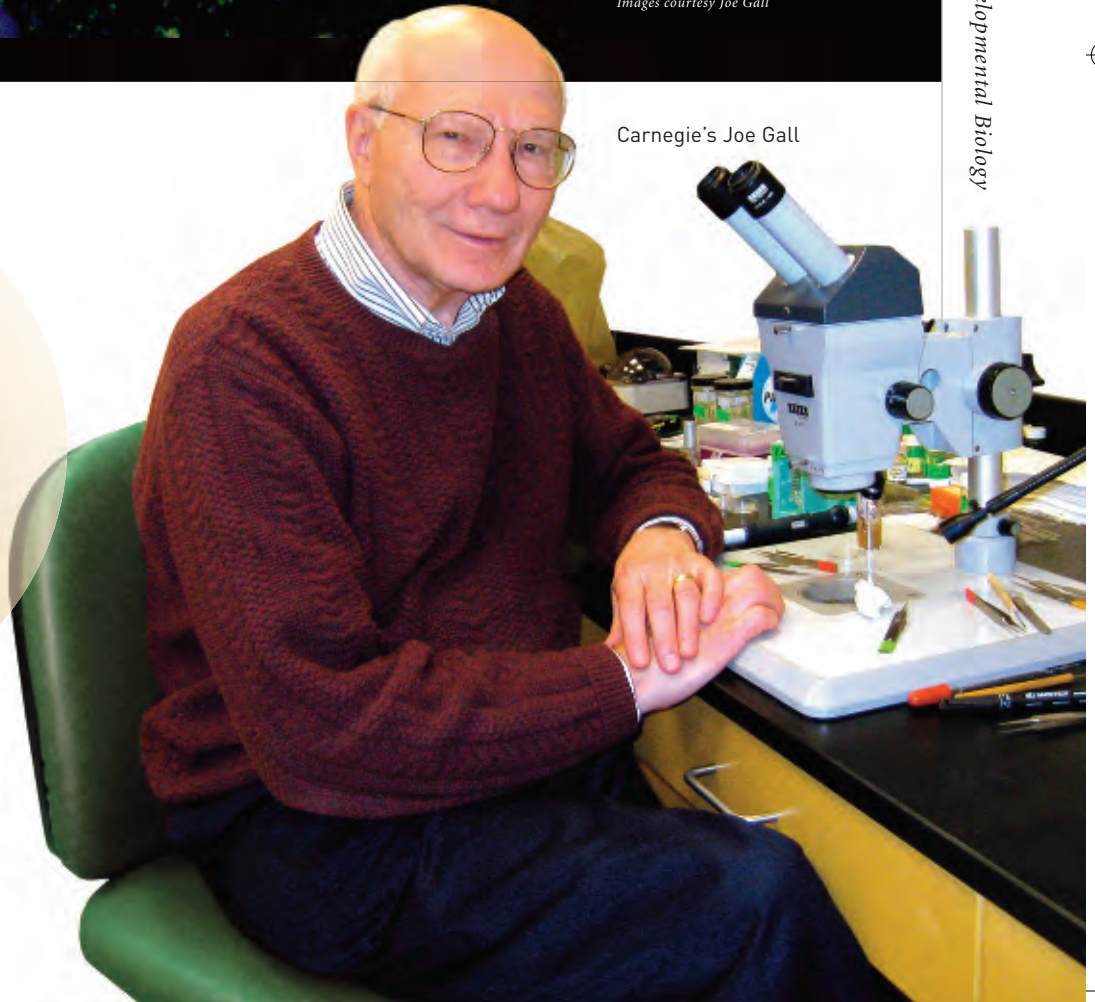
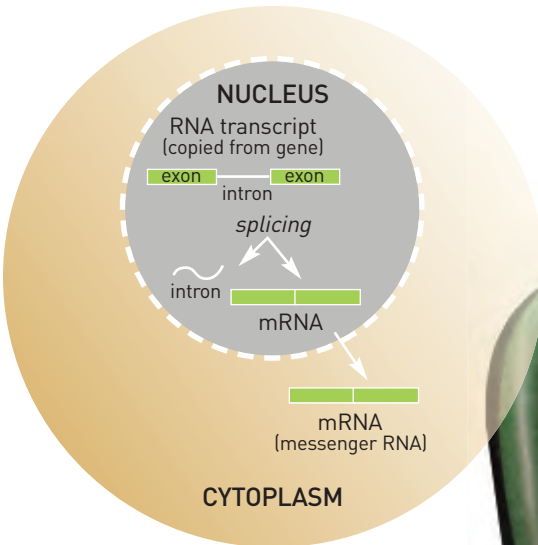


These images show the isolation of the nucleus from the immature egg called the oocyte (A), the nuclear envelope swollen away from the gelled nuclear contents (B), and nuclear envelope removal (C).



The Gall lab has been studying features of giant chromosomes (left) found in the oocytes of frogs and other amphibians for decades. These chromosomes are larger than any others, but the reason oocytes contain such unusual chromosomes largely remains a mystery.

*Images courtesy Joe Gall*



Carnegie's Joe Gall



# Global Ecology

*Linking Ecosystem Processes with Large-Scale Impacts*



## Coral Reefs in Danger: The Long View

Coral reefs are havens for marine biodiversity and underpin the economies of many coastal communities. But they are very sensitive to changes in ocean chemistry resulting from greenhouse gas emissions. In order to provide a historical perspective on environmental change, a team of scientists including Carnegie's Ken Caldeira and former-postdoc Kenneth Schneider compared the current growth of coral in a section of Australia's Great Barrier Reef to studies dating back to the 1960s and 1970s.

The hard parts of coral reefs are made primarily of calcium and carbon, whereas the soft parts are created by photosynthesis and lost by respiration. The team focused on rates of calcium carbonate ( $\text{CaCO}_3$ ) deposition and dissolution, as well as photosynthesis and oxygen respiration in the reef. They measured rates of coral reef net carbonate accumulation that are 44% lower than those measured 40 years ago. However, the rates of nighttime calcium carbonate dissolution are nearly three times higher today than they were in the study from the 1970s. Nevertheless, there has been no detectable change in the area of coral coverage.

The team suspects that the primary reason for the decline in reef growth is increasing ocean acidification, resulting from human-caused carbon dioxide emissions. These results are consistent with separate findings of Carnegie's Kate Ricke, along with Schneider and Caldeira, showing that—apart from the decline in reef growth—ocean chemistry is altered by climate change and that within a few decades there will no ocean anywhere with the chemical characteristics to support reef growth.

The team looked at microenvironments where the dissolution occurs, including the role of sea cucumbers—which live off the bits of organic matter in the carbonate sand and rubble that they ingest. Earlier research from Caldeira and Schneider found that these lowly organisms might be responsible for half of the  $\text{CaCO}_3$  dissolution of the reef observed at night.

Right now, this reef is growing more during the day than it is dissolving at night. But with greenhouse gas emissions contributing to ocean acidification, this situation is not likely to last. Since this is just one reef and one measurement period, the team could not draw global conclusions from their results. But their observations were consistent with the view that if carbon dioxide emissions are not abated, ocean acidification will continue over the coming decades and cause this reef to enter a state in which nighttime dissolution outweighs daytime growth.

**BOTTOM RIGHT:** Sea cucumbers like this *Stichopus hermanni* live off the bits of organic matter in the carbonate sand and rubble that they ingest. They might be responsible for half of the reef's calcium carbonate dissolution observed at night.

*Image courtesy Kenneth Schneider*





Caldeira and Schneider have studied coral in Australia's One Tree Island reef to determine how coral growth and dissolution has changed over the past 40 years.



Ken Caldeira is in action at Australia's One Tree Island.

*Image courtesy Ken Caldeira*





**RIGHT:** Brothers Bill (left) and Leander (right) Anderegg are planting young aspens for a drought experiment.

**FAR RIGHT:** The Anderegg brothers (Leander on left and Bill on right) are conducting a census of the aspen environment understory to understand how aspen die-offs affect other plant communities.

*Images courtesy Leander Anderegg*



# Global Ecology

*Continued*

## When Forests Crash

Widespread tree die-offs, often triggered by severe drought and rising temperatures, have devastated large swaths of several major North American forests and portend a bleak outlook for these forests as a result of climate change. Until recently, scientists knew relatively little about what types of drought are lethal and how trees die during severe drought, hindering their prediction of when and where forests might die-off as the climate warms.

A team of researchers led by brothers William Anderegg, a then-Ph.D. student, and Leander Anderegg, an undergraduate at the time, examined a recent widespread die-off of trembling aspen in the western U.S.

Along with staff scientist Joe Berry and director Chris Field, the Anderegg brothers unraveled the characteristics of the lethal drought and how the aspens died in a series of seven papers. They found that the recent die-off of Colorado trembling aspen trees was from decreased precipitation exacerbated by high summer temperatures during the 2000-2003 drought, leading to the most extreme summer water stress of the past century.

The Andereggs looked at different isotopic ratios of water in aspen sap to learn from where in the soil aspens take up water. They discovered that aspens generally use shallow soil moisture, which evaporated due to increased temperatures during the 2002 summer. They looked at climate data and found that these high temperatures were part of a long-term, increasing trend, likely linked with climate change.

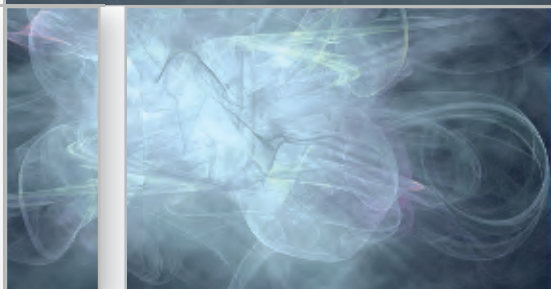
The brothers conducted several experiments. They subjected aspens to drought stress and observed trees dying in the wild to learn how they died. They learned that the drought damaged the ability of the trees to provide water to their leaves: The trees' "veins" became blocked. The failing hydraulic system drove the mortality, which has continued for a decade after the drought. Strikingly, they discovered that even the surviving trees are likely more vulnerable to future droughts, such as the severe 2012 drought. Finally, the brothers used this physiological knowledge to develop a predictive model to forecast when and where aspen trees might die in the future.

Forests store about 45% of the carbon found on land. Widespread tree death can radically transform ecosystems, affecting biodiversity, posing fire risks, and even harming local economies. Rapid shifts in ecosystems, particularly through vegetation die-offs, could be among the most striking impacts of climate change around the globe. ■



# Matter at Extreme States

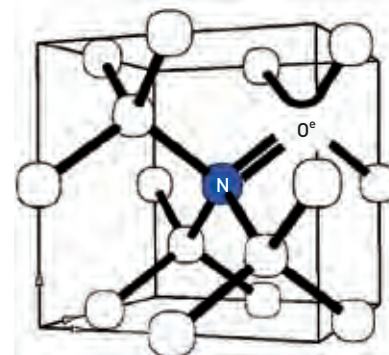
*Probing Planetary Interiors, Origins, and Extreme States of Matter*



## Diamond Defect Boosts Quantum Technology

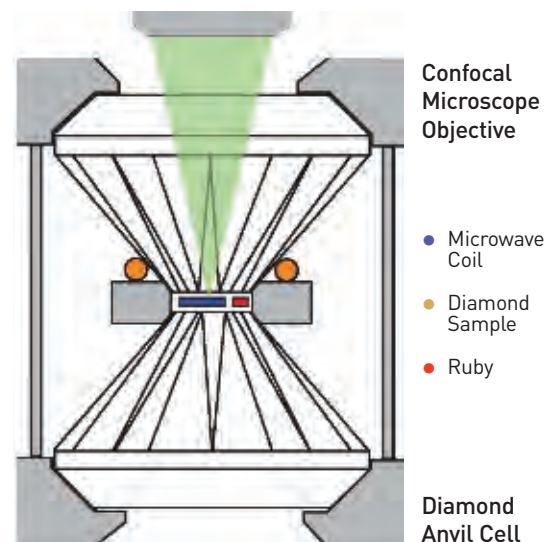
There is a remarkable defect in synthetic diamond produced by chemical vapor deposition that allows researchers to measure, witness, and potentially manipulate electrons in a way that may lead to new “quantum technology,” such as quantum computing. Normal computers process bits, the fundamental ones and zeros, one at a time. In quantum computing, a “qubit” can be a one or a zero at the same time. This state allows multitasking and could exponentially increase the computing capacity of a tiny machine.

The introduction of a nitrogen defect (N) within a diamond’s scaffold-like structure comes from a missing carbon atom that forms a vacancy (V), called the NV center. The vacancy neighbors a nitrogen atom. This center traps an electron, creating a negatively charged (NV-) center. Monitoring the center’s behavior provides a window to understand how electrons respond to different conditions and the potential to serve as a “qubit” in future quantum computers.



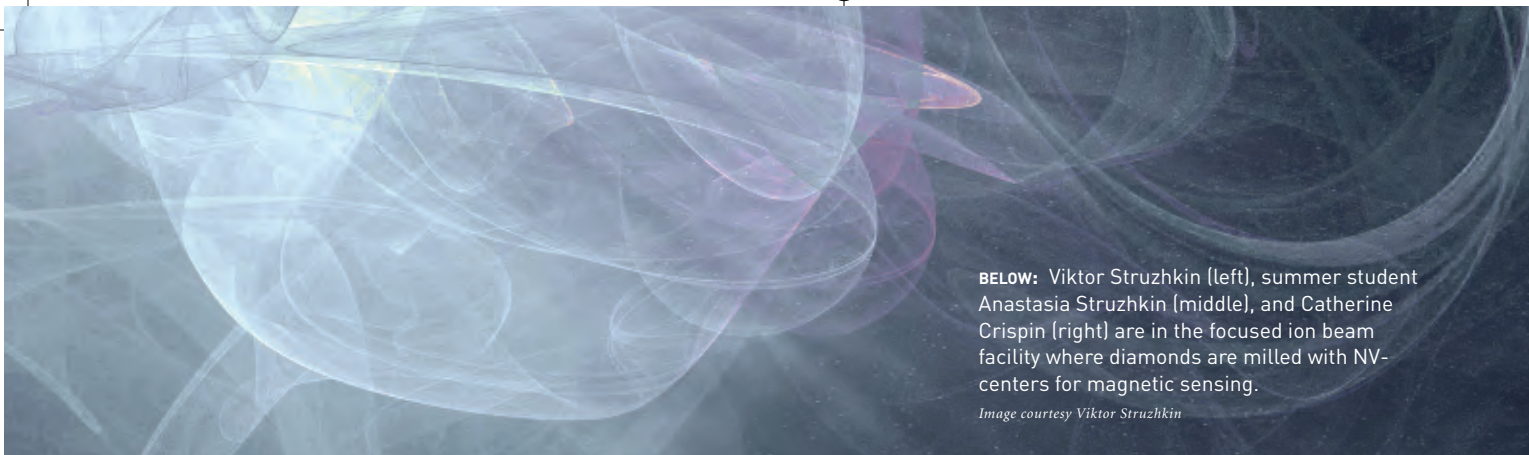
This diagram shows the scaffolding-like structure of a diamond that is lacking a carbon atom at the NV-center. The additional electron trapped at the center offers researchers a window to understand electron behavior.

*Image courtesy WikiCommons*



This diagram shows a diamond anvil cell with the laser light and a sample in place; this cell is part of the optically detected magnetic resonance system.

*Image courtesy Viktor Struzhkin*



**BELOW:** Viktor Struzhkin (left), summer student Anastasia Struzhkin (middle), and Catherine Crispin (right) are in the focused ion beam facility where diamonds are milled with NV-centers for magnetic sensing.

*Image courtesy Viktor Struzhkin*

Electrons occupy different orbits around their atom and, by analogy, spin like the Earth. For the first time, Viktor Struzhkin and his team observed what happens to electrons in these NV- centers under high-pressure and normal temperatures. Their technique offers a powerful new tool for analyzing and manipulating electrons to advance our understanding of high-pressure superconductivity, as well as magnetic and electrical properties.

Struzhkin and team subjected single-crystal diamonds to pressures up to 600,000 times atmospheric pressure at sea level (60 gigapascals, GPa) in a diamond anvil cell and observed how electron spin and motion were affected. They optically excited the NV- centers with light and scanned microwave frequencies in a process called optically detected magnetic resonance to determine changes. The NV- center is very sensitive to magnetic fields, electrical fields, and stress. The experiment was made possible by the use of the recently acquired focused ion beam (FIB).

Until now, researchers thought that electrons immediately surrounding the vacancy area contributed to the electronic structure and spin dynamics. This team found instead that the greatest contributions come from more distant electronic states starting at next-to-nearest neighbor atoms.

In addition to overturning previous beliefs about electron structure and spin, the researchers found a sensitive means to measure pressure. This method can detect changes in pressure of about 10 atmospheres after one second. The team found that even up to pressures of 500,000 atmospheres (50 GPa), pressure can be controlled to a fraction of an atmosphere on timescales of seconds.





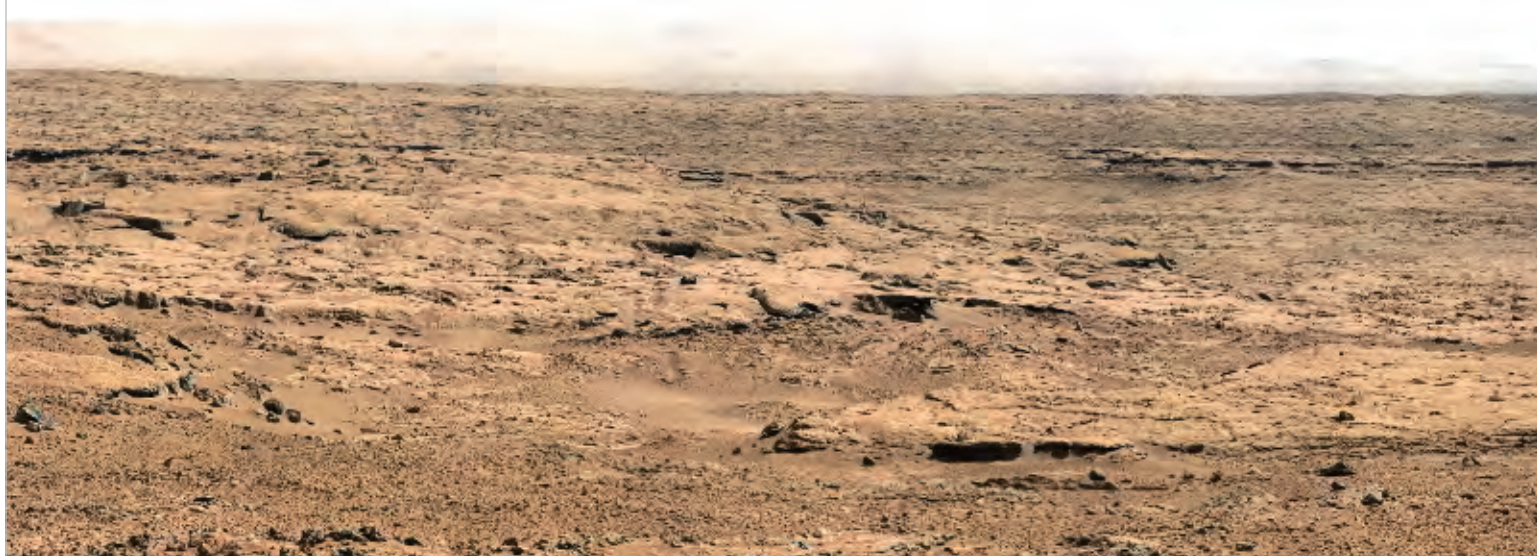
The unusual Martian meteorite, Northwest Africa (NWA) 7034, is the first meteorite that scientists have found that is linked to the Martian crust.

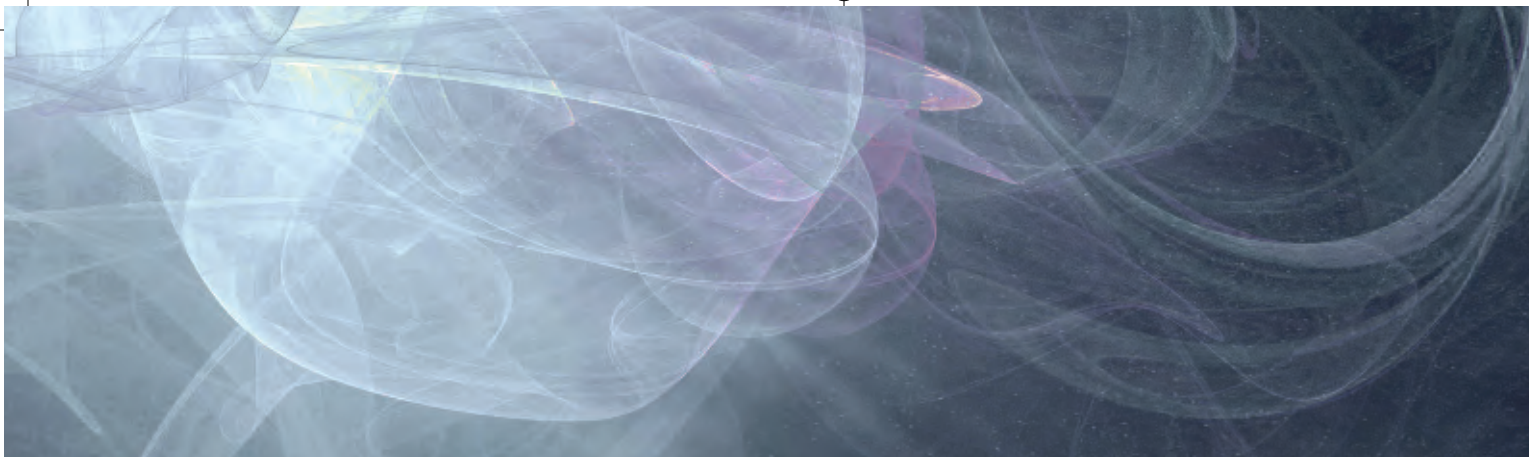
*Image courtesy Carl Agee, University of New Mexico*

## Martian Carbon Conundrum

Molecules containing large chains of carbon and hydrogen—the building blocks of life—have been the tantalizing targets of many Mars missions. Theories about the origin of the large carbon macromolecules in Martian meteorites include contamination from Earth or other meteorites, chemical reactions on Mars, or remnants of ancient Martian life. Andrew Steele and team have been studying meteorites to determine the sources and processing of this carbon.

In one study, Steele's team examined samples from 11 Martian meteorites whose ages span about 4.2 billion years. They detected in 10 of the samples large carbon compounds in mineral grains that crystallize at high temperatures. Using sophisticated techniques, the team showed that some of the carbon was from meteorites and not from contamination, but that the carbon was not biological in origin.





They then looked at the carbon molecules in relation to other minerals to understand the chemical processing. They found that the carbon was created during volcanism on Mars, showing that the planet has undertaken organic chemistry for most of its history.

The team also studied the Allan Hills 84001 meteorite that was reported to contain relicts of ancient biology. But Steele found that the material could have been created by incomplete chemical reactions that produce the graphite form of carbon and not by biological processes.

Recently Steele's team helped colleagues study a new class of Martian meteorite that likely originated from the Martian crust. The meteorite, NWA 7034, has an order of magnitude of more water than any other Martian

meteorite and its texture is different. It has cemented fragments of basalt, which forms from rapidly cooled lava, with feldspar and pyroxene, most likely from volcanism. This composition is common for lunar samples but not for other Martian meteorites. Steele and his team studied organic carbon within the feldspar. Although the carbon is similar to other Martian meteorites, a different non-biological process was at work.

Overall these and other investigations have identified both cooling magma and hydrothermal origins for organic carbon in Martian meteorites. Their invaluable insights are being applied to NASA's Curiosity and Sample Analysis at Mars (SAM) missions, of which Steele is a member, in their search for organics on the surface. ■

This image of the Martian surface is a panoramic mosaic of several images taken by NASA's Curiosity rover. The Martian meteorites that Andrew Steele and others study are rocks that were ejected from the Red Planet by an asteroid or other impact years ago; the rocks later landed on Earth. Scientists can tell these meteorites are from Mars because their composition matches the compositions of rocks on Mars that various Martian missions have analyzed.

*Image courtesy NASA/JPL-Caltech/Malin Space Science Systems*



# Plant Science

## *Characterizing the Genes of Plant Growth and Development*



46

Plant Science

### Codependency Breakdown

Coral reefs support some 25% of ocean biodiversity, but these reefs have dramatically deteriorated in recent decades. Up to 70% have either died or are now stressed, as a result of coral “bleaching” largely due to climate change. The nutrient-providing single-celled alga *Symbiodinium*, which lives within the host coral’s tissue, loses pigmentation and the capacity to perform photosynthesis and/or is expelled from the host. Although much is known about the environmental causes of bleaching, little is known about the cellular and molecular events that lead to the breakdown between these codependent partners. Arthur Grossman’s lab and colleagues at Stanford University are taking new approaches to the problem.

There is a large diversity of corals and related organisms, such as sea anemones, that harbor symbiotic algae. These algae provide their hosts with fixed carbon and energy through photosynthesis. In exchange, the algae receive a safe haven and a uniform environment within the host tissue. The Grossman lab has been developing methods to isolate pure cultures of different groups of *Symbiodinium* from corals and sea anemone. They have worked with Stanford’s John Pringle to develop and exploit a proxy

system to introduce the isolated alga into the sea anemone *Aiptasia pallida*, which grows much faster than corals, to examine host-symbiont molecular interactions.

The group has also worked to understand photosynthetic processes and the connection to the mechanisms behind coral bleaching. Elevated oceanic temperatures—a consequence of CO<sub>2</sub> emissions and global warming—can trigger bleaching by disrupting photosynthetic processes, leading to the production of extremely damaging reactive oxygen species (ROS). ROS, which are generated at high rates in light, interact with various molecules in the cell, cause disruption of normal cellular processes, and ultimately cause bleaching and cell death.

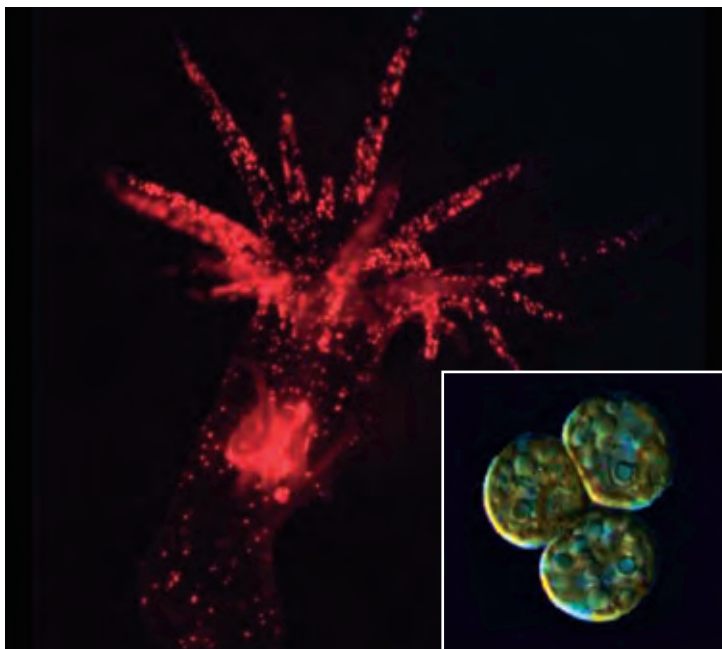
To examine the process of bleaching in more detail, the scientists used the proxy *Aiptasia-Symbiodinium* system and the field-collected corals to determine whether bleaching could occur in the dark—at a time when there is no photosynthetically generated ROS. Surprisingly, both the corals and the sea anemone experienced bleaching with increasing temperature, even in total darkness; bleaching, mostly from expulsion of alga from the host, was similar in the light and in the dark. Moreover, damage to the photosynthetic apparatus occurred at elevated temperatures, even in the dark. This work shows that there is more than one pathway leading to bleaching and could affect the strategies used for remediation.

**BOTTOM RIGHT:** Arthur Grossman and team used the host sea anemone *Aiptasia pallida* (left in image) to understand the molecular interactions of bleaching between it and its symbiont, the single-celled algae *Symbiodinium* (below).

*Images courtesy Arthur Grossman*



Corals, such as those shown here, support some 25% of ocean biodiversity. They have dramatically deteriorated in recent decades, largely as a result of climate change.



Arthur Grossman

*Image courtesy Robin Kempster*

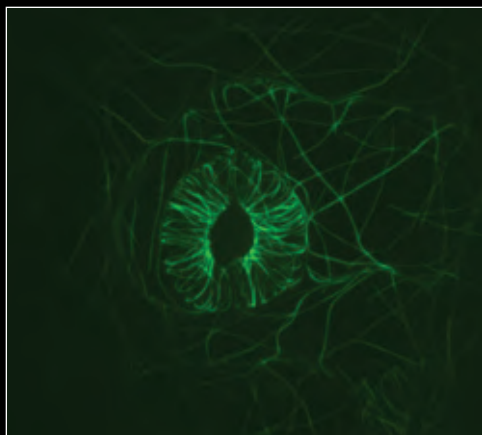
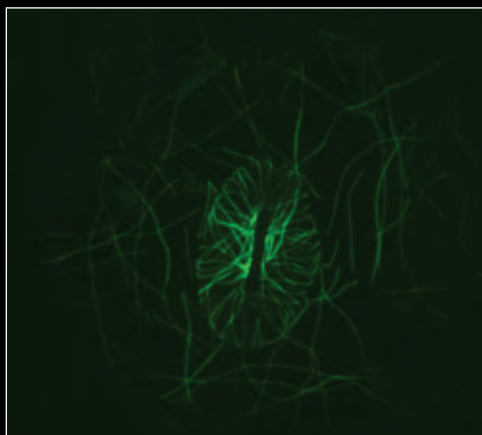






# Plant Science

*Continued*



**ABOVE LEFT:** These tiny mouth-like structures on plant leaves and stems are composed of two cells on the either side of a tiny pore. These guard cells control the opening and closing of the pores to regulate carbon dioxide intake and the release of oxygen and water.

*Image courtesy Winslow Briggs*

**ABOVE RIGHT:** Rajnish Khanna (foreground) is a visiting scientist in the Winslow Briggs (left) lab. His interdisciplinary research of cellular mechanisms regulating stomatal function in plant responses is helping unravel how plants respond to environmental signals.

*Image courtesy Robin Kempster*



## How Guard Cells Guard

Plants have tiny pores called stomata on their leaves and stems. Stomata regulate carbon dioxide intake and the release of oxygen and water. A pair of guard cells controls the pores' openings and closings in response to environmental changes. But understanding how these guard cells perform this essential regulation has been elusive. Researchers in the Briggs and Ehrhardt labs have shown for the first time that subcellular structures called microtubules are involved in guard-cell function. This finding could be important for crop improvement and adapting plants to climate change.

Until now, plant microtubules were known to help shape growing cells and to move chromosomes during cell division. Their major protein is called tubulin. Microtubules "move" by growing at one end and shortening at the other, one tubulin molecule at a time, and they often associate with one another into bundles. Guard cells are unique in that their microtubules are radially arranged.

The researchers tagged tubulin with a green fluorescent protein to study microtubule behavior. They used live confocal imaging to see if guard-cell function is related to changes in the microtubules. When the stomata opened, the fluorescence was more intense. The researchers induced the pores to close with darkness, a drought-response hormone, hydrogen peroxide, and sodium hydrogen carbonate. In each case there was a decline in the number of visible microtubules. The scientists found that the number of growing ends and their rate of growth did not change, but that there was significantly less tubulin in the closed state. They believe that the decline is related to microtubule degradation at the non-growing end.

The researchers wondered if aggregation was involved. Using live 3-D imaging they found that when guard cells open, the pores' microtubule fluorescence tripled. In the open state there is more tubulin and more association among the proteins.

The researchers examined whether the function of the microtubules was affected by two microtubule inhibitors. One inhibitor, oryzalin, disaggregates microtubules. In its presence, the stomata close in the dark but no longer open in the light. Another inhibitor, taxol, serves to stabilize microtubules. In its presence, stomata will open in the light but fail to close in the dark. The results confirm the close association between microtubules and the functioning of stomata. Very recently the Ehrhardt laboratory also described another dramatic change involving blue light and microtubules, which could change our understanding of the growth changes accompanying the development of phototropic curvature. ■



# First Light & The Carnegie Academy for Science Education (CASE)

*Teaching the Art of Teaching Science and Math*



## Continuing Friendship and STARs

The Friendship Collegiate Academy public charter school in northeast Washington, D.C., and CASE continued their professional development partnership in science, technology, engineering, and math (STEM) fields.

This summer, eighteen 9<sup>th</sup>-12<sup>th</sup> grade science, mathematics, technology, and dance teachers participated in the program. The teachers learned how to conduct experiments in the manner of professional laboratories, they connected the mathematics in science to mathematics classes and vice versa, and they developed a fresh awareness of what it is like to be a student.

In two one-week sessions, CASE modeled project-based laboratory learning using the newly debuted CASE STEM Kits. Carnegie scientists discussed their scientific research and career paths. The teachers learned ways to manage their classes like a professional lab, working in research teams that changed members and size as the science and materials might dictate. Teachers gave presentations on what they experienced; most chose to role-play the old and new teaching methods. One point became clear: Math and science are inextricably linked and are not isolated topics.

The kit “Experiment with Enzymes” develops students’ abilities to observe and design an assay procedure to characterize an enzyme. An industrial application prompted the project-based scenario: What conditions provide a specified amount of oxygen gas in exactly one minute? Using the second kit, “Bacterial Transformation,” teachers transferred DNA to bacteria to confer antibiotic resistance to the cells. Although versions of these kits have been operating since the 1990s, the CASE STEM Kits incorporate the new Next Generation Science Standards and Advanced Placement Biology curriculum.

Julie Edmonds runs the Student Teacher Astrobiology Researchers (STARs) program to teach teachers and students about astrobiology, the science of the origin of life and where it could exist. One teacher from Woodrow Wilson High School, another from Coolidge High School, and nine Washington, D.C., high school students participated. The objective was to find and characterize interesting organisms on “Planet Carnegie” (Carnegie headquarters). Researchers from Carnegie’s NASA Astrobiology Institute, including George Cody, Alycia Weinberger, Derek Smith, and Verena Starke, also participated.





**ABOVE:** Student Teacher Astrobiology Researchers (STARs) teachers and students learn about astrobiology, the science of the origin of life and where it could exist, in the First Light lab in Carnegie's administration building.

*Image courtesy Toby Horn*

**LEFT:** Friendship Collegiate Academy teachers learn how the new "Experiment with Enzymes" CASE STEM Kit characterizes enzymes so that they can use the kit later in their classrooms.

*Image courtesy Toby Horn*



# First Light & The Carnegie Academy for Science Education (CASE)

*Continued*



**BELOW LEFT:** Newly arrived 2013 Math for America DC Fellows participate in a "Math on the Mall" tour in Washington, D.C. From left to right: Amanda Shuman, Dan Oldakowski, Dale Glasspiegel, Candace Farrell, mentor Guy Brandenburg, Erin Goers, Catherine Day, and Genesis Docena. Carnegie launched Math for America DC and houses its staff, but it is now a separate organization.

*Image courtesy Monica Thomas*

## Math for America DC Gaining Ground

Two main initiatives in Math for America DC (MfA DC) are the Fellowship Program and the Master Teacher Program. The fellowship program, launched in 2008, now has a total of 28 fellows. The number of experienced math teachers in the Master Teacher Program has grown from one master teacher in 2011 to five in 2013.

Twenty-one MfA DC Fellows are teaching sixth to twelfth graders in high-need public and charter schools in Washington, D.C. The others are working towards their master's degrees at American University. After completing their training program, MfA DC Fellows commit to four years of teaching in D.C. schools. Overall, MfA DC Fellows have taught some 1,500 students. The program, funded by NSF, Math for America in New York, and private donations, covers tuition, fees, healthcare, and stipends during training and teaching.

The fellows go through a rigorous selection and orientation process. Twenty-five potential fellows went through two rounds of interviews with a panel of MfA DC mentors, staff, master teachers, and American University faculty; only seven were appointed to the current cohort.



Monica Thomas is the program manager for Math for America DC.



Marlena Jones is the Math for America DC Master Teacher program coordinator.

To qualify for the Master Teacher Program, master teacher candidates must be outstanding, experienced public school teachers who have taught math for at least four years and have demonstrated leadership in their schools and beyond. The program's goal is to establish a community of leaders in mathematics in the larger community who teach mathematics in an engaging way and who can guide and mentor MfA DC Fellows. These master teachers, who receive stipends, commit to teaching five years in the D.C. school system.

Both groups receive regular professional development from James Tanton, who emphasizes the understanding of underlying math concepts instead of rote memorization. The groups receive regular mentoring and coaching, and they network extensively within the mathematics-teaching community. ■

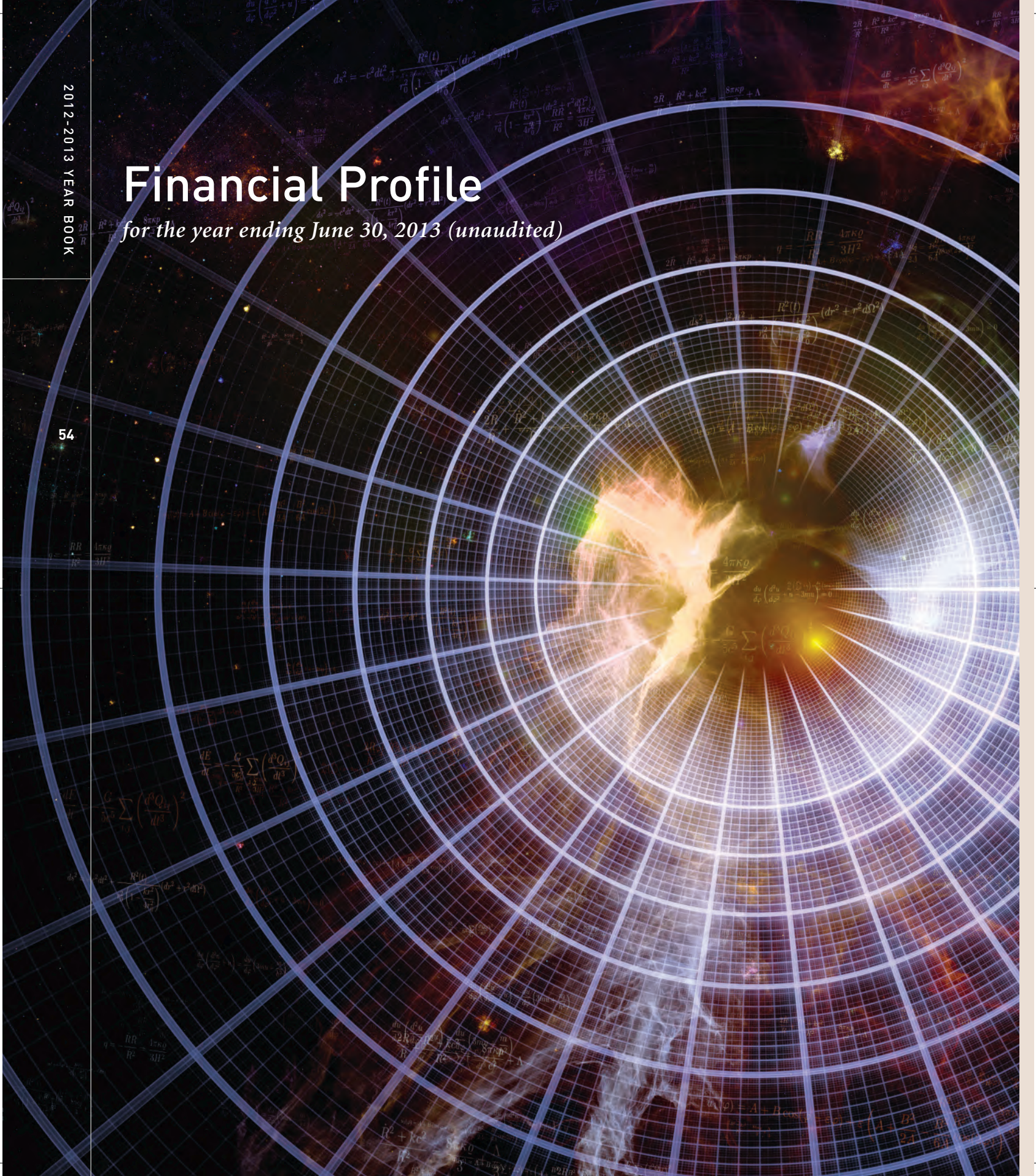


*Images courtesy Monica Thomas*



# Financial Profile

for the year ending June 30, 2013 (unaudited)



**Reader's Note:** *In this section, we present summary financial information that is unaudited. 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](http://www.CarnegieScience.edu).*

The Carnegie Institution of Washington completed fiscal year 2013 in sound financial condition due to the positive returns (+14.0%) of 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, 2013, the endowment was valued at \$855 million. Over the period 2001-2013, average annual 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 Finance committee of the board, Carnegie's endowment has been allocated among a broad spectrum of asset classes including: fixed-income instruments (bonds), equities (stocks), absolute return investments, real estate partnerships, private equity, and natural resources partnerships. The goal of this diversified approach is to generate attractive overall performance and minimize the volatility that would exist in a less diversified portfolio.

The Finance committee of the board regularly examines the asset allocation of the endowment and readjusts 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, 2013.

Asset Class	Target	Actual
Common Stock	37.5%	40.6%
Alternative Assets	55.0%	53.9%
Fixed Income and Cash	7.5%	5.5%



*Carnegie Institution for Science*

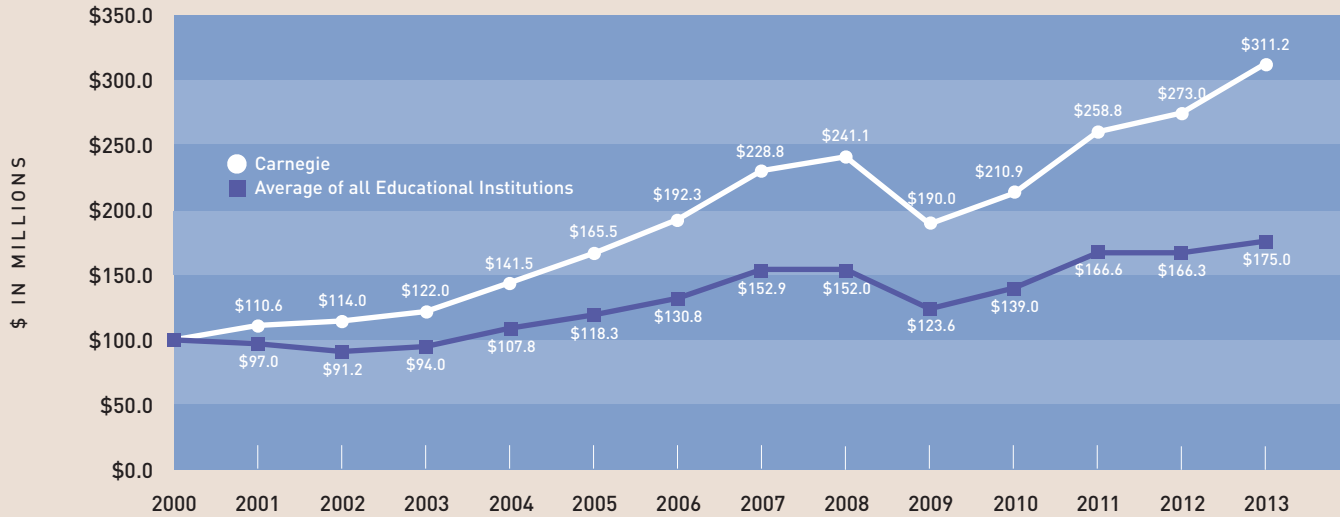
Carnegie's investment goals are to provide high levels of current support to the institution and to maintain the long-term spending power of its endowment. The success of Carnegie's investment strategy is illustrated in the following figure that compares, for a hypothetical investment of \$100 million, Carnegie's investment returns with the average returns for all educational institutions for the last thirteen 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 5.00% 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 5.0% and adjusted for inflation and for debt. This method reduces volatility from year-to-year. The following figure depicts actual spending as a percentage of ending market value for the last 20 years.

In fiscal year 2013, Carnegie benefitted from continuing federal support. Carnegie's federal support has grown from \$24.5 million in 2006 to more than \$37.8 million in new grants in 2013. 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.

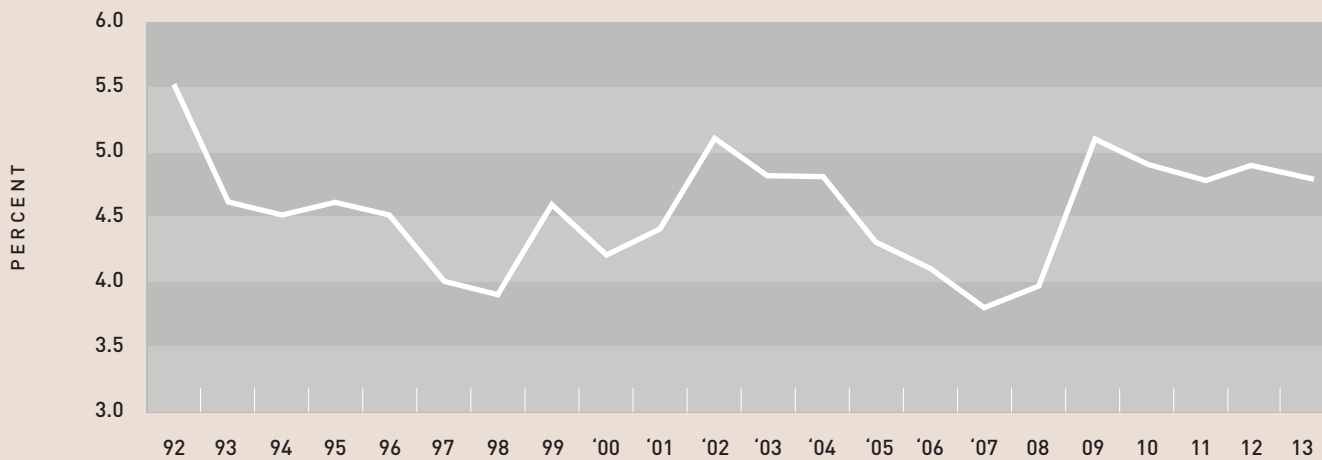
Carnegie also benefits from generous support from foundations and individuals. Funding from foundations has grown from an average of about \$3 million/year in the period from 2000 to 2004 to \$7.6 million in 2013. Within Carnegie's endowment, there are a number of "funds" that provide support either 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 2013 appears in an earlier section of this year book. In addition, Carnegie receives important federal and 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 (2000-2013)



Average returns for educational institutions are taken from Commonfund reports on endowment performance.

### Endowment Spending as a Percent of Ending Endowment Value\*



\*Includes debt financing.

*Carnegie Institution for Science***Statements of Financial Position (Unaudited)**

June 30, 2013, and 2012

	2013	2012
<b>Assets</b>		
Current assets:		
Cash and cash equivalents	\$ 2,131,428	\$ 2,224,055
Accrued investment income	17,496	47,721
Contributions receivable	14,100,999	18,495,658
Accounts receivable and other assets	10,423,326	21,436,261
Bond proceeds held by Trustee	15,698	15,694
<b>Total current assets</b>	<b>\$ 26,688,947</b>	<b>\$ 42,219,389</b>
Noncurrent assets:		
Investments	856,597,311	794,835,568
Property and equipment, net	160,452,487	152,340,983
<b>Total noncurrent assets</b>	<b>\$1,017,049,798</b>	<b>\$947,176,551</b>
<b>Total assets</b>	<b>\$1,043,738,745</b>	<b>\$989,395,940</b>
<b>Liabilities and Net Assets</b>		
Accounts payable and accrued expenses	\$ 9,559,263	\$ 11,449,485
Deferred revenues	28,235,748	29,670,190
Bonds payable	65,685,422	65,706,919
Accrued postretirement benefits	20,356,658	19,991,999
<b>Total liabilities</b>	<b>\$ 123,837,091</b>	<b>\$126,818,593</b>
<b>Net assets</b>		
Unrestricted	\$ 273,199,070	\$253,993,414
Temporarily restricted	591,675,668	553,628,669
Permanently restricted	55,026,916	54,955,264
<b>Total net assets</b>	<b>\$ 919,901,654</b>	<b>\$862,577,347</b>
<b>Total liabilities and net assets</b>	<b>\$1,043,738,745</b>	<b>\$989,395,940</b>

**Statements of Activities<sup>1</sup> (Unaudited)**

Periods ended June 30, 2013, and 2012

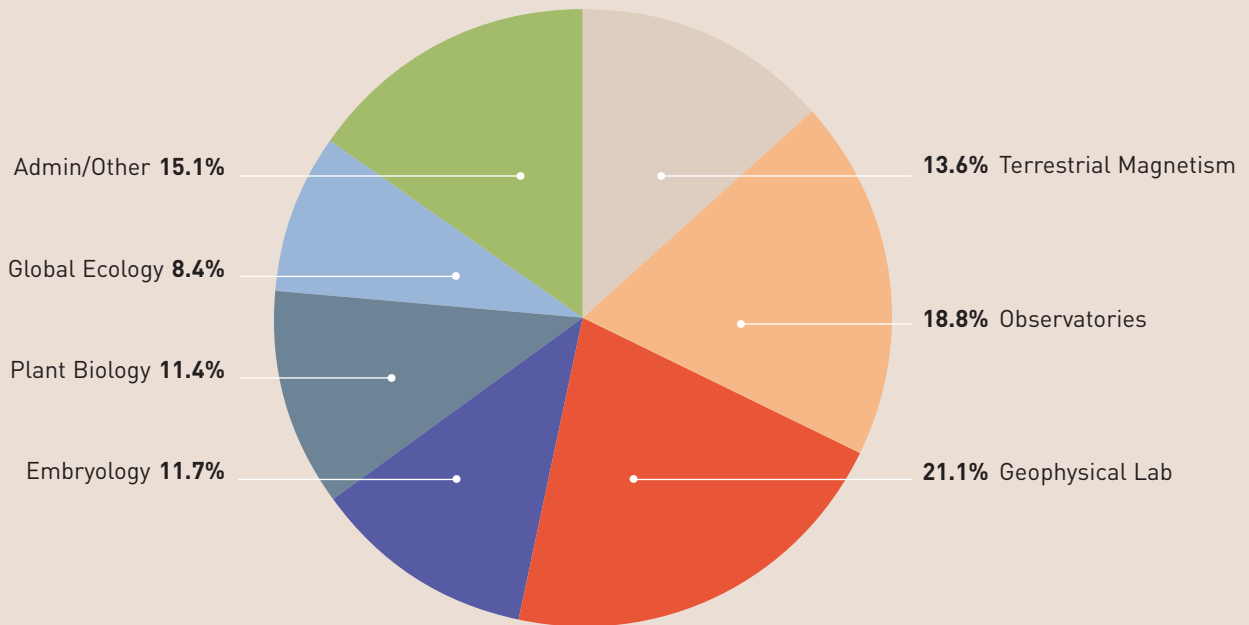
	2013	2012
Revenue and support:		
Grants and contracts	\$ 38,545,813	\$ 40,529,751
Contributions, gifts	9,916,611	26,801,795
Other income	342,775	7,820,546
Net external revenue	\$ 48,805,199	\$ 75,152,092
Investment income and unrealized gains (losses)	\$ 107,781,363	\$ 36,181,149
Total revenues, gains, other support	\$ 156,586,562	\$ 111,333,241
Program and supporting services:		
Terrestrial Magnetism	\$ 13,540,172	\$ 14,972,184
Observatories	18,733,368	20,071,881
Geophysical Laboratory	21,003,255	20,425,062
Embryology	11,643,914	11,467,512
Plant Biology	11,327,868	10,778,313
Global Ecology	8,427,241	8,241,999
Other programs	757,789	852,665
Administration and general expenses	14,341,283	11,259,427
Total expenses	\$ 99,774,890	\$ 98,069,043
Change in net assets before pension related changes	\$ 56,811,672	\$ 13,264,198
Pension related Changes	512,635	(2,079,935)
Net assets at the beginning of the period	\$ 862,577,347	\$ 851,393,084
Net assets at the end of the period	\$ 919,901,654	\$ 862,577,347

<sup>1</sup> Includes restricted, temporarily restricted, and permanently restricted revenues, gains, and other support.



*Carnegie Institution for Science*

### 2013 Expenses by Department (\$99.8 Million)





# Science Sampler

2012-2013 YEAR BOOK

61



# Small Size, Huge Impact

*Some 80 Carnegie investigators, with postdoctoral fellows and other colleagues, a dedicated support staff of instrument builders and technicians, business administrators, facilities staff, and more contributed to some 795 papers published in the most prestigious scientific journals during the last year. A sampling follows. Many discoveries were widely covered by the media.*

For a full listing of personnel and publications see:  
<http://carnegiescience.edu/yearbook2013>

1  
Year

80  
Carnegie  
Investigators

795  
Published  
Papers







## The Department of Embryology Genetics/Developmental Biology

### Carnegie Investigators

#### Research Staff Members

**Alexsky Bortvin**  
**Donald D. Brown**, *Director Emeritus*  
**Chen-Ming Fan**  
**Steven Farber**  
**Joseph G. Gall**  
**Marnie Halpern**  
**Nicholas T. Ingolia**  
**Allan C. Spradling**, *Director*  
**Yixian Zheng**

#### Staff Associates

**Jeffrey Han**  
**David MacPherson**  
**Christoph Lepper**

### Representative Papers

Aversive cues fail to activate fos expression in the asymmetric olfactory-habenula pathway of zebrafish  
*Frontiers in Neural Circuits* 7, 98, doi: 10.3389/fncir.2013.00098, 2013

Female mice lack adult germline stem cells, but sustain oogenesis using stable primordial follicles  
*Proceedings of the National Academy of Sciences USA* 110, 8585-8590, 2013

Ovulation in *Drosophila* is controlled by secretory cells of the female reproductive tract  
*eLife* 16;2:e00415. doi: 10.7554, 2013

Regulation of pluripotency and self-renewal of ES cells through epigenetic threshold modulation and mRNA pruning  
*Cell* 151, 576-589, 2012

Stable intronic sequence RNA (sisRNA), a new class of noncoding RNA from the oocyte nucleus of *Xenopus tropicalis*  
*Genes & Development* 26, 2550-2559, 2012

Visualization of lipid metabolism in the zebrafish intestine reveals a relationship between NPC1L1-mediated cholesterol uptake and dietary fatty acid  
*Chemistry & Biology* 19, 913-925

**Front row (left to right):** Allan Spradling, Yixian Zheng, Joseph Gall, Marnie Halpern, Alex Bortvin, Steve Farber, Chen-Ming Fan, Fred Tan. **Second row:** Antara Ghosh, Ella Jackson, Rejeanne Juste, Zehra Nizami, Lynne Hugendubler, Pat Cammpn, Ankita Das, Glenese Johnson, Wilber Ramos. **Third row:** Jen Anderson, Zhonghua Liu, Jui-Ko Chang, Ming-Chia Lee, Allison Pinder, Lakshmi Gorrepati, Stephanie Kuo, Megha Ghildiyal. **Fourth row:** Gaelle Talhourne, Sveta Deryusheva, Mike Harris, Weiren Liu, Nick McGlincy, Christine Simbolon, Micah Webster, Kiara Eldred, Joseph Tran, Marlow Minor, Lei Lei. **Fifth row:** Abi Subhedi, Will Yarosh, Steven Ching, Vanessa Quinlivan-Repasi, Jess Otis, James Thierer, Arash Adeli, Elim Hong, Tagide deCarvalho, Ethan Greenblatt. **Sixth row:** Michelle Roza, Xiaobin Zheng, Mike Sepanski, Yuxuan Guo, Shiyang Jin, Andrew Levitt, Rebecca Obniski, Dianne Williams, Erik Duboue, Michael Thomsen. **Seventh row:** Gennadiy Klimachev, Bob Levis, Carol Davenport, Vicki Losick, Erin Zeituni, Sheryl Murray, Yihan Wan, Steve DeLuca. **Eight row:** Mary Best, Lydia Li, Youngjo Kim, Simen Vlasov, Eugenia Dikovskaia, Tyler Harvey, Matt Sieber, Pavol Genzor, Safia Malki, Mahmud Siddiqi, Rosa Alcazar, Allen Strause. **Back row:** Pedram Nozari, Troy Horn, Gregory Moore, Bill Kupiec, Tom McDonough, Dolly Chin.



## The Geophysical Laboratory Matter at Extreme States, and Earth and Planetary Sciences

### Carnegie Investigators

#### Research Staff Members

**George D. Cody**  
**Ronald E. Cohen**  
**Yingwei Fei**  
**Alexander F. Goncharov**  
**Robert M. Hazen**  
**Russell J. Hemley**  
**Ho-kwang Mao**  
**Bjørn O. Mysen**  
**Douglas Rumble III**  
**Anat Shahar**  
**Andrew Steele**  
**Timothy A. Strobel**  
**Viktor V. Struzhkin**

### Representative Papers

Electronic excitations and metallization of dense solid hydrogen  
*Proceedings of the National Academy of Sciences USA 110, 13757-13762, 2013*

Melting Earth's core  
*Science 340, 442-443, 2013*

Mineral evolution  
*McGraw-Hill Yearbook of Science & Technology 2013, pp. 247-249*  
McGraw-Hill, New York, 2013

Pressure-induced superconductivity in CaC<sub>2</sub>  
*Proceedings of the National Academy of Sciences USA 110, 9289-9294, 2013*

Unique meteorite from early Amazonian Mars: Water-rich  
basaltic breccia Northwest Africa 7034  
*Science 339, 780-785, 2013*

**Front row (left to right):** Neil Bennett, Charles Le Losq, Joseph Lai, Gary Bors, George Cody, Danielle Appleby, Alia Awadallah, Russell Hemley, Yingwei Fei, Andrea Mangum. **Second row:** Quintin Miller, Andrew Steele, Dyanne Furtado, Merri Wolf, Gabor Szilagyi, Jabrane Labidi, Timothy Strobel, Robert Hazen, Zhisheng Zhao, Sergey Lobanov, Bjorn Mysen, Stephen Gramsch, Dionysis Foustoukos. **Third row:** Stephen Hodge, Amol Karandikar, Stevce Stefanoski, Roxane Bowden, Caitlin Murphy, Craig Schiffrics, Muhetaer Aihaiti, Michelle Scholtes, Reinhard Boehler, Alexander Goncharov, Victor Lugo, Szczesny Krasnicki, Yangzheng Lin, Haiyun Shu. **Back row:** Nicholas Holtgrewe, Yufei Meng, Morgan Phillips, Haidong Zhang, Helen Venzon, Takaki Muramatsu, Ileana Perez-Rodriguez, Valerie Hillgren, Kadek Hemawan, Xiaojing Tan, Huiyang Gou, Liuxiang Yang, Jinfu Shu, Trong Nguyen, Yonghui Zhou, Duck Young Kim, Peng Zhang, Junyue Wang, Subhasish Mandal, Manuvesh Sangwan, Vincenzo Stagno, Xiaoming Liu, Yuki Shibasaki, Jianjun Ying, Jian-Bo Zhang.



## The Department of Global Ecology Global Ecology

### Carnegie Investigators

#### Research Staff Members

**Gregory Asner**  
**Joseph A. Berry**  
**Kenneth Caldeira**  
**Christopher B. Field**, *Director*  
**Anna Michalak**

### Representative Papers

Consequences of widespread tree mortality triggered by drought and temperature stress  
*Nature Climate Change* 3, 30-36, 2013

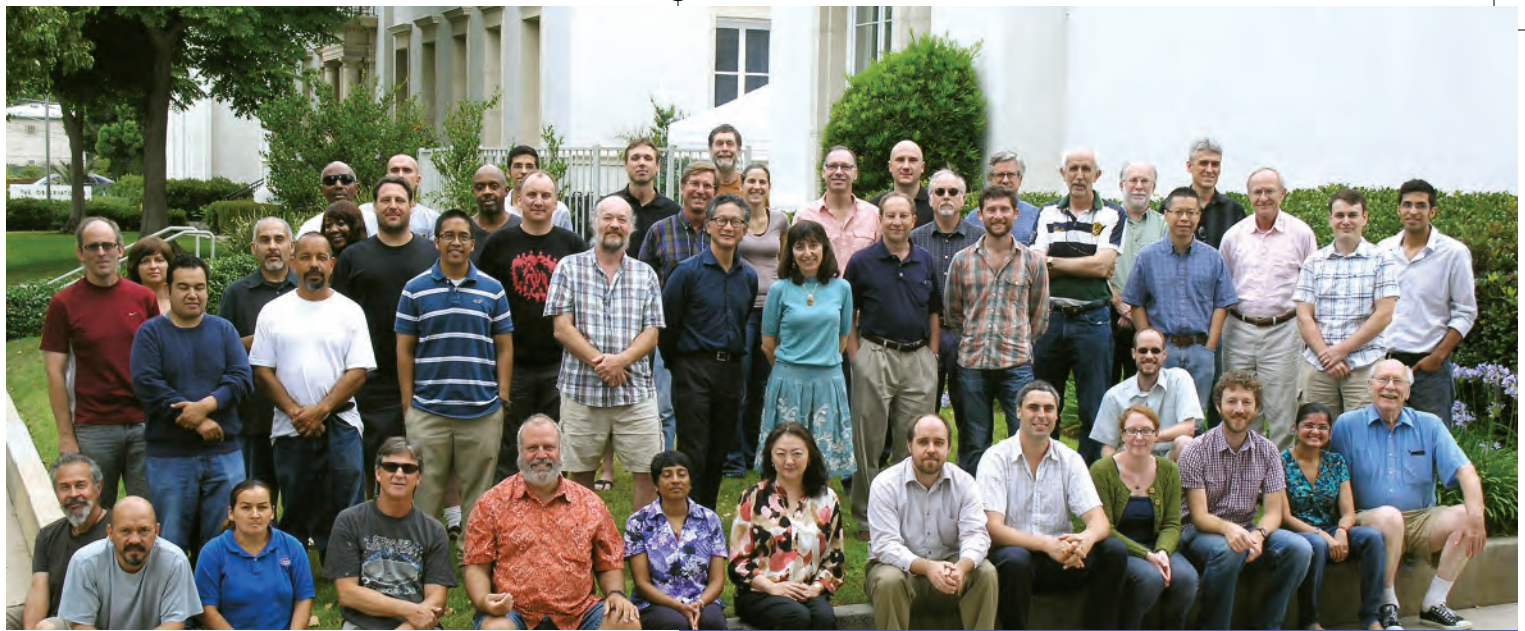
Geography of forest disturbance  
*Proceedings of the National Academy of Sciences USA* 110, 3711-3712, 2013

Lion hunting behaviour and vegetation structure in an African savanna  
*Animal Behaviour* 85, 899-906, doi:10.1016/j.anbehav.2013.01.01

Record-setting algal bloom in Lake Erie caused by agricultural and meteorological trends consistent with expected future conditions  
*Proceedings of the National Academy of Sciences USA* 110, 6448-6452, 2013

Temperature change vs. cumulative radiative forcing as metrics for evaluating climate consequences of energy system choices  
*Proceedings of the National Academy of Sciences USA* 109, E1813-E1813, 2012

**Front row (left to right):** Chris Field, Chun Ma, Monalisa Chatterjee, Ari Kornfeld, Kate Kryston, Jeff Ho, Robin Martin, Xiaochun Zhang, Dahlia Wist, Leslie White. **Second row:** Eva Sinha, Mae Qiu, Yuntao Zhou, Elif Tasar, Eren Bilir, Kate Ricke, Yuanyuan Fang, Jen Johnson, Chao Li, Mike Mastrandrea. **Third row:** Paulo Brando, Nick Vaughn, Kelly McManus, Abby Bethke, Ismael Villa, Yoichi Shiga, David Knapp, Jovan Tadic, Claire Baldeck, Rebecca Hernandez, Garret Huntress. **Fourth row:** Eric Kissel, Marion O' Leary, Todd Tobeck, Ken Caldeira, Sinan Sousan, Ricarda Winkelmann, Vineet Yadav, Anna Michalak, Joe Berry, Andrew Levy. **Back row:** Grayson Badgley, Doug MacMartin, Peter Frumhoff, Mike Dini, Greg Asner, Chris Anderson, Mark Higgins, Katie Mach



## The Observatories Astronomy

### Carnegie Investigators

#### Research Staff Members

**Andrew Benson**  
**Alan Dressler**  
**Wendy Freedman**, *Director*  
**Luis Ho**  
**Juna Kollmeier**  
**Patrick McCarthy**  
**Andrew McWilliam**  
**John Mulchaey**  
**Augustus Oemler, Jr.**, *Director Emeritus*  
**Eric Persson**  
**George Preston**, *Director Emeritus*  
**Michael Rauch**  
**François Schweizer**  
**Stephen Shectman**  
**Joshua Simon**  
**Ian Thompson**

#### Research Associates

**Christopher Burns**, *Research Associate*  
**Jeffrey Crane**, *Staff Associate*  
**Dan Kelson**, *Staff Associate*  
**Barry Madore**, *Senior Staff Associate*

#### Las Campanas Research Staff

**Mark Phillips**, *Associate Director, Las Campanas Observatory and Magellan Telescopes*  
**Miguel Roth**, *Director, Las Campanas Observatory*

### Representative Papers

A comprehensive chemical abundance study of the outer halo globular cluster M75  
*Astronomy & Astrophysics* 554 81, 2013

Astronomical spectrographs  
*Planets, Stars and Stellar Systems* T. D. Oswalt and I. S. McLean, eds., p. 587, Springer, Dordrecht, 2013

Carnegie Hubble Program: a mid-infrared calibration of the Hubble Constant  
*The Astrophysics Journal* 758, 24, 2012

Dark matter halo merger histories beyond cold dark matter – I. Methods and application to warm dark matter  
*Monthly Notices of the Royal Astronomical Society* 428, 1774, 2013

The low-mass, highly accreting black hole associated with the active galactic nucleus 2XMM J123103.2+110648  
*The Astrophysics Journal Letters* 759, L16, 2012

**Front row (left to right):** Robert Storts, Jerson Castillo, Maria Lopez, Steve Wilson, Alan Bagish, Vgee Ramiah, Gillian Tong, Joshua Adams, Guillermo Blanc, Victoria Scowcroft, Ian Roederer, Rik Williams, Mansi Kasliwal, George Preston. **Second row:** Jorge Estrada, Greg Ortiz, Edward Villanueva, Christoph Birk, Alan Uomoto, Wendy Freedman, Alan Dressler, Louis Abramson, Barry Madore, Luis Ho, François Schweizer, Andrew Benson, Roozbeh Davari. **Third row:** Scott Rubel, Greg Vanzyl, Earl Harris, Daniel Masters, Jeffrey Crane. **Back row:** Charlie Hull, Irina Strelnik, Luis Ochoa, Sharon Kelly, Vincent Kowal, John Holmes, Paul Collison, John Grula, Juna Kollmeier, Mark Seibert, Pat McCarthy, Matt John, Stephen Shectman, Andy McWilliams.



## The Department of Plant Biology Plant Science

### Carnegie Investigators

#### Research Staff Members

**M. Kathryn Barton**  
**Winslow R. Briggs**, *Director Emeritus*  
**José Dinneny**  
**David Ehrhardt**  
**Wolf B. Frommer**, *Director*  
**Arthur R. Grossman**  
**Seung Y. Rhee**  
**Zhi-Yong Wang**

#### Adjunct Staff

**Devaki Bhaya**  
**Matthew Evans**  
**Eva Huala**

#### Young Investigator

**Martin Jonikas**

### Representative Papers

Brassinosteroid, gibberellin, and phytochrome impinge on a common transcription module in *Arabidopsis*  
*Nature Cell Biology* 14, 810-817, 2012

Endodermal ABA signaling promotes lateral root quiescence during salt stress in *Arabidopsis* seedlings  
*Plant Cell* 25, 324-341, 2013

Evidence of coral bleaching independent of photosynthetic activity  
*Current Biology* 23, 1782-1786, 2013.

Fluorescent sensors reporting the activity of ammonium transporters in live cells  
*eLife*, 2, e00800, 2013.

Interaction between BZR1 and PIF4 integrates brassinosteroid and environmental responses  
*Nature Cell Biology* 14, 802-809, 2012

Sucrose efflux mediated by SWEET proteins as a key step for phloem transport  
*Science* 335, 207-211, 2012.

**Front row left to right:** Wolf Frommer, Sue Rhee, Hye In Nam, Min Fan, Charlotte Trontin, Lina Duan, Geng Yu, Shouling Xu, Jiaying Zhu, Ankit Walia, Jose Dinneny. **Second row:** Yang Bi, Lee Chae, Jonas Danielson, Muh-Ching Yee, Ru Wui, Martin Jonikas, Matt Prior, Thorsten Seidel, Soeren Gehne, Zubin Huang, Thomas Hartwig, Wenqiang Yang, Neil Robbins. **Third row:** Naoia Williams, Evana Lee, Ray Von Itter, Dahlia Wist, Viviane Lanquar, Tie Liu, Keith Frazer, Luke Mackinder, Lily Cheung, Renate Weizbauer. **Fourth row:** Shahram Emami, Chuan Wang, Michelle Davison, Eva Huala, Peifen Zhang, Witchukorn Phuthong, Lance Cabalona, Franklin Talavera-Rauh, Greg Reeves, Masayoshi Nakamura, Chan Ho Park. **Fifth row:** Mingyi Bai, Meng Xu, Robert Muller, Ting-Ting Xiang, Eva Nowack, Ruben Alvarez Rellan, Turkan Eke, Flavia Bossi, Weronika Patena, Rebecca Yue, Sam Parsa. **Sixth row:** Devaki Bhaya, Matt Evans, Arthur Grossman, Munever Aksoy, Cheng-Hsun Ho, Ricardo Nilo Poyanco, Claudia Catalanotti, Hulya Aksoy, Diane Chermak, Donghui Li, Jennifer Scerri, Sunita Patil, Wei-Chuan Kao, Tuai Williams, Antony Chettoor. **Back row:** Lauro Neto Bucker, Jose Sebastian, David Huang, Theo Van De Sande, Davide Sosso, Kieran Parker, Jim Guo, Kate Dreher, Rich Jorgesen, Xiaobo Li, Leif Pallesen, Ted Raab, Adam Longhurst, Garret Huntress, Alexander Jones.



## The Department of Terrestrial Magnetism Earth/Planetary Science and Astronomy

### Carnegie Investigators

#### Research Staff Members

**Conel M. O'D. Alexander**  
**Alan P. Boss**  
**R. Paul Butler**  
**Richard W. Carlson**  
**John E. Chambers**  
**Linda T. Elkins-Tanton, Director**  
**Matthew J. Fouch**  
**Erik H. Hauri**  
**David E. James**  
**Alan T. Linde**  
**Larry R. Nittler**  
**Diana C. Roman**  
**Scott S. Sheppard**  
**Steven B. Shirey**  
**Fouad Tera, Emeritus**  
**Alycia J. Weinberger**

#### Senior Fellows

**Vera C. Rubin**  
**I. Selwyn Sacks**

### Representative Papers

Diamonds and the geology of mantle carbon  
*Reviews in Mineralogy and Geochemistry* 75, 355-421, 2

Differentiated planetesimals and the parent bodies of chondrites  
*Annual Review of Earth and Planetary Sciences* 41, 529-560, 2013

Galactic chemical evolution and the oxygen  
 isotopic composition of the solar system  
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**Front row (left to right):** Contract employee Adelio Contreras, Jared Marske, Tyler Bartholomew, Wan Kim, Janice Dunlap, Pamela Arriagada, William Key, Roy Dingus.  
**Second row:** Shaun Hardy, Brian Schleigh, Steven Golden, (V.I.) Jiuxing Xia, Brian Jackson, Robin Dienel, Vera Rubin, (V.I.) Tetsuo Takanami, Christelle Wauthier, Debbie Smith, Joleen Carlberg, Kelsey Druken. **Third row:** Quintin Miller, Aki Takigawa, Fouad Tera, Marion Le Voyer, Marion Garçon, Lindy Elkins-Tanton, Jacqueline Faherty, Terry Blackburn, Alycia Weinberger, Diana Roman, Timothy Rodigas. **Fourth row:** Jianhua Wang, Maceo Bacote, Liyan Tian, Mary Horan, Jemma Davidson, (Temp) Casey Leffue, Merri Wolf, Ben Pandit, Erik Hauri, Rick Carlson, Ryan Porter. **Back row:** John Chambers, Sandy Keiser, Tim Mock, Michael Crawford, Alan Boss, Daniela Power, Conel Alexander, Steve Shirey, (Senior Merle A. Tuve Fellow) Doug Wiens.



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