Carnegie Science

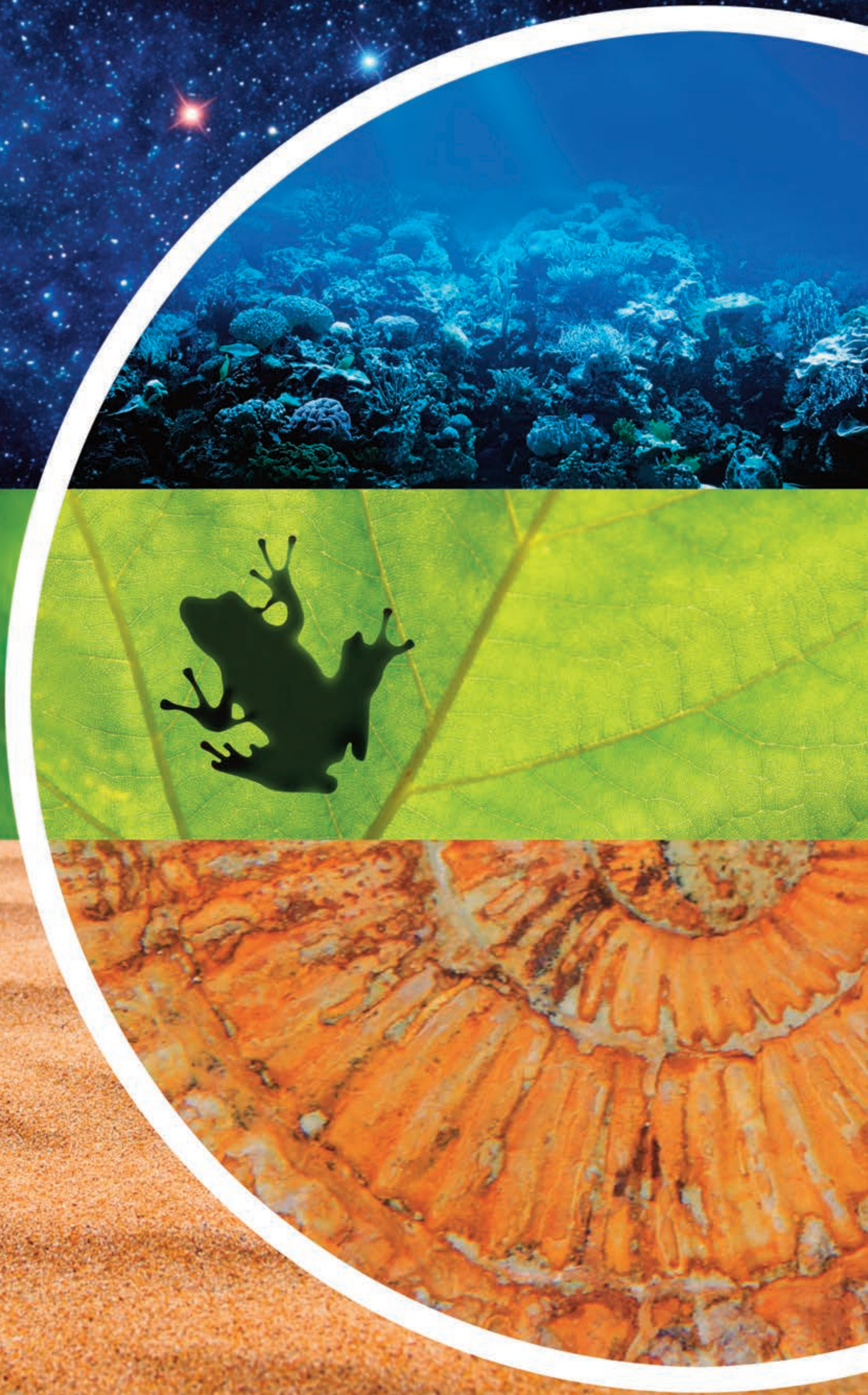
1530 P Street, N.W. | Washington DC 20005
Phone: 202.387.6400 | Fax: 202.387.8092 |
www.carnegiescience.edu

ISSN 0069-066X

Carnegie Institution for Science
2013-2014 Year Book

Carnegie Science

2013-2014 Year Book



WWW.CARNEGIESCIENCE.EDU

Department of Embryology
3520 San Martin Dr. / Baltimore, MD 21218
410.246.3001

Geophysical Laboratory
5251 Broad Branch Rd., N.W. / Washington, DC 20015-1305
202.478.8900

Department of Global Ecology
260 Panama St. / Stanford, CA 94305-4101
650.462.1047

The Carnegie Observatories
813 Santa Barbara St. / Pasadena, CA 91101-1292
626.577.1122

Las Campanas Observatory
Casilla 601 / La Serena, Chile

Department of Plant Biology
260 Panama St. / Stanford, CA 94305-4101
650.325.1521

Department of Terrestrial Magnetism
5241 Broad Branch Rd., N.W. / Washington, DC 20015-1305
202.478.8820

Office of Administration
1530 P St., N.W. / Washington, DC 20005-1910
202.387.6400

FSC LOGO HERE

New paper info goes here... this year book contains 30% post-consumer recycled fiber. By using recycled fiber in place of virgin fiber, the Carnegie Institution preserved 13.25 trees, saved 38 pounds of waterborne waste, saved 5,627 gallons of water, and prevented 1,226 pounds of greenhouse gasses. The energy used to print the report was produced by wind power. Using this energy source for printing saved 2,627 pounds of CO_2 emissions, which is the equivalent to saving 1,786 miles of automobile travel.

Design by Tina Taylor, T2 Design
Printed by DigiLink, Inc.

2013-2014 YEAR BOOK

The President's Report

July 1, 2013 - June 30, 2014

CARNEGIE INSTITUTION FOR SCIENCE

About Carnegie

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

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

Carnegie Institution for Science

Contents

From the Tide Pool to the Stars

“Our own interest lay in relationships of animal to animal… it seems apparent that species are only commas in a sentence, that each species is at once the point and the base of a pyramid, that all life is relational to the point where an Einsteinian relativity seems to emerge.

And then not only the meaning but the feeling about species grows misty. One merges into another, groups melt into ecological groups until the time when what we know as life meets and enters what we think of as non-life: barnacle and rock, rock and earth, earth and tree, tree and rain and air…Then one can come back to the microscope and the tide pool and the aquarium.

But the little animals are found to be changed, no longer set apart and alone. And it is a strange thing that most of the feeling we call religious, most of the mystical outcrying which is one of the most prized and used and desired reactions of our species, is really the understanding and attempt to say that man is related to the whole thing, related inextricably to all reality, known and unknowable…the profound feeling of it made a Jesus, a St. Augustine, a St. Francis, a Roger Bacon, a Charles Darwin, and an Einstein.

Each of them in his own tempo and with his own voice discovered and reaffirmed with astonishment the knowledge that all things are one thing and that one thing is all things—plankton, a shimmering phosphorescence on the sea and the spinning planets and an expanding universe, all bound together by the elastic string of time.

It is advisable to look from the tide pool to the stars and then back to the tide pool again.”

—John Steinbeck

The Log from the Sea of Cortez (1951)

THE PRESIDENT'S COMMENTARY

John Steinbeck's beautiful writing captures the essence of Carnegie, the integration of science, history, art, and humanity. This is what we strive to do, in exploring our own origins, how the Earth we live on was formed and functions, and how our genes can miraculously form a flower or a brain.

I want to send you greetings from our headquarters at P Street Northwest! I hope that many of you will find a time to visit our building and our labs this year. There is much to see and much to tell. The most important thing I have to say is a giant set of thank-yous, first to the trustees who chose me for this wonderful opportunity to serve science and people, second to my predecessor Dick Meserve who has helped me in numerous ways and continues to offer his time and advice generously, and third, but certainly not last, to the hundreds of Carnegie people I have met during the past few months. They have been unendingly welcoming and encouraging. Their offers of help have been received with gratitude. There is much to do, and they are the people who make it happen.

Carnegie Science research can be celebrated for its extraordinary breadth: the deep history of the universe, the deep history of the Earth, and the deep history of life. This emphasis on history can be a bit misleading, since it seems to imply less interest in the present and future. On the contrary, in that history lies our ability to understand the present and inform the future.

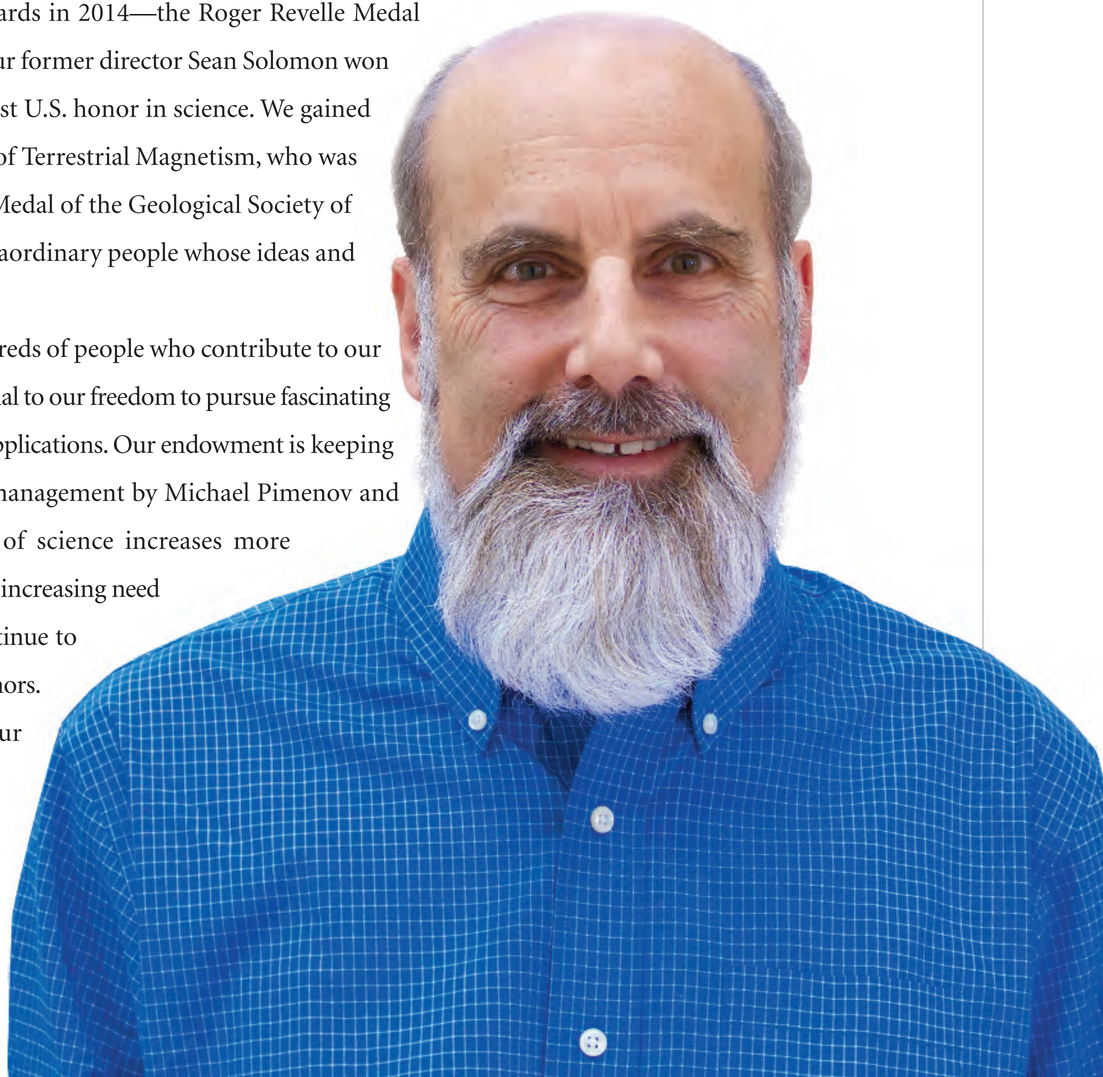
News about people! This year we welcome Craig Barrett to our Board of Trustees. Craig is renowned for his work of many years as a dynamic leader of Intel. Dr. Meserve joined the board of the Kavli Foundation, our partners in the yearly Kavli Lecture at P Street and creators of many distinguished Kavli institutes. I congratulate trustee Mary-Claire King who received the prestigious

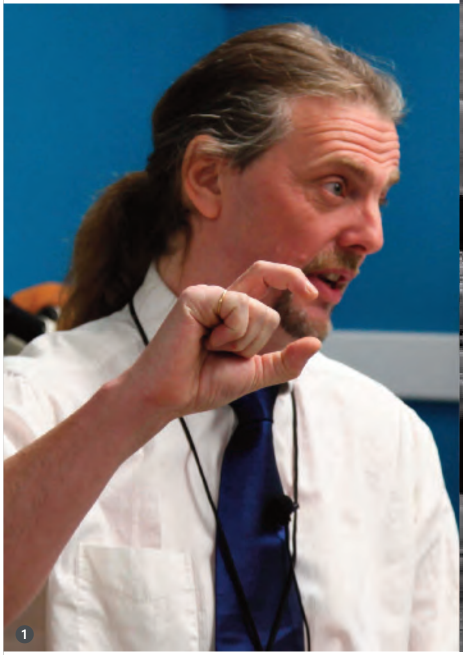
"What a year it has been for our science!"

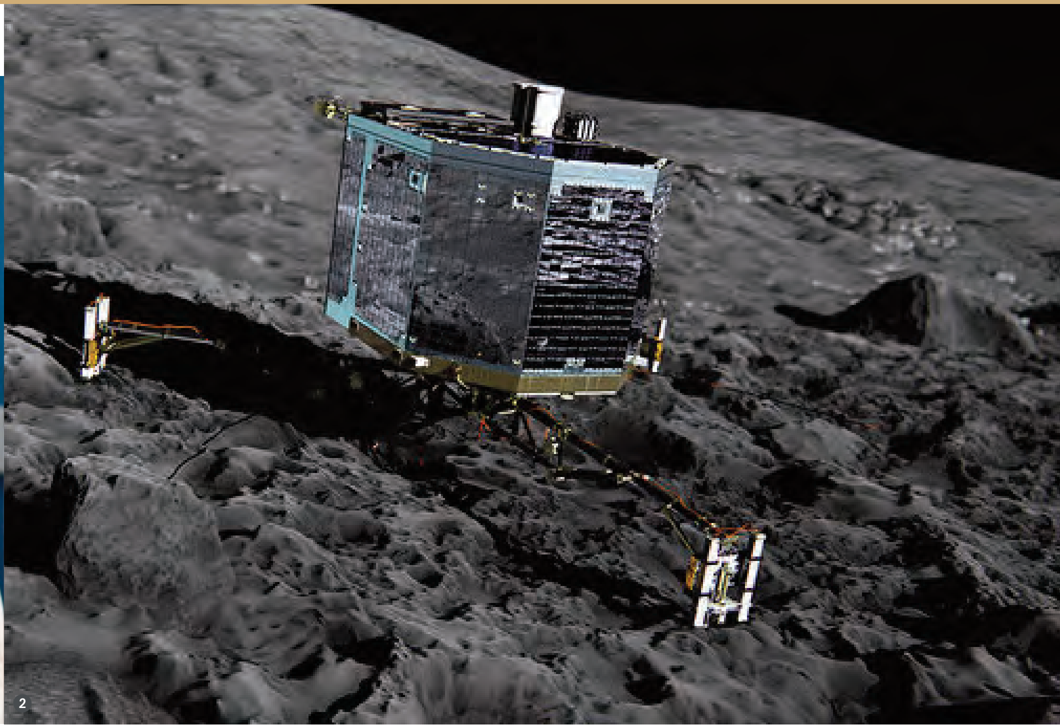
2014 Lasker-Koshland Special Achievement Award in Medical Science and director Chris Field who received two major awards in 2014—the Roger Revelle Medal and the BBVA Climate Change Award. Our former director Sean Solomon won the National Medal of Science, the highest U.S. honor in science. We gained a new director in 2014, Richard Carlson of Terrestrial Magnetism, who was the recipient of the 2013 Arthur L. Day Medal of the Geological Society of America. These awards all recognize extraordinary people whose ideas and discoveries have changed our world.

We are also grateful to the hundreds of people who contribute to our private funding base, support that is essential to our freedom to pursue fascinating mysteries that do not—yet—have direct applications. Our endowment is keeping pace with general inflation due to fine management by Michael Pimenov and our Finance Committee, but the cost of science increases more rapidly than standard inflation due to the increasing need for advanced instrumentation, so we continue to be dependent on the generosity of our donors.

What a year it has been for our science! I list just a few examples here.




1


2


3


4

❶ Carnegie's Andrew Steele analyzed chemical measurements of comet 67P sent from one of the Philae lander's instruments.

❷ The European Space Agency's Philae lander is depicted on the comet 67P.
Image courtesy ESA

❸ José Dinneny in the lab
Image courtesy Robin Kempster

❹ Roots are genetically engineered to produce luminescent proteins, which are used to see fine details of root structures. These, unlike fluorescent proteins, do not require excitation light to produce their effect. Luminescent proteins generate their own light.
Image courtesy Rubén Rellán-Álvarez

The signal traveled more than 310 million miles, from the 216-lb. (98-kg.) Philae lander lost somewhere on the surface of the comet 67P, to Earth. Nearly half an hour passed before the signal, traveling at the speed of light, reached the control center in Germany, then to the science team and the computer of Carnegie scientist Andrew Steele. Quickly he began to analyze the first-ever direct chemical measurements of cometary material by an instrument at the surface. To his delight, the dust and gravel of 67P contain a remarkable mix of chemicals that will intrigue and mystify scientists for years to come, and the comet is rich in water. Philae's success is an example of the tentacles of science reaching out to explore mysteries in even the most far removed of objects.

Plants have tentacles too and, due to Carnegie Science's José Dinneny, root tentacles can be seen growing as never before. He engineers the plants to have luminescent roots that can be seen growing in a slab-shaped soil container. By manipulating the environment around the growing roots, he investigates the guidance systems that allow plants to maximize importation of essential substances including water and chemicals. Like Philae, the plants detect water.

Chromosomes are often seen as compact structures, the condensed form in which they move during cell division. When cells are not dividing, chromosomes open up and some of their genes become active. In some cell types of some organisms, the chromosomes extend into giant forms that appear to have looped tentacles reaching into cellular space. New methods of super-resolution microscopy are employed by Carnegie Science's Joseph Gall to examine one kind of giant chromosome, the "lampbrush chromosome." He can watch individual genes at work and the machinery that binds the genes and controls their activity states. Using other techniques, the Gall lab has discovered remarkable circular RNA molecules in both the nucleus and cytoplasm of frog eggs, which are distinct from the usual linear protein-coding RNAs.

Explorations of space include deep inner space, not just the insides of cells but the insides of atoms. At high pressure, atoms begin to change behavior. Carnegie Science researchers are especially adept at creating novel substances using high pressures and temperatures, so high that even the chemical interactions among atoms change from the ordinary to the bizarre. A crystal combining sodium and chloride should be a one-to-one lattice of NaCl, but instead $NaCl_3$ can form, breaking all the rules. Carnegie's Tim Strobel has exceptional instincts about exploring the high pressure space, and is creating new materials with strange and useful properties. In some cases the materials revert back to normal forms when the pressure goes down, like someone recovering from being on stage, but in other potentially useful cases the material retains its odd structure even at normal pressures and temperatures. Thus an entire new world of materials science is upon us. One example is Strobel's creation of a completely new form of silicon (Si_{24}) that forms rings that effectively absorb light in wavelengths well matched to the solar spectrum. Such a material may be a dream come true for designers of new semiconductors and energy devices.

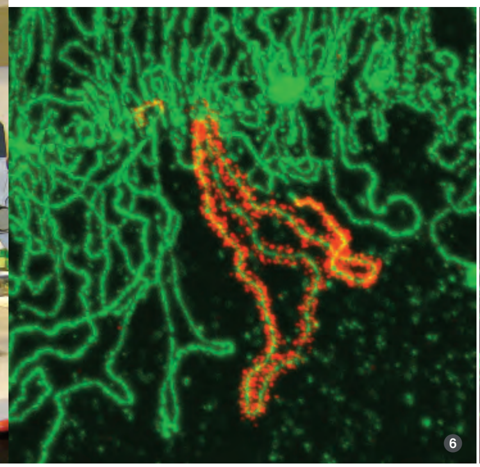
Dreams came true in November when the country of Peru announced its plan to have no net deforestation starting in 2021. This ambitious plan to arrest the loss of Amazon and Andean forests was an outcome linked to many years of hard work by Carnegie Science's Greg Asner and his colleagues, teaming up with the Peruvian government. If a photo is worth a thousand words, the Asner group's hundreds of thousands of images were worth billions. Those words would give anyone a reinforced sense of what is at stake: the natural heritage of Peru. Supported by dramatic visualizations of how much of Peru's forests are at stake, and the damage being done by illegal gold mining and other devastation, progressive Peruvian leaders announced the new goal. The old phrase "you don't know what you got 'til it's gone" does not have to be true. New ways of seeing can lead to new ways of thinking, new levels of appreciation, and new promise for sustainable management. The outcome is good for Amazon and Andean forests, good for the vast numbers of species that inhabit those forests, and good for the species that has the power to protect and use them wisely.

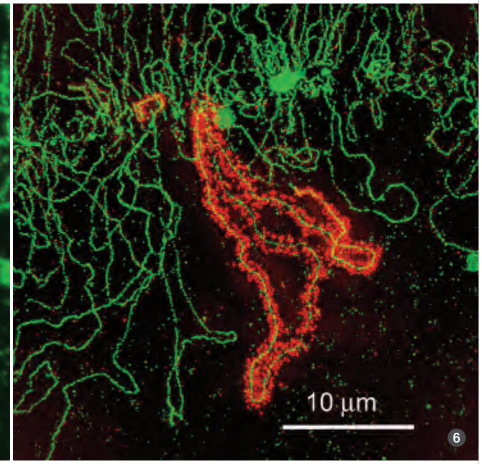
While scientists often feel frustration at rejection of climate science driven by propaganda, in fact the trend in recent times is toward greatly increased public acceptance that climate change is real and that human activities contribute substantially to it. The recent agreement in Lima is a step, not as large a step as we need, but still a start on reducing human-driven climate change. No doubt skeptics will remain, even in Miami as it sinks farther into salt water, but the best hope for intelligent

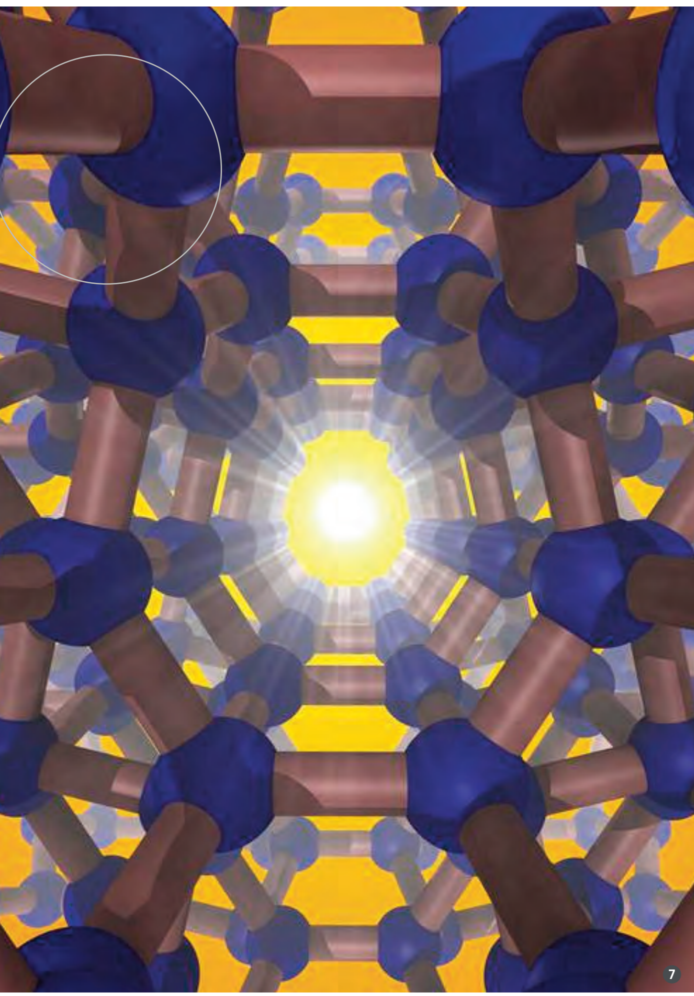
❺ Carnegie's Joseph Gall

❻ The same region of a giant lampbrush chromosome are viewed by confocal microscopy (left) and by super-resolution microscopy (right). Each green loop is an active gene. The orange granules probably correspond to transcripts from a specific gene. The super-resolution image was taken at Indiana University by Gall collaborators Sidney Shaw and James Powers.

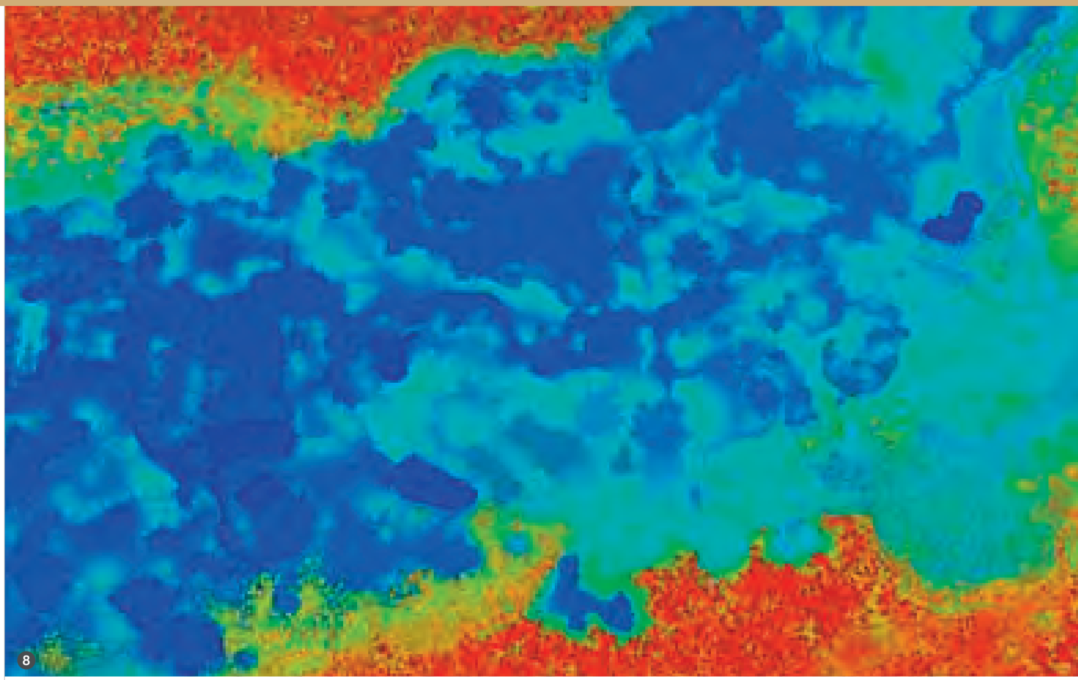
❼ The image at right shows the open channels of a new form of silicon, Si_{24}. Tim Strobel and team were able to synthesize this silicon that could be used for solar absorption, something that has never before been achieved. The material has an open framework.
Image at right courtesy Timothy Strobel




10 µm

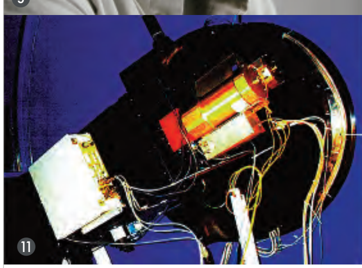



Relevance


8


Carne
8


9


11


10

❽ Carnegie's Greg Asner's team, in close collaboration with officials from the Peruvian Ministry of Environment, used the Carnegie Landsat Analysis System-lite (CLASlite) to detect and map both large and small gold-mining operations in Peru. The team corroborated the satellite results with on-ground field surveys and Carnegie Airborne Observatory (CAO) data and found that the geographic extent of mining had increased 400% from 1999 to 2012 and that the average annual rate of forest loss has tripled since the Great Recession of 2008.
Map Image courtesy Greg Asner
Image courtesy Robin Kempster

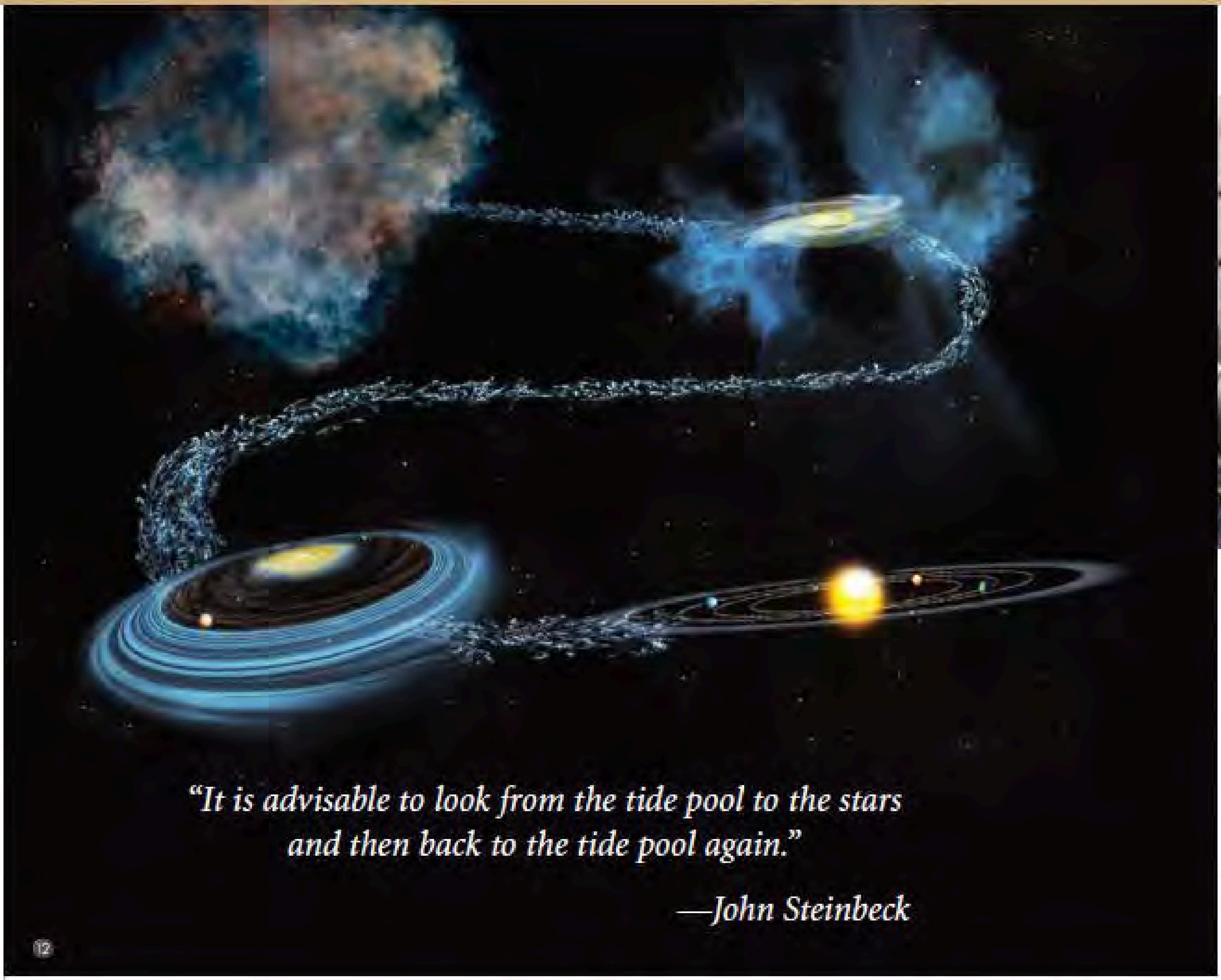
❾ Astronomer and instrument designer Steve Shectman (below) was elected to the National Academy of Sciences this past year.

❿ Carnegie's Las Campanas Observatories, known for its near-perfect viewing conditions, is home to the 6.5-meter twin Magellan telescopes. Steve Shectman has developed numerous telescope instruments over the years. With lead designer Rebecca Bernstein and team he brought MIKE (the Magellan Inamori Kyocera Echelle) spectrograph ⓫ on line. It has been used for over a decade to observe the spectra of even relatively faint objects in great detail.
Image courtesy Yuri Beletsky

actions as individuals and as nations is to come to grips with measurements that tell us actual trends and the possible benefits of alternative solutions. Chris Field and Ken Caldeira of Carnegie, in addition to their world-leading research, have been voices of reason in many public interviews, explaining the implications of scientific data in a factual and balanced manner.

Our twin Magellan telescopes at Carnegie's observatory in Las Campanas, Chile, have become famous for a variety of reasons. One is the extraordinary hospitality offered visitors by our Chilean team on the mountain. Another is the near-perfect viewing conditions. What is not always sufficiently celebrated, as one after another incredible discovery is made, is the design of the instruments themselves. Carnegie has some of the world's finest instrument designers and builders, including a crack team at the Observatories shop headed by Vince Kowal. Now one of our leading instrument designers, Dr. Steve Shectman, has been recognized by election to the U.S. National Academy of Sciences. This recognition, from his scientific peers, is among the highest honors a scientist can achieve. We are delighted for Steve and look forward to his wizardry continuing to allow Magellan astronomers and others to discover celestial wonders.

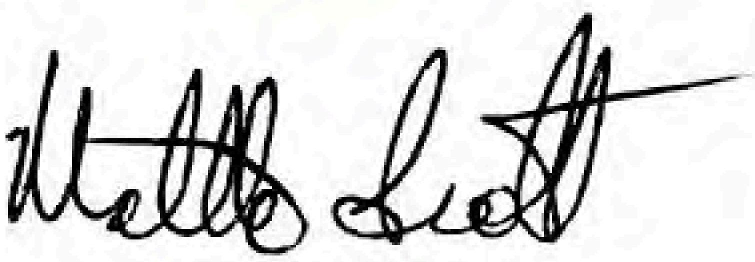
We carry within us the vast history of the universe, as elements that formed in burning stars. The idea of atoms and molecules having histories inflates the imagination and maybe the ego. Newsflash: one human body's atoms are derived from many stars! Which stars did YOU come from? A new report this year from Carnegie scientist Conel Alexander and colleagues addressed the history of a molecule with single importance to life: water. Their work addressed the question of whether the water we now drink came from the Sun's original early molecular cloud, or whether the water came from chemical reactions that created "new" water in the Sun's proto-planetary disc—from which the planets formed. If the former, then quite likely the formation of other planetary systems included water from interstellar space ice. If the latter, then the abundance and timing of water production in a developing planetary system would depend heavily on the chemistry induced by the star at its center. Hydrogen isotope ratios in our world's water, along with modeling of different scenarios for its origin, showed that at least some of our water came from interstellar ice. This should give some of you who have an entrepreneurial spirit the idea for a



⑫ This illustration shows water in our Solar System through time from before the Sun's birth through the creation of the planets. Carnegie's Conel Alexander and team looked at the origin of today's water on Earth. *Illustration courtesy Bill Saxton, NSF/AUI/NRAO*

completely honest representation of a new food shop: Interstellar Ice Cream, Inc. Some of the water in that ice cream, in all ice cream, has been water since before our Sun formed and may have traveled a long, long way before contributing new atoms to fattening human bodies.

When John Steinbeck and his marine biologist buddy Ed Ricketts set off on an expedition to explore the Sea of Cortez, it was science that motivated them but art, Steinbeck's beautiful thoughts and beautiful prose, emerged. What emerges from Carnegie Science is a sense of the unity of science, of the unity of history, and of the artistic and scientific explorations that are at the core of being human.



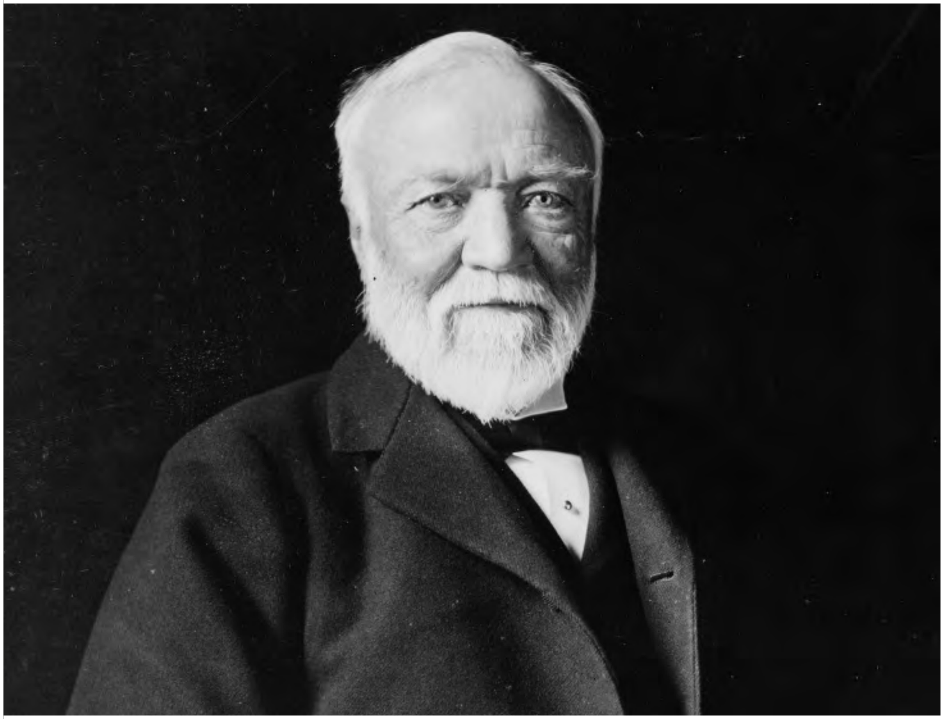
President, *Carnegie Science*

2013-2014 YEAR BOOK

Friends, Honors & Transitions

Carnegie Friends

Image courtesy Theodore C. Marceau, Library of Congress



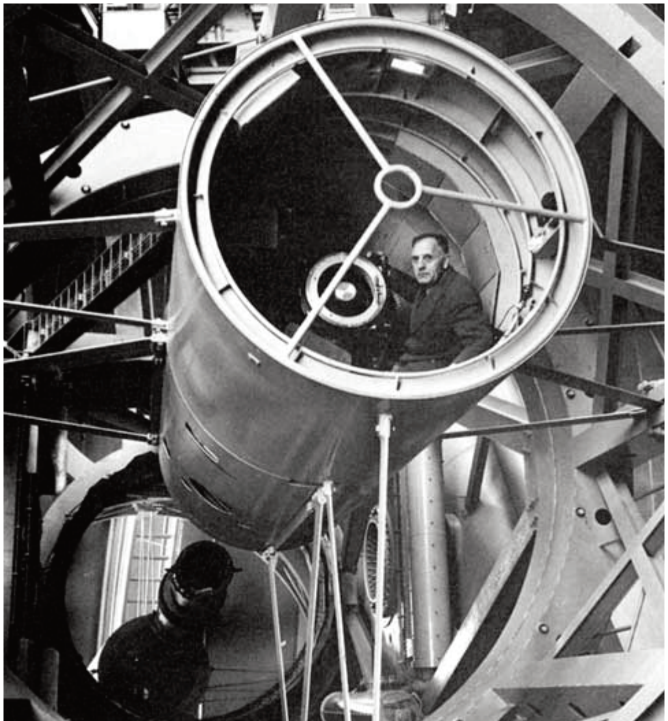
Lifetime Giving Societies

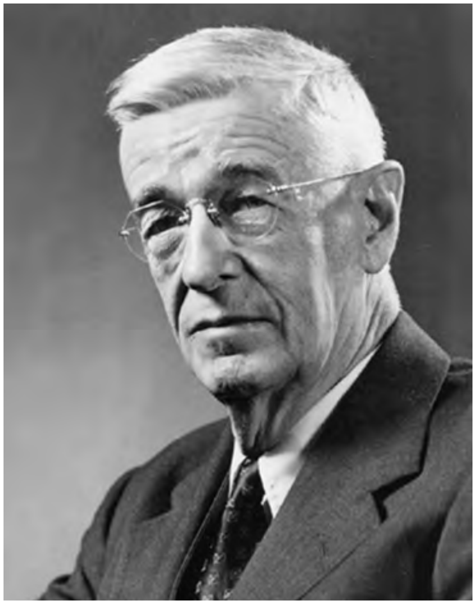
The Carnegie Founders Society

Andrew Carnegie, the founder of the Carnegie Institution, established it with a gift of $10 million, ultimately giving a total of $22 million to the institution. His initial $10 million gift represents a special amount. Thus, individuals who support Carnegie with lifetime contributions of $10 million or more are recognized as members of the Carnegie Founders Society.

....

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





The Edwin Hubble Society

The most famous astronomer of the 20th century, Edwin Hubble, was a Carnegie astronomer. His observations that the universe is vastly larger than we thought, and that it is expanding shattered our old concept of cosmology. Science often requires years of work before major discoveries like his can be made. The Edwin Hubble Society honors those whose lifetime support has helped the institution to foster such long-term, paradigm-changing research by recognizing those who have contributed between $1,000,000 and $9,999,999.

....

Anonymous (2)
D. Euan and Angelica Baird
William and Cynthia Gayden
Michael and Mary Gellert
Robert G. and Alexandra C. Goelet
William T. Golden*
Crawford H. Greenewalt*
David Greenewalt*
Margaretta Greenewalt*
Robert and Margaret Hazen
William R. Hearst III
Richard E. Heckert*
Kazuo and Asako Inamori
Michael T. Long
Burton and Deedee McMurtry
Jaylee and Gilbert Mead*
Cary Queen
Deborah Rose, Ph.D.
William J. Rutter
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 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.

....

Anonymous (3)
Philip H. Abelson*
Bruce and Betty Alberts
Mary Anne Nyburg Baker and G. Leonard Baker, Jr.
Daniel Belin and Kate Ganz
Liselotte Beach*
Bradley F. Bennett*
Didier and Brigitte Berthelemot
Gary P. and Suzann A. Brinson
Donald and Linda Brown
Richard Buynitzky*
A. James Clark
Tom and Anne Cori
H. Clark and Eleanora K. Dalton*
John Diebold*
Jean and Leslie Douglas*
Herbert A. Dropkin
Michael A. Duffy
James Ebert*
Bruce W. Ferguson and Heather R. Sandiford
Stephen and Janelle Fodor
Henrietta W. Hollaender*
Antonia Ax:son Johnson and Goran Ennerfelt
Paul A. Johnson*
Paul and Carolyn Kokulis
Gerald D. and Doris* Laubach
Lawrence H. Linden
John D. Macomber
Steven L. McKnight
Richard A. and Martha R. Meserve
J. Irwin Miller*
Al and Honey Nashman
Evelyn Stefansson Nef*
Alexander Pogo*
Elizabeth M. Ramsey*
Vera and Robert* Rubin
Allan R. Sandage*
Leonard Searle*
Frank N. Stanton*
Christopher and Margaret Stone
William and Nancy Turner
Michael G. Wilson
Laure Woods

Second Century Legacy Society

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

....

Anonymous (3)
Philip H. Abelson*
Paul A. Armond, Jr.
Bradley F. Bennett*
Francis R. Boyd, Jr.*
Lore E. Brown
Richard Buynitzky*
H. Clark and Eleanora K. Dalton*
Hugh H. Darby*
Herbert A. Dropkin
Nina V. Fedoroff
Julie D. Forbush*
William T. Golden*
Crawford H. Greenewalt*
Margaretta Greenewalt*
Gary K. Hart and Cary S. Hart
Caryl P. Haskins*
Robert and Margaret Hazen
Richard E. Heckert*
Henrietta W. Hollaender*
Paul A. Johnson*
Paul and Carolyn Kokulis
Gilbert and Karen Levin
Chester B.* and Barbara C. Martin
Robert Metcalf
Al and Honey Nashman
Alexander Pogo*
Elizabeth M. Ramsey*
Holly M. Ruess
Allan R. Sandage*
Leonard Searle*
Maxine and Daniel Singer
Frank N. Stanton*
Fay M. Stetzer
Thomas H. B. Symons, C.C.
John R. Thomas, Ph.D.
Hatim A. Tyabji

....

*** Deceased**

Annual Giving

Gifts Received Between July 1, 2013, and June 30, 2014

The Barbara McClintock Society

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

....

$1,000,000 or more
George P. Mitchell*

$100,000 to $999,999
Anonymous (2)
H. Clark and Eleanora K. Dalton*
Herbert A. Dropkin
Michael and Mary Gellert
Deborah Rose, Ph.D.

$10,000 to $99,999
Anonymous (2)
Didier and Brigitte Berthelemot
Gary P. and Suzann A. Brinson
Steven B. Crystal
Michael A. Duffy
Stephen and Janelle Fodor
William and Cynthia Gayden
Robert G. and Alexandra C. Goelet
Sibyl R. Golden
Gary K. Hart and Cary S. Hart
Robert and Margaret Hazen
Douglas E. Koshland
Michael T. Long
Burton and Deedee McMurtry
Richard A. and Martha R. Meserve
Al and Honey Nashman
Ray and Meredith Rothrock
Leonard Searle*
Tom Steyer and Kat Taylor
William and Nancy Turner
Michael G. Wilson
Laure Woods

Image courtesy Cold Spring Harbor

Other Individual Giving

$1,000 to $9,999
Anonymous (4)
Paul A. Armond, Jr.
Henry H. Arnhold
Mary B. Bailey
Charlotte S. Barus
Richard C. Becker
Giuseppe Bertani
Charles Bestor
Samuel and Diane Bodman
Page H. Boteler
Anthony Cavalieri and Ellen Look
Kevin F. Clines
John and Anne Crawford
Igor Dawid and Keiko Ozato
John P. de Neufville
John D. Diekman
Charles E. and Joan M. Dorgan
Jo Ann Eder
Wallace and Charlotte Ernst
Sandra and Andrew Faber
William B. Fagan
Bruce W. Ferguson and Heather R. Sandiford
Christopher Field and Nona Chiariello
Desmond G. FitzGerald
Oscar P. Fitzgerald
Raymond C. Fletcher
Wendy Freedman and Barry Madore
Jonathan Gainsley
Geoffrey Glasrud
Adam Green
Claire M. Haldan
Rush D. Holt and Margaret Lancefield
Thomas D. Holt
Charles Bowditch Hunter
Kathleen E. Jolly
Sam Katzman
Mary-Claire King
Paul and Carolyn Kokulis
Gerald D. Laubach
Alan and Agnes Leshner
Gilbert and Karen Levin
Lawrence H. Linden
John and Jean Lively
Michael Maley
Frederick K. Martin
James Mattingly
Donald H. McClelland
Michael R. McCormick
Lauren A. Meserve
Christine Ogata
Catherine A. Piez
Leonard Reed
David B. Rickard
Alice Rivlin and Sidney Winter
Vera C. Rubin
Cristián Samper
David B. Singer
Kimball D. Smith
Mary Agnes Smith
Dorothy Spiewak
Allan Spradling
Thomas F. Stephenson
Christopher and Margaret Stone
Lawrence A. Taylor
William L. Taylor
John R. Thomas, Ph.D.
Ian Thompson
Scott B. Tollefsen
Mark Welsh
Peter H. and Jean S. Wick
Fredrick P. Woodson
Mary Lou and Mark Zoback

Under $1,000
Anonymous
Judith Clark Adams
Jagannadham and Lalita Akella
Donald J. Albers
Beth Anderson
Sheldon Applegate
Joseph P. Ardizzi
Louis G. Arnold
Susan H. Artes
Lynn Atkins
Ulanda Aung
Lee Bailey
Lawrence C. Baldwin
Jody Banks
Cheryl A. Bantz
Benjamin G. Barbin
Frank E. Barone
Colin Barr
Robert L. Bartholomew
Rhoda Baruch
Manuel N. Bass
Constantine H. Bayz
Edward Beenstock
Harvey E. Belkin
Peter M. Bell
Lyndsay Benedict
Stacey Beneville
Theodore G. Benitt
James D. Bennett
Sally J. Bensusen
Richard J. Bergemann
Leslie C. Berlowitz
Todd Bernstein
Morris M. and Madeleine G. Birnbaum
Henry C. Black
Daryn Blanc-Goldhammer
Joe Bolster
Trevor Bolton
Jenny K. Bong
Tom I. Bonner
Kurt R. Borski
Aaron Bosanko
Sean A. Bowen
Randolph Boyle
Robin Brett
Winslow R. Briggs
Peter C. Brockett and Laureen B. Chang
Harold and Naomi Brodsky
Nolan Brooks
Carin Brown
Jeanette S. Brown*
Lore E. Brown
Peter Brown and Sherri Brown
Thomas E. Brown
William L. Bryan
David and Rosemary Buden
Marjorie Burger
Gordon Burley
Donald M. Burt
Henner Busemann
William L. Busis
Randal Byrd
Nicol Cabe
Christopher L. Cahill
John A.R. Caldwell
Julia Caldwell
Eugene Camali
Allan M. Campbell
Georgia A. Canellos
Ryan Carlisle
Carol Laikin Carpenter
David S. and Gerrie Carpenter
Willard Carpenter
Timothy J. Carr
Jacob Carringer
Dana Carroll
Sarah Carter
Morris J. Chalick
Shirley Chan
Peter Chang
Liang-Chen Chen
Kenneth M. Chick
Matthias Chiquet
Asit Choudhuri
Ian Christy
Hilary W. Clark
Paul S. Clark
William P. Cleveland
Mary K. Coder
Marshall Cohen and Barbara Footer
Gregory Colello
John R. and Annette W. Coleman
Jack and Rita Colwell
John Douglas Cooper
Douglas R. Cowie
William E. Cramer
Muriel H. Cronin
Eleanore Crosby
Daniel L. Crotty
Donald F. Crumrine
Daniel Cutaia
Kate Cwynar
Martin Czigler
Howard H. Dana, Jr.
Stewart Daniels
John Mark Darnell
Emily Darugar
Alice M. Davis
John E. Davis and Bonnie Freeman
Nicholas F. Davis
Scott Davis
Judy Day
Cristina Del Amo
John B. Denniston
Sameer Desai
Robert C. DeVries
Jennifer DeWitt
John M. and Jane M. Dick
John F. Dilley
Jennifer Djaferis
Bruce R. Doe
Jeffrey L. Doering
Laura D. Dominguez
Paul R. Doser
James A. and Margo A. Drummond
Daniel Du Bois
Samuel Dyer
Richard O. Earley
David H. Eggler
Bennett Ellenbogen
Meredith Engel
Joseph W. Erkes
Sunil Erraballi
Mark Evans
Deborah Ezell
Steven Farber
John E. Farhood
Brent H. Farmer
Tobias P. Fischer
Carolina Flores-Helizon
Kenneth A. Foland
Myriam Fontaine
Frederick Forro, Jr., and Dorothy M. Forro

David France
John Robah Franklin
Michael Franks
Laurence W. Fredrick
David H. Freeman
Richard T. Freeman
Bevan M. French
J. Luis Frenk
Mitchell Friedman
Ralph Fruchtman
Frederick S. Fry, Jr.
Joseph H. Gainer
David R. Gambrel
Mary L. Garnett
James Garulski
Dr. and Mrs. Arthur Gelb
Domenico Gellera
Amy Gerber-Stroh
Susan A. Gerbi-McIlwain
Rajat Ghoshal
Peter Giguere
M. Charles and Mary Carol Gilbert
Kirsten H. Gildersleeve
Sven F. Girsperger
William and Gayle Glauz
Kenneth H. Globus
Jeffrey M. Goecker
Greg Goers
Abhay Gokhale
James R. Golden
David J. Goldston
Barbara Graves and
Robert W. Schackmann
Thomas and Josephine Greeley
Nathanael Green
David L. Greenewalt
Frederick Greenewalt
Nanette and Irvin Greif
Michael Griffin
Philip M. Grimley
Donald H. Groelsema
Marianne U. Gustafson
Ronald R. Gustafson
Necip Guven
Milo Gwosden
William and Dorothy Hagar
Catherine L. Haight
James T. and Patricia A. Haight
B. Fenton Hall
Richard L. Hallberg
Steven J. Hamilton
Joseph Hammons
Bret D. Hampton
Paul A. Hanle
Patricia M. Hare
Roy Kenneth Harrill
Janet E. Harris
Joseph R. Harris and
Cynthia Uleman
Walter A. Harrison
Richard Hart
Stanley R. Hart
William K. Hart
Richard S. Hartman
Aaron Hasson
William T. Heath
Susan Helder
H. Lawrence Helfer
Paul W. Henderson
George A. Herbert, Jr.
Michael J. and Phyllis H. Herman
Luis Herrera
Jo Ann Hersh
Mary Ellen Hertz
Vera J. Hewitt
Jutta B. Hicks
Norman Hilgendorf
Wayne Hinkel
Henry P. Hoffstot, Jr.
Diane Holt
Lisa L. Holt
Wayne J. Hopkins
Michael H. Horner
Julianna Horvath
Leonora Horwin
Léo Houziaux
Warner T. Howe
J. Stephen Huebner and
Emily Z. Huebner
Larry D. Huffman
Munir and Jennifer L. Humayun
Sandra N. Humphrey
Edward Hurwitz
Bryant Idzik
Bobby R. Inman
Renate Jaacks and Linda Ford
Roger Jaccaud
Richard Jack
John H. Jacobs and Joan Gantz
Steven D. Jacobsen
Richard Jacobson
Jack C. James
Bernard W. Janicki
Cynthia Jehle
Florence and Martin Jesser
William D. Johns
Jillene Johnson
Robert S. Johnson
Theodore J. Johnson
Blair Jones
Richard A. Jorgensen
Jennifer R. Just
Nan E. Kaeser
Anne Kallfisch
Kenneth J. Kallfisch
Gina Kapaun
Peter G. Katona
Deborah Keller
Alex Kelly
James P. Kelly and
Beverlee Bickmore
Charles A. Kengla
Amanda Beth Key
James Key
Ann E. Keyes
Richard P. Kiel
Edmund W. Kiessling
Sean-Ryan King
Marguerite J. Kingston
Mary Beth Kirkham
Ralph L. Kiser
Katherine Kistler
Mark Allen and Pilar Kleinman
Michael D. Korschek
Kim Korte
Olavi Kouvo
Michael H. Koval
G. Gary Kowalczyk
Jonathan Kranz
Audrey S. Krause
Jeffrey L. Kretsch
Walter Kulakowski
Girard A. Labossiere
Arlo U. Landolt
John S. Langford III
Gregg LaPore
Margaret K. Latimer
Arthur and Faith LaVelle
Samuel A. and Mary M. Lawrence
Kurt L. P. Lawson
Calvin D. Lee
Harold H. Lee
Jennifer Lees
Lavonne Lela
Mary Leppert
Frederick K. Lepple
Nikki Levy
Kathleen D. Lewis
Paula Lewis
Steven and Nancy L'Hernault
Peter C. Lincoln
Britta Lindgren
Brigitte D. Linz
Stephen Litwin
Joseph Q. Livingston
Thomas H. Llanso
Felix J. Lockman
Thomas J. Loeffler
Matthew Lombardi
Jonathan Loonin
Brian B. Loretz
Christopher A. Loretz
Thomas E. Lovejoy
Mary L. Lovering
Peter B. Lyons
John J. Mackey
Juliet MacLean
Madhu Madhavan
Alan Mager
Richard J. Mahler
Anthony P. Mahowald
Steven R. Majewski
Gary Mallard
Bernard M. Malloy
Gretchen Mann
Stephen P. Maran
Jerry Markowitz
Janet E. Marott
Cindy Marsh
Andrew Marshall
Barbara C. Martin
Sam Martin
John R. Mashey
James M. and Roxane Mattinson
David A. Mauriello
Peter J. Maynard
Robert H. and Dorothy A. McCallister
Dennis McCormick
Sheila McCormick
Charlene McDonald
Don H. McDowell
Darren McElfresh
Carol McGuire
Joshua McKay
Stephen A. McKinniss
David McMeans
Jerry E. McMillan
Neil R. McNamara
Daniel Meekins
D. Joel Mellema
Amy Meserve
T. Spencer Metcalf
Mark Michael
Alan Miller
Dennis F. Miller
Harvey L. Miller
Michael Miller
Jennifer Milne
Joseph F. Moore
Michael B. Moran
James Morgan
Mary Lee Morrison and
William B. Upholt
John Morrow
John W. Mothersole
Gary G. Mrenak
Lee Muchnikoff
Michael Mullarkey

Karthik Murali
Joellyn Murphy
Ned Murphy
Seanan Murphy
Charles G. Myers
Ralph H. Nafziger
Norma J. F. Nager
Junta Nakai
Stuart Neff
Nentcho Nentchev
Trevor L. and Deborah W. Neve
Phillip and Sonia Newmark
Tham Nguyen
Donald S. Nicholson
Richard L. Nielsen
John Ray Nooncaster
Judith V. Nordin
Jan Null
Michael D. Oberdorfer
John Oliva
Michael E. Ollinger
Kathie L. Olsen
Gilbert Omenn and Martha Darling
Eric O'Neil
John H. and Roberta Overholt
Ryan D. Overman
Philip Pace
Raymond and Bette Ann Page
Michael S. Paisner
Lawrence Pakula
Brett Palmer
Dr. and Mrs. R. Bryce Parry
Niels M. Pedersen
Rudy Perez
Han T. Phan
Eric Philburn
James Phillips
Stephen Pierce
Elizabeth A. Piotrowski
Travis Plummer
Joseph Poletti
Arthur Pollak
Pavel Pomarleanu
Jeremy Porath
Daniel Porter
Lauren Porter
Justin Pourkaveh
Daniel Powell
Richard S. Preisler
Sherry Preiss
Joy Pretcher
David J. Proch
Jennifer Proescher
Dale A. Prouty
Paul Provance
Arnold J. Pryor
Laura Puckett
Daniel W. Pugh
Evelynn U. Putnam
Aparajit Raghavan
Shirley Raps
Andre and Beverly Rausch
Mary Ready
Patrick Reavey
Graham Redinger
Donald Regnell
Garrett E. Reisman
Minocher Reporter
Robert J. Reschly, Jr.
R. Michael Rich
Benjamin E. Richter
Herman H. Rieke
Massimo A. Righini
Harry and Grace Rissetto
Cristina Roark
Garth A. Roark
Barbara W. Robertson
Peggy Robertson
Rich Robison
Peter Roitman
Nancy Roman
Shirley M. Ross
Christopher S. Rubel
Raymond E. Ruth
Eileen Ryan
Michael and Linda Ryan
Lawrence E. Sager
Christian Salomone
Lyndon Sapozhnik
Anne K. Sawyer
Christine R. Saylors
Theodore Scambos
Linda Scharlatt
Robert Schechter
Mark Schenkman
Brendan Schlagel
Eberhard A. Schmidt
Maarten Schmidt
Cynthia Schulz
Matthew Schumacher
François Schweizer
Veronica M. Schweyen
Eugene and Alicia Scott
Malcolm G. Scully
Christopher T. Seagle
Amy E. Seitz
Brian P. Seitz
Frederic T. Selleck
Scott Seramur
Avraham Shapiro
Inez Parker Sharp
Claire Carter Shaver
Shane Shepherd
Rick Sherman
Nobumichi Shimizu
Walter Shropshire, Jr.
Ashley Sidon
Eli C. Siegel
Randolph B. Sim
Mary Ellen Simon
Lani Martinez Sinfield
Jeffrey R. Singer
Justin Sloan
Christine D. Smith
Deirdre Smith
Michael D. Smith
Robert C. Smith
David E. Snead
Polina Sokolova
Andrew W. Sorrells
Matthew W. Soule
Mark Spacco
Daniel M. Spees
Frank Spokane
Ken and Jean Stadel
Madeleine B. Stanicci
Erich W. Steiner
Steven M. Steinsnyder
M. Virginia Stockbridge
Carl Strickler
Richard L. Strombotne
Lubert Stryer
Leslie and Robert Sulla
Daoyuan Sun
Thomas H. B. Symons, C.C.
Heather Tahl
Gary R. Tanigawa
Colin Taylor
David Taylor
Ethan Taylor
Kevin Taylor
Leslie C. Taylor
Abigail Terhune
Michael Thacher and
Rhonda L. Rundle
Norbert Thonnard
Thomas R. Thornbury
Michael Tobias
Susan B. Tobias
Darayus Toorkey
Priestley Toulmin III
Charles H. Townes
John F. Tracy
Tim Tran
Martin Trees
James Tucker
Andrew Tufano
Christy Turner
Michael S. Turner
Trina Unzicker
Perry Urken
Ali Vakili
Lee Van Duzer
W. Karl Van Newkirk
Arthur H. Vaughan
Joshua Villbrandt
Yan Leonard Vinnik
Daniel and Eloise Vitiello
Robert and Ann von der Lippe
Willem L. Vos
Thomas A. Waddell
Mallory and Diana Walker
Richard J. Walker and Mary F. Horan
Douglas J. Wallis
William Wallner
Wayne H. Warren, Jr.
Skyler Weaver
Brad K. Weber
Johannes Weertman
Paul J. Werner and
Christel S. Cranston
Brian White
Edward White V
William M. White
Henry Wild
Spencer H. Wile
James E. Williams
Jeremy Winter
Evelyn M. Witkin
Jemma Wolcott-Green
Cecily J. Wolfe
Adeline E. Wong
James A. Wood
Sean Woodall
Margaret D. Woodring
Mary Jo Woods
Julianne Worrell
Frank K. Wyatt III
Robert J. Yamartino
Charles Yanofsky
Pamela D. Yerkes
David Young IV
Richard Young and Bonnie Beamer
Robert A. Young
Shu-cheng Yu
Leon Zar
Robert A. Zarzar
Timothy A. Zimmerlin
Matthew S. Zipfel

* **Deceased**

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

Foundations and Corporations

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

$100,000 to $999,999
Anonymous
Carnegie Corporation of New York
The Ellison Medical Foundation
The Grantham Foundation for the Protection of the Environment
John D. and Catherine T. MacArthur Foundation
The Andrew W. Mellon Foundation
The Ambrose Monell Foundation
Gordon and Betty Moore Foundation
The Rose Hills Foundation
Searle Scholars Program

$10,000 to $99,999
Anonymous (2)
The Abell Foundation, Inc.
Association of American Medical Colleges
Battelle
The Brinson Foundation
Carnegie Institution of Canada/Institution Carnegie du Canada
Chesapeake Bay Trust
The Crystal Family Foundation
Michael A. Duffy Revocable Trust
Durland Co., Inc.
Fodor Family Charitable Trust Fund
Fondation de France
The Gayden Family Foundation
Golden Family Foundation
Gary and Cary Hart Trust
Hazen Foundation
Richard W. Higgins Foundation
Laurel Foundation
The Michael T. Long Family Foundation
Longfield Family Charitable Foundation
The G. Harold & Leila Y. Mathers Charitable Foundation
The McMurtry Family Foundation
MGW & CJW 2007 Trust
The Kenneth T. and Eileen L. Norris Foundation
The Ralph M. Parsons Foundation
Rothrock Family Fund
Society for Developmental Biology
The Helen Hay Whitney Foundation

$500 to $9,999
American Society of Human Genetics
Arnhold Foundation, Inc.
Atlantis Research Foundation
The Baruch Fund
The Bodman Foundation
The Boeing Gift Matching Program
Bristol-Myers Squibb Foundation, Inc.
Cavalieri-Look Fund
The Nick DeWolf Foundation
Ernst Charities
Bill and Melinda Gates Foundation
Arthur and Linda Gelb Charitable Foundation
The Greenfield Family Foundation, Inc.
Hicks Family Charitable Foundation
Rush Holt & Margaret Lancefield Fund of the Princeton Area Community Foundation
Japan Tech
Laubach Family Fund
Linden Trust for Conservation
Robert W. and Gladys S. Meserve Charitable Trust
Microsoft Matching Gifts Program
Omenn-Darling Family Advised Fund
Honey Perkins Family Foundation, Inc.
The Pfizer Foundation Matching Gifts Program
Rickard Family Foundation
Roxiticus Foundation
The SDLM Trust
Dorothy G. Spiewak Trust
The Spradling/Griffin Charitable Gift Fund
Stephenson Foundation
SunTrust Foundation
TOPS Department
Wells Fargo
Xerox Corporation
ZGF Architects LLP
The Zoback Trust

Honors & Transitions

Honors

Embryology

Allison Pender received Carnegie's Service to Science Award for her superior management of the Biopolymer Core Facility for over 20 years.

Geophysical Laboratory

Duck Young Kim received the 2013 Jamieson Award for his high-pressure science work.

Global Ecology

Christopher Field was co-recipient of the Max Plank Research Prize for increasing our knowledge on the effects of climate change. He also received the BBVA Climate Change Award.

Observatories

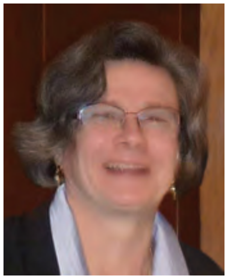
Stephen Shectman was elected to the National Academy of Sciences.

Planet Biology

Postdoctoral fellow **Rubén Rellán-Álvarez** received the Marschner Young Scientist Award from the International Plant Nutrition Colloquium.

Terrestrial Magnetism

Richard Carlson received the 2013 Arthur L. Day Medal from the Geological Society of America. **Mary Horan** was awarded Carnegie's Service to Science Award for her stellar management of the Geochemistry Laboratory.



★ *Allison Pender*

★ *Duck Young Kim*

★ *Christopher Field*

★ *Stephen Shectman*

★ *Rubén Rellán-Álvarez*

★ *Richard Carlson*

★ *Mary Horan*

Honors & Transitions


★ *Richard A. Meserve*


★ *Matthew P. Scott*


★ *Nick Ingolia*


★ *Frederick Tan*


★ *Linda Elkins-Tanton*


★ *David James*

Transitions

Trustees/Administration

On September 1, 2014, **Richard A. Meserve** stepped down as Carnegie president and **Matthew P. Scott** began his presidential tenure.

Embryology

Staff member **Nick Ingolia** left Embryology for UC-Berkeley. **Frederick Tan** joined the staff. He works on bioinformatics.

Terrestrial Magnetism

Director **Linda Elkins-Tanton** left Terrestrial Magnetism for Arizona State University. **Richard Carlson** is the new director. Staff member **David James** retired.

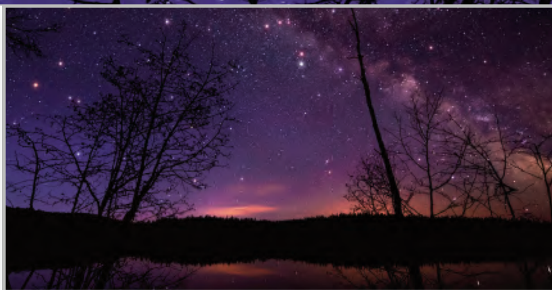
2013-2014 YEAR BOOK

Research Highlights

Image courtesy Robin Kempster

Astronomy

Investigating the Birth, Structure, and Fate of the Universe



New Method Dates Old Stars

Astrophysicist and instrument developer Rebecca Bernstein, with Andrew McWilliam, Janet Colucci, and colleagues, created a new technique for analyzing the chemistry and determining the ages of collections of old stars called globular clusters. They recently used it to measure the chemical abundances and ages of 31 clusters in our neighboring galaxy Andromeda. Researchers can compare the detailed chemical history of old stars there to those in the Milky Way to understand how galaxies form.

The chemical abundances of stars reveal the formation histories of their parent galaxies. Elements in the atmosphere of a star absorb radiation emitted in the star's core, producing telltale features revealed in the spectrum of the star's light.

The oldest stars in a galaxy contain mostly hydrogen and helium. As generations of stars live their lives, new elements are produced in their cores. When the stars explode as supernovae, those new elements are released. New stars form from the enriched chemical gas, whose composition varies depending on the type of supernova. Young stars have more heavy elements than older stars.

The relative elemental abundances reveal the history of star formation and stellar evolution in a galaxy, yielding insights into a galaxy's formation history.

Astronomers can evaluate individual stars in the Milky Way, but the same level of detail had not been possible to obtain previously in other normal-mass galaxies, including Andromeda. So Bernstein and colleagues refined a technique first reported on in 2005. They analyzed the combined light from stars in globular clusters. Initially, the team experimented with clusters in the Milky Way to verify the technique by comparing the new method with standard methods of analyzing individual stars. They then applied the method of analyzing "integrated light" to 31 Andromeda globular clusters.

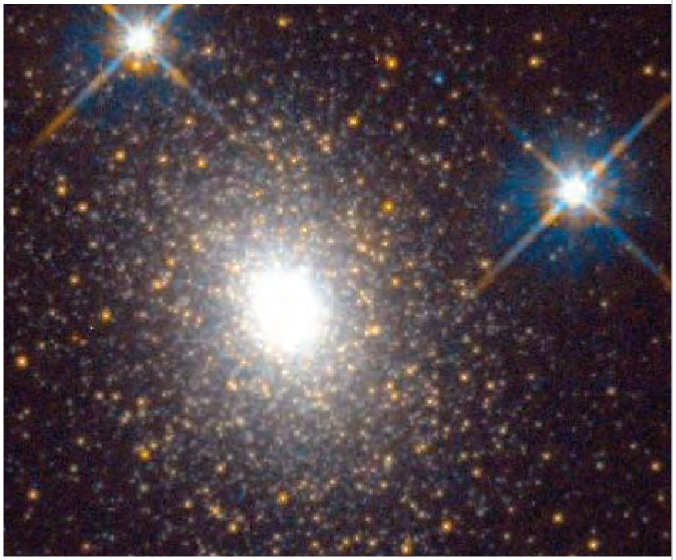
This study provides a brand-new window on Andromeda's chemical history. The chemistry revealed that most globular clusters are at least 10 billion years old, with only one appearing to be about 2 billion years old. In general, the relative elemental abundances in Andromeda clusters are similar to those found in Milky Way globular clusters and suggest that early chemistry was dominated by material from Type II supernovae, which have a distinctive signature of hydrogen and helium in their spectra. They found that one anomalous Andromeda cluster might have been a massive dwarf galaxy swallowed by Andromeda late in the galaxy's formation.

(Right) In addition to her research into extragalactic background light and the chemical enrichment of galaxies, Rebecca Bernstein is a world leader in developing state-of-the-art instrumentation for large telescopes.

Image courtesy Tim Neighbors

The Andromeda galaxy, or M31, is the Milky Way's largest galactic neighbor; it is about 2.5 million light-years away. This image, a composite of 11 different images from NASA's Galaxy Evolution Explorer, shows what the galaxy looks like in the ultraviolet range of the spectrum. The blue-white rings contain hot, young, massive stars. The central orange-white ball reveals cooler, old stars.

Image courtesy NASA/JPL-Caltech



The above giant globular cluster of stars orbits near the center of the Andromeda galaxy and contains over 300,000 stars with a similar lineage.

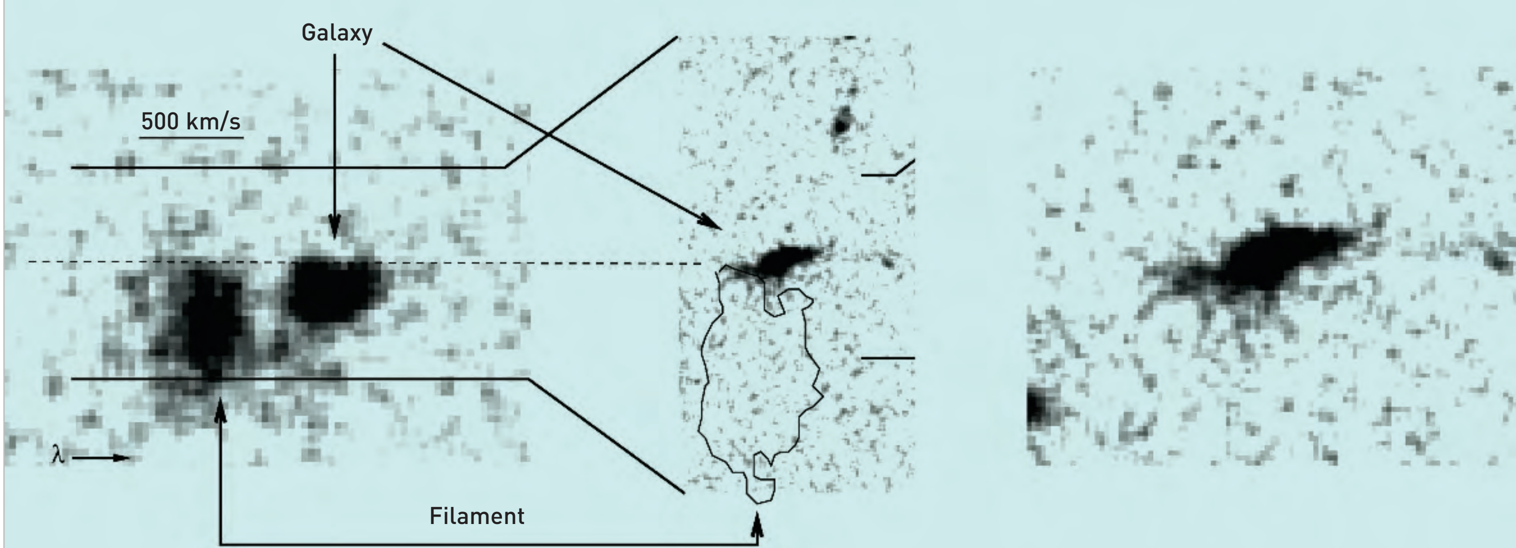
Image courtesy M. Rich, K. Mighell, J. D. Neill, W. Freedman, NASA

Astronomy

Continued

Michael Rauch and colleagues are...
recording the telltale faint light from gas flows,
employing the deepest astronomical
observations ever.

Magellan 2-D Spectrum **Hubble Space Telescope Image**



The figure shows the discovery spectrum of the so-called Lyman-alpha line of this object from one of the Magellan telescopes at left. The centered, enlarged area shows an image of the underlying galaxy taken with the Hubble Space Telescope. The velocity difference between the filament and the galaxy suggests that hydrogen from the intergalactic medium is falling into the galaxy in a filamentary stream. The galaxy responds to the influx of fuel by making new stars and producing copious amounts of radiation. The nature of the strange filaments is not yet clear—they may be gas glowing on its final descent into the galaxy or a swarm of smaller satellites just having passed through the main galaxy.

Image courtesy Michael Rauch

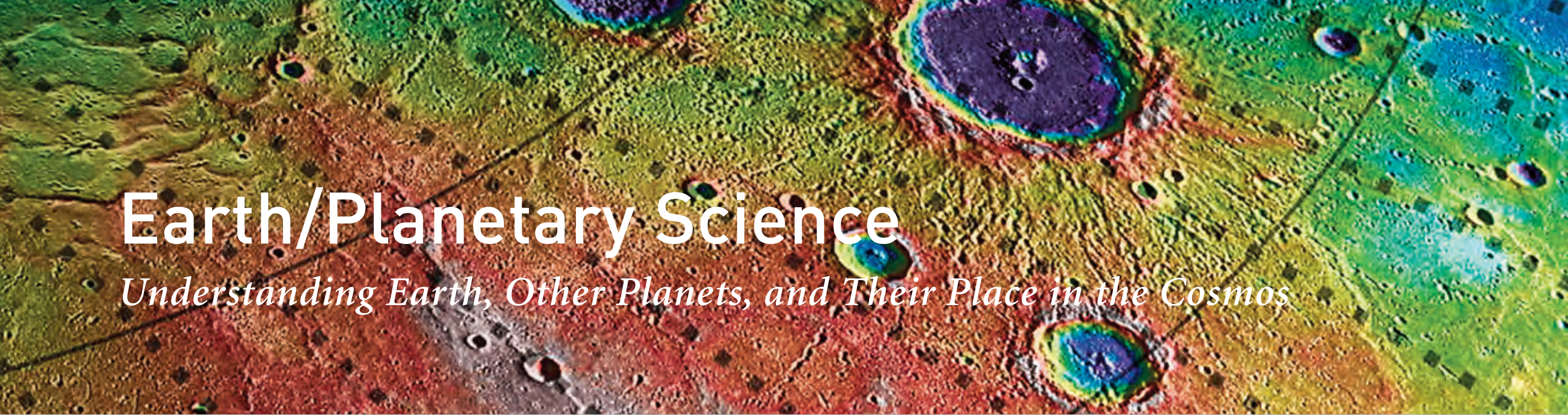
Understanding the Galactic Ecosystem

Michael Rauch is interested in unraveling the cosmic web.

Astronomers believe that the young universe initially was filled with an almost uniform and opaque gas, the intergalactic medium (IGM). Galaxies are thought to form partly through the infall of gas from this reservoir and partly from mergers of smaller units. They return some of their gas, enriched by chemical elements made in their stars, to the IGM and, at early times, burn off the intergalactic “fog” with their energetic photons, leaving the universe in the transparent state that still prevails today.

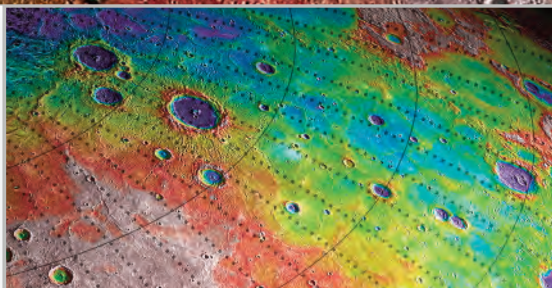
Key components of this galactic ecosystem, like the actual infall of gas, have remained sketchy, as they literally happen in the dark. Early galaxies are small and do not shine brightly, and the gas is exceedingly tenuous. Michael Rauch and colleagues are trying to fill in the blanks by recording the telltale faint light from such gas flows, employing the deepest astronomical observations ever undertaken.

Gas flows in and out of galaxies are not completely invisible. Radiation from hot stars and collisions between atoms incite the electrons in the gas atoms (mostly hydrogen) to emit light of a characteristic wavelength, the so-called Lyman-alpha transition. Rauch uses spectrographs aimed at seemingly empty spots of sky to find distant galaxies where these processes are underway. Not only does Lyman-alpha radiation help pinpoint galaxies in crucial phases of growth, but also the shape of the observed Lyman-alpha emission line reveals whether the gas is falling in or flowing out, how it is arranged spatially, and how the associated galaxy is keeping it lit. A few years ago, a first plausible candidate for the infall of gas was found in a faint galaxy observed at a time when the universe was about 15% of its current age. A recurrent finding in Rauch’s surveys is that Lyman-alpha halos show interactions between galaxies and their infalling satellite building blocks. In the mayhem, satellites may get stripped of their chemically enriched gas and energetic photons may escape from the stripped stars or through holes punched into the gaseous cocoon around the main galaxy. These processes could explain the long-standing puzzles as to how the universe gets “polluted” with chemical elements and how the IGM was made transparent by galactic radiation.



Earth/Planetary Science

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



Solar System's Edge Redefined

The Solar System has a new most-distant member. New work from Carnegie's Scott Sheppard and Chadwick Trujillo of the Gemini Observatory reports the discovery of a distant dwarf planet beyond the known edge of the Solar System. The dwarf planet called 2012 VP113 was nicknamed Biden after the vice president (VP). This is likely one of thousands of distant objects that are thought to form the so-called inner Oort cloud. The known Solar System can be divided into three parts: rocky planets like Earth that are close to the Sun; gas giant planets that are farther out; and the frozen objects of the Kuiper Belt, such as Pluto, just beyond Neptune's orbit. Beyond this, there appears to be an edge to the Solar System where only one object, Sedna, was previously known to exist. But the newly found 2012 VP113 has an orbit that stays even beyond Sedna. 2012 VP113's closest orbit point to the Sun brings it to about 80 astronomical units (AU) from the Sun, where one AU is defined as the distance of the Earth from the Sun. For context, the rocky planets and asteroids exist at distances ranging between 0.39 and 4.2 AU. Gas giants are found between 5 and 30 AU, and the Kuiper Belt (thousands of icy objects, including Pluto) ranges from 30 to 50 AU.

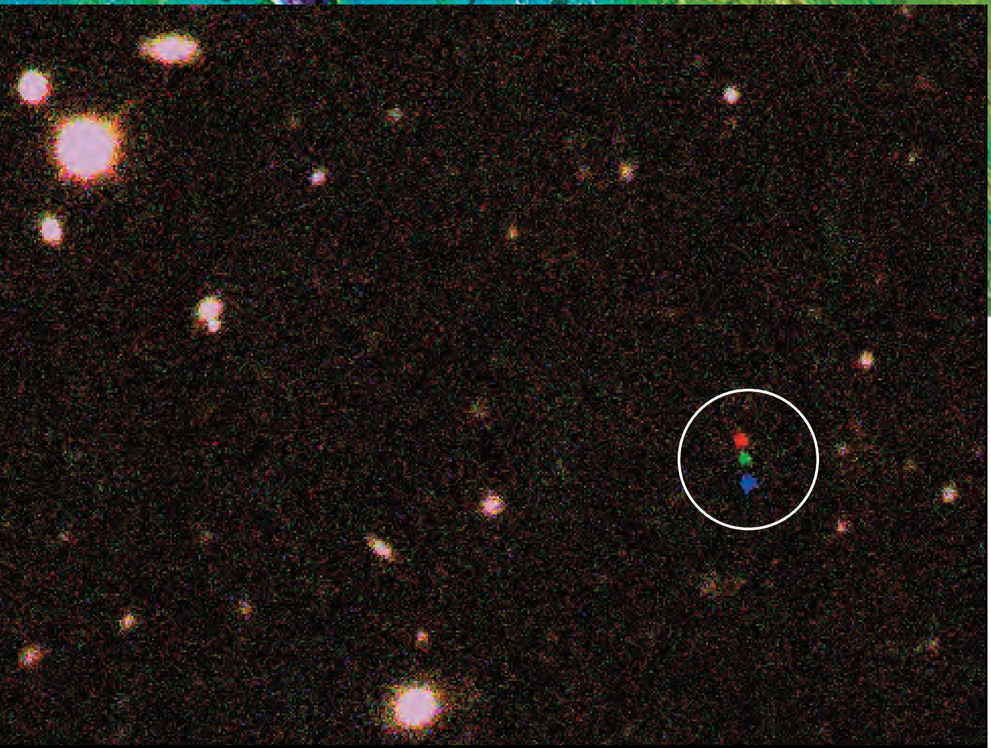
Scott Sheppard (shown) and Chadwick Trujillo have redefined the known edge of the Solar System.

Image courtesy Scott Sheppard

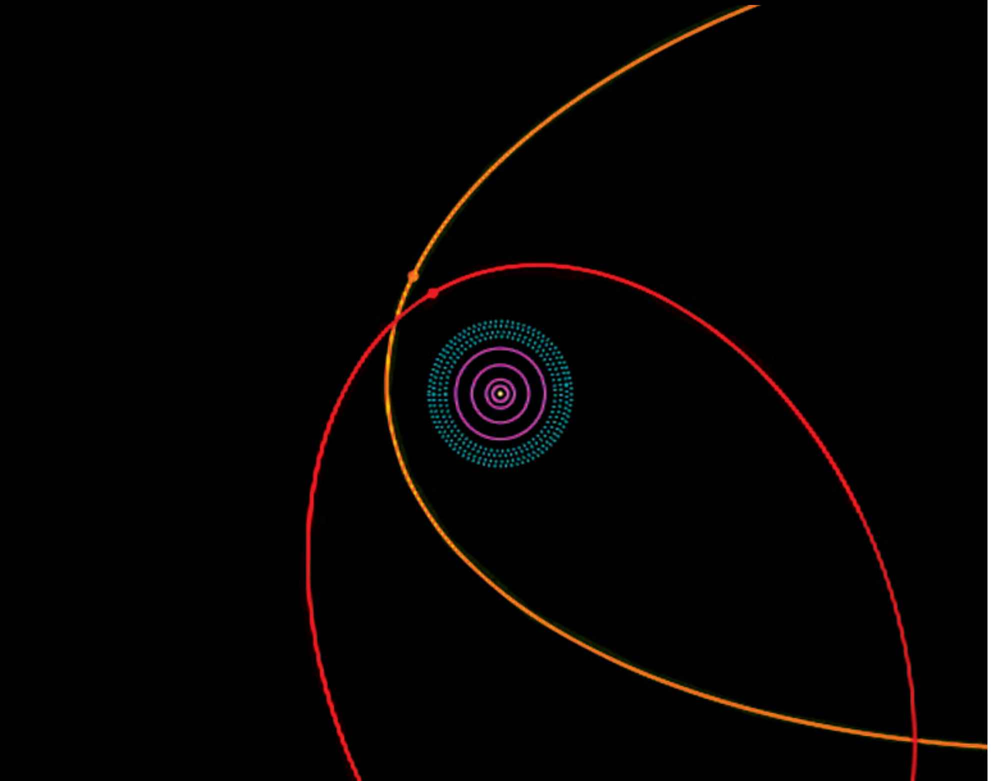
In our Solar System there is a distinct edge at 50 AU. Before 2012 VP113, only Sedna was known to stay significantly beyond this boundary for its entire orbit.

Based on the small fraction of the sky surveyed to date, the team expects there are about 900 objects sized larger than 620 miles (1,000 km) with orbits like 2012 VP113 and Sedna and that the total population is larger than the Kuiper Belt and main asteroid belt.

Both Sedna and 2012 VP113 were found near their closest approach to the Sun, but they both have orbits that go out to hundreds of AU, at which point they would be too faint to be seen from Earth. In fact, the similarity in the orbits found for Sedna and 2012 VP113 suggests that an unknown massive perturbing body may be shepherding these objects into these similar orbital configurations. A Super Earth or an even larger object could create the effect seen in the orbits of these objects.



. . . the discovery of
a distant dwarf planet
beyond the known edge of the Solar System.



(Above) These are the discovery images of 2012 VP113, affectionately called "Biden" because of the VP in its provisional name; it has the most distant orbit known in our Solar System. Three images of the night sky, each taken about two hours apart, were combined into one. The first image was artificially colored red, second green, and third blue. 2012 VP113 moved between each image as seen by the red, green, and blue dots. The background stars and galaxies did not move, and thus their red, green, and blue images combine to show up as white.

Image courtesy Scott Sheppard and Chad Trujillo

(Left) This diagram of the outer Solar System shows the orbits of Sedna (in orange) and 2012 VP113 (in red). The Sun and terrestrial planets are at the center, surrounded by the orbits (in purple) of the four giant planets Jupiter, Saturn, Uranus, and Neptune. The Kuiper Belt, which includes Pluto, is the dotted light blue region.

Image courtesy Scott Sheppard

Earth/Planetary Science

Continued

Giving Birth to Planetary Systems

In the first days of our Solar System, dust and gas that surrounded our young Sun in a disk slowly accumulated into planetesimals that grew into protoplanets and eventually planets. Much is still not known about how volatile molecules, such as water and organic molecules, survived the heat and collisional turmoil of the planetary formation process. Yet they obviously found a way to Earth, which is thus able to support life.

Carnegie's Alycia Weinberger uses Las Campanas Observatory's sophisticated new Magellan Adaptive Optics (MagAO) system, which she helped commission, to observe early phases of planet formation in circumstellar disks. Planetesimal chemistry forms the basis for protoplanet chemistry and, ultimately, planetary chemistry. While her colleagues at Carnegie can collect meteoritic and cometary samples from the Solar System, Weinberger relies on telescopically observed light to investigate planetary systems around other stars. By doing so, she can directly observe an epoch of planet formation that happened over 4.56 billion years ago in our own Solar System.

Collisions between planetesimals, and even their evaporation, can create an ongoing circumstellar disk around a star, where protoplanets can continue to grow and form. Hundreds of stars have been observed to be surrounded by these so-called debris disks. Stars illuminate their disks, but our images of stellar environs are normally swamped by the light coming directly from the star. MagAO concentrates the starlight in a central core so that the full power of Magellan's 6.5-meter aperture reveals the structures of disks.

Weinberger uses spectroscopy, the ability to break light down into its component colors, to look for the fingerprints of different molecules and to determine what size the dust grains are by how well they scatter starlight of different wavelengths. Both water and organic molecules have spectral signatures at near-infrared wavelengths, where MagAO works outstandingly well to provide pristine images of stars and their surroundings. As planets form, they can perturb planetesimals, so she also seeks to measure the size of collisional debris at different locations in a disk and determine how energetic the planetesimal collisions must be to generate the observed dust.

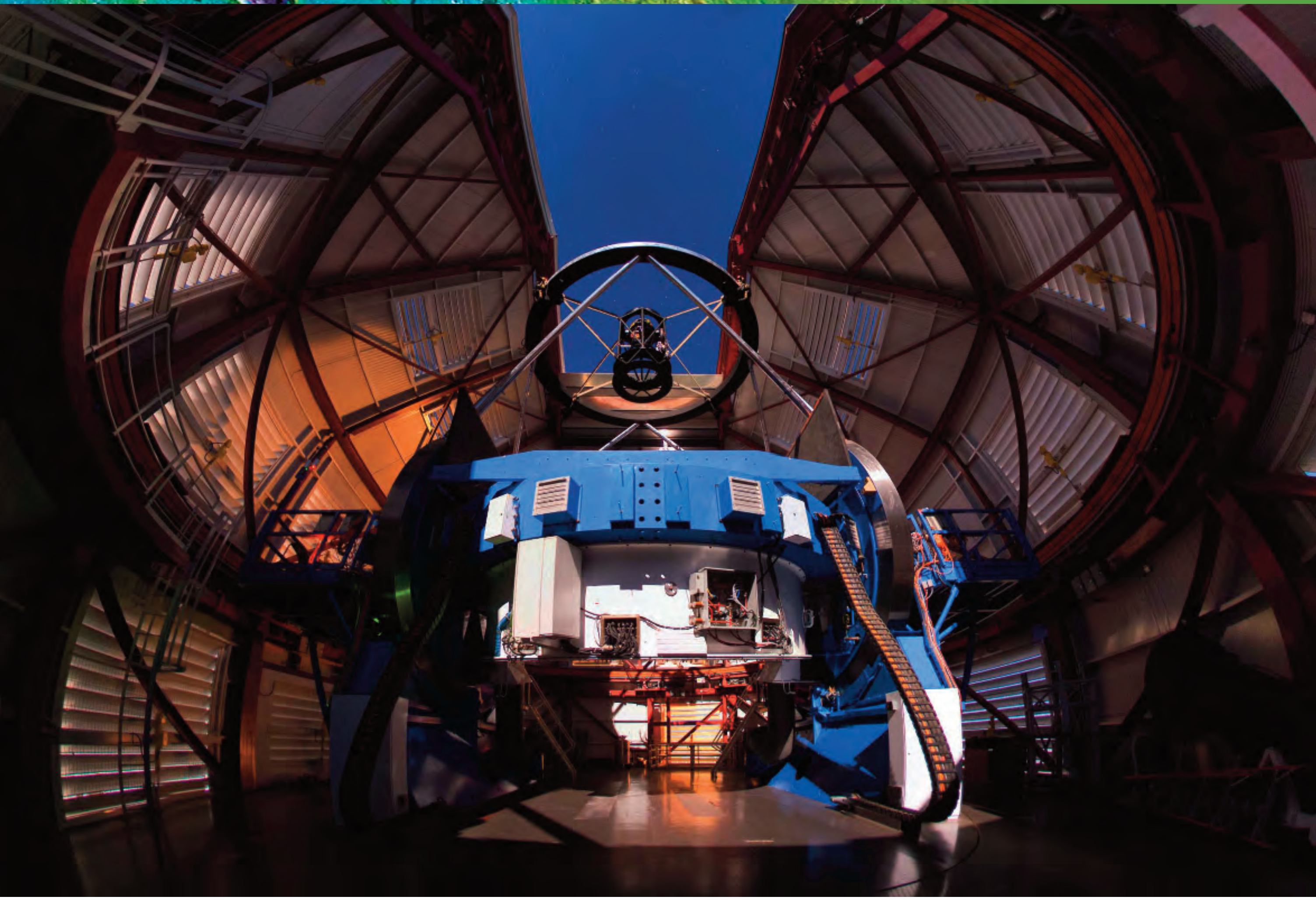
Finding evidence of organic molecules and water would show that other systems have the building blocks of life and also might indicate how they survived our own Solar System's early days to create life-nurturing conditions on our own planet. ●

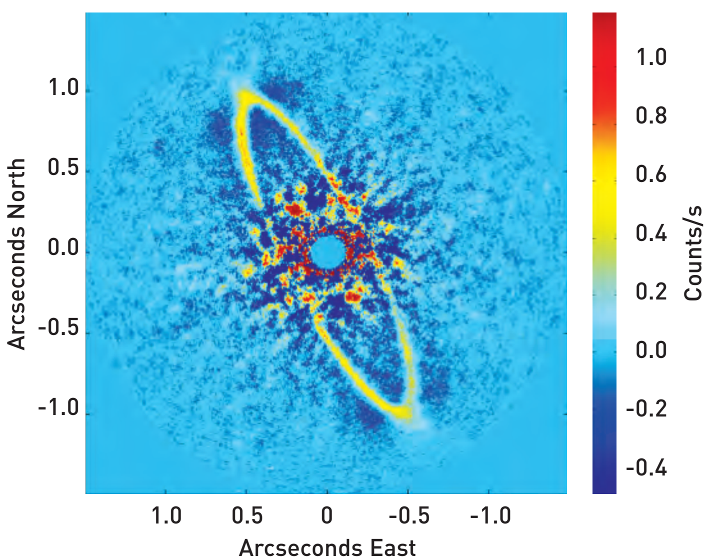
(Right, top) The Magellan Telescope with Magellan Adaptive Optics' Adaptive Secondary Mirror mounted at the top, looking down on the 6.5-meter (21-foot) diameter Primary Mirror.

Image by Moonlight courtesy Yuri Beletsky, LCO/Magellan Staff

(Right) The narrow ring of dust around the star HR 4796 reflects light, and is shown here as imaged at 3.7 microns wavelength using Magellan AO. This is just one of seven images made of the disk at different wavelengths, and together they show that the color of the disk comes from scattering by small silicate grains, perhaps mixed with organics and water ice.

Image courtesy Carnegie fellow Timothy Rodigas





Alycia Weinberger uses the facilities at Carnegie's Las Campanas Observatory to understand early phases of planet formation.

Image courtesy Alycia Weinberger

Deciphering the Complexity of Cellular, Developmental, and Genetic Biology

Harnessing the Data Avalanche

Frederick Tan holds a unique position at Embryology in this era of high-throughput sequencing where determining DNA and RNA sequences has become one of the most powerful technologies in biology. DNA provides the basic code shared by all our cells to program our development. While there are about 30,000 human genes, 98% of DNA sequences are comprised of repetitive and regulatory sequences within and between genes. Measuring the specific set of DNA sequences that are transcribed into RNA helps reveal what and how our tissues are doing by showing which genes are active.

Modern sequencing platforms, such as the Illumina HiSeq 2000, generate only short, ordered sequences, usually 100 consecutive bases—adenine, guanine, cytosine, and thymine—in each reaction. But by doing this on billions of molecules in parallel, these sequencers generate between 100,000 and 1 million times more data than previous methods. That's where Tan fits in. Departmental scientists cope with this data avalanche by combining their biological insights with complex computer algorithms and statistical methods. Tan manages the genomics and bioinformatics facilities and guides others on their use.

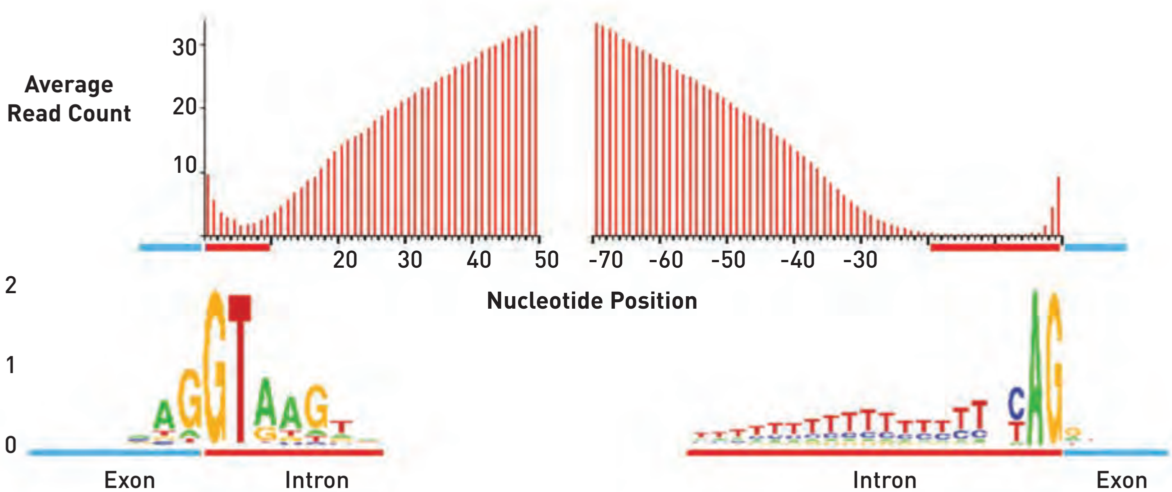
Tan shares his knowledge by leading workshops, group-study sessions, and teaching courses to familiarize Carnegie and Johns Hopkins researchers with bioinformatics approaches. He started a study group called Data Wranglers Anonymous where people learn to handle large numbers of data files, conduct exploratory data analyses, and write programs to extract useful information. Tan also created a series called Nitty Gritty Workflows to discuss sequence analysis pipelines. Speakers describe software programs they used and why they chose specific parameters—important for troubleshooting and establishing best practices. He helped Embryology host the fourth annual Practical Genomics Workshop and has ambitious plans for future training.

Tan also conducts his own research using the yeast *S. cerevisiae.* He studies recombination—the rearrangement of genetic material—by adapting systems he helped developed as a postdoc in the Koshland lab to current sequencing methods. He is exploring methods that sequence over 10,000 consecutive DNA bases, allowing sequencing across chromosome translocation junctions that contain repetitive DNA—a characteristic often associated with genetic rearrangements in cancer.

(Right, top) Carnegie scientists discuss different ways to isolate specific categories of sequencing reads from next-generation sequencing data at a recent Data Wranglers Anonymous session.

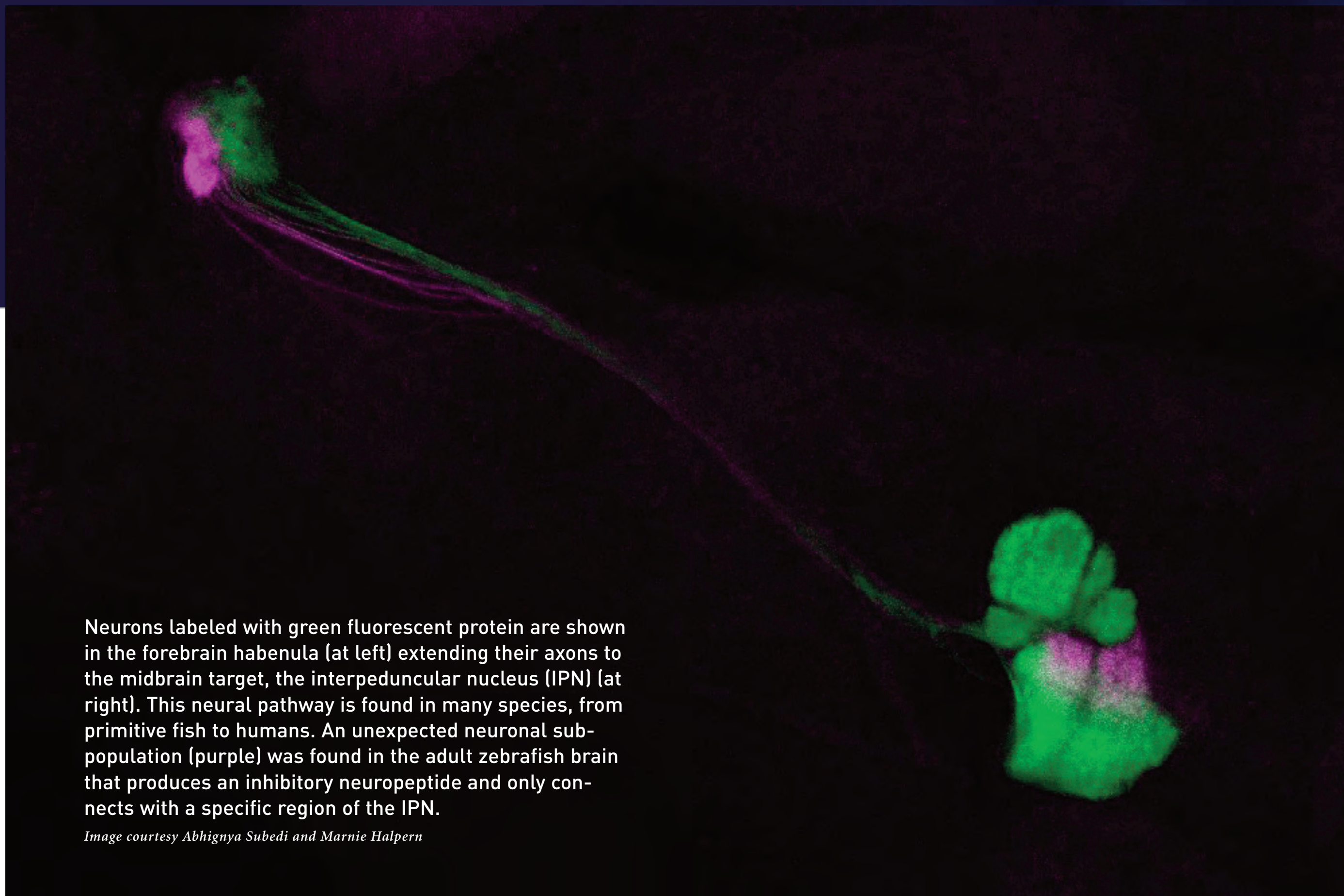
Image courtesy Bill Kupiec

Wrangling Data



Carnegie scientists worked at a recent Data Wranglers Anonymous session on a program to calculate the average number of gene sequencing reads derived from the ends of non-coding DNA segments called introns. Sequencing is the process of determining the order of nucleotides, the basic units of adenine, thymine, guanine, and cytosine, within a DNA molecule. The top histogram and subsequent sequence motif analysis (bottom with nucleotides in letter code) gave a clue to Carnegie scientist Joseph Gall and his student Gaëlle Talhouarne that stable introns found in the frog *Xenopus* oocyte cytoplasm, the cellular material outside of the nucleus, are in a special circular formation known as a lariat.

From RNA *20(9):1476-1487.*



Neurons labeled with green fluorescent protein are shown in the forebrain habenula (at left) extending their axons to the midbrain target, the interpeduncular nucleus (IPN) (at right). This neural pathway is found in many species, from primitive fish to humans. An unexpected neuronal subpopulation (purple) was found in the adult zebrafish brain that produces an inhibitory neuropeptide and only connects with a specific region of the IPN.

Image courtesy Abhignya Subedi and Marnie Halpern

New Markers to Map the Brain

In 2013 the Obama administration formed The BRAIN Initiative (Brain Research through Advancing Innovative Neurotechnologies), an ambitious endeavor to identify all nerve cell types in the human brain and understand how they connect. The goals of this initiative may eventually be achieved, but characterizing the human brain would be significantly accelerated by comparative studies on animal models. Currently, there are no comprehensive connectivity maps for any vertebrate brain. Part of the challenge is to identify unique subsets of neurons. Researchers in Marnie Halpern's lab are using new DNA sequencing technologies in zebrafish to find neuronal markers for a pathway that modulates important functions such as stress, fear, sleep, learning, and memory.

Researchers in Marnie Halpern's lab are using new DNA sequencing technologies in zebrafish to find neuronal markers...

Abhignya Subedi (left) and Erik Duboué examine 3-D reconstructions from confocal microscopy of the larval zebrafish brain.
Image courtesy Bill Kupiec

Graduate student Abhignya Subedi, along with postdoctoral associate Erik Duboué, took advantage of transgenic zebrafish that have neurons in the habenular region of the forebrain and their axonal extensions to the midbrain target—the interpeduncular nucleus (IPN)—labeled with the green fluorescent protein (GFP). They used the fluorescently labeled axons as a guide to carefully dissect the IPN out of adult fish brains. The tiny tissue pieces were pooled from several brains, and all of the messenger RNA (mRNA) was extracted and copied into DNA. Subedi and Duboué then used next-generation DNA sequencing to identify messages that are highly enriched and discovered several that are only "turned on" in a subset of neurons in discrete regions of the IPN.

Such studies are providing a far more detailed picture of the diverse types of neurons and their distribution within the poorly understood IPN. Similarly, Halpern's team has found unexpected neuronal populations in the habenular nuclei that project only to limited regions of the IPN; a new connectivity map is emerging for an essential forebrain to midbrain pathway.

This forebrain to midbrain pathway has been implicated in a variety of conditions such as schizophrenia, depression, and drug abuse. Greater knowledge of its precise neurons and their synaptic partners could be the foundation for potential therapies.

Global Ecology

Linking Ecosystem Processes with Large-Scale Impacts

Behind the Scenes of the Climate Change Assessment

In March 2014 a technical support unit (TSU) of ten, headquartered at Global Ecology, successfully completed an enormous management effort of the 1,800-page assessment *Climate Change 2014: Impacts, Adaptation, and Vulnerability* and its two summaries. These documents were issued by the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) Working Group II, cochaired by Global Ecology director Chris Field. Science codirectors Katie Mach and Mike Mastrandrea managed the input of over 190 governments and nearly 2,000 experts from around the world to complete the report.

The IPCC, established in 1988, assesses information about climate change and its impacts. In September 2008 Field was appointed cochair of Working Group II. The process, managed by the TSU and prescribed by the IPCC, ensures that the report is comprehensive, incorporates government and scientists' reviews, and remains policy relevant and neutral. It also involved a line-by-line approval of the 32-page policymaker summary.

Government representatives itemized the topics to address, which were used to produce the outline in July 2009. The report expanded on the previous assessment with 10 new chapters, including a broader ocean assessment and material on poverty, human security, livelihood, and urban and rural areas.

From January to June 2010, governments and organizations nominated 1,200 experts, and 242 lead authors and 66 review editors were elected.

Experts reviewed thousands of sources; over 12,000 references were cited. The report went through two extensive rounds of review, one in the summer of 2012 and the other in the spring of 2013. In all, 1,729 experts reviewed the report and over 50,000 comments were addressed.

Mach and Mastrandrea worked with the cochairs to produce the summaries—a 60-page technical summary and the high-profile 32-page policymaker summary. Their perspective allowed them to see the patterns, similarities, and overlap among the different topics to highlight the most important findings. The policymaker summary was sent for government review in October 2013, with Mach and Mastrandrea coordinating the comment-response process.

As a last step, the policymaker summary went through a line-by-line approval process at a March 2014 meeting in Japan. Government representatives, scientists, and others gathered in an auditorium for a five-day, virtually nonstop review cochaired by Field and Vicente Barros. Every line was scrutinized aloud. In the end, all IPCC governments and scientists were in full consensus of the content.

This image shows the synthesis report approval meeting in Copenhagen. This dialogue was the final component of the scientist/government interactions in the Fifth Assessment Report. Chris Field, cochair of Working Group II, is second from right.

Image courtesy IPCC and Katie Mach.

Mike Mastrandrea and Katie Mach, housed at Global Ecology, codirected the complex and global five-year process that culminated in *Climate Change 2014: Impacts, Adaptation, and Vulnerability* from the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) Working Group II. Chris Field, director of Global Ecology (top), cochairs Working Group II.

Image courtesy Robin Kempster

Snapshot of the Assessment's Scope & Process

Statistics courtesy IPCC Working Group II

THE REPORT — 2009 -2014

- **1** scoping meeting to outline **30** chapters
- **1217** author nominations representing **92** nationalities
- **242** lead authors and **66** review editors from **70** countries
- **436** contributing authors from **54** countries
- Over **12,000** scientific references cited

THE 1ST ORDER DRAFT EXPERT REVIEW — Summer 2012

- **1774** individuals registered as expert reviewers
- **19,598** comments

THE 2ND ORDER DRAFT EXPERT AND GOVERNMENT REVIEW — Spring 2013

- **2631** individuals registered as expert reviewers
- **28,544** comments
- **1271** expert reviewers from **67** countries
- **33** governments

THE FINAL GOVERNMENT DISTRIBUTION — October 2013

- **2350** comments on the Final Draft Policymaker Summary
- **241** reviewers from **45** governments

TOTAL REVIEWS

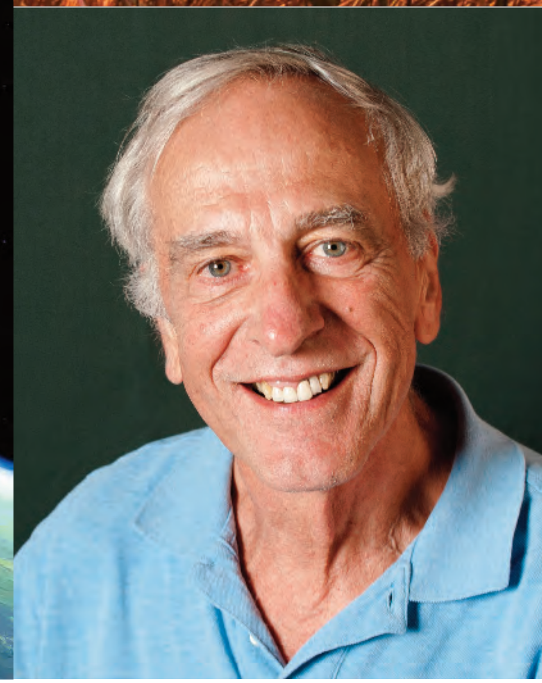
- **50,492** comments
- **1729** expert reviewers from **84** countries
- **49** governments

THE WGII APPROVAL SESSION — March 2014

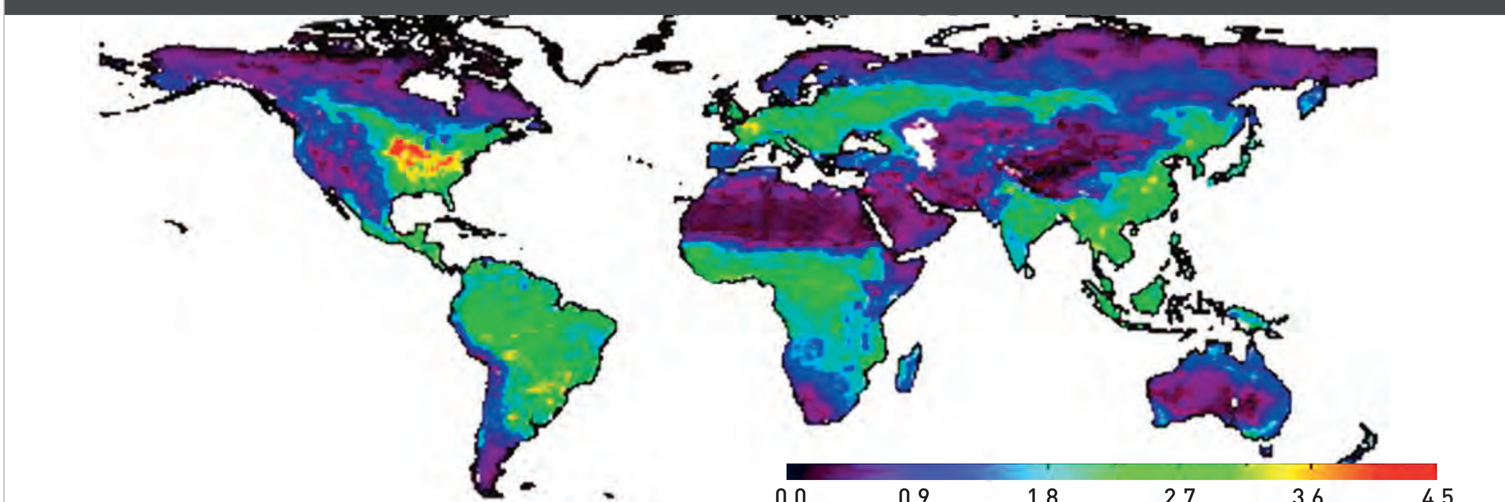
- 25-29 March 2014, Yokohama, Japan
- The Summary for Policymakers was approved line-by-line and accepted by the panel, which has **195** member governments

The artwork shows the process of measuring photosynthesis, via sun-induced fluorescence, from space.

Image courtesy Pat Rawlings, Keck Institute for Space Studies



Max (SIF) (mW/m²/sr/nm)



Global Ecology

Continued

Breakthrough for Crop Estimates

New research from a team including Carnegie's Joe Berry reveals a fundamentally new approach for measuring photosynthetic activity on a global scale. The technique will improve the monitoring of agricultural productivity and can be applied to natural ecosystems. Both uses are particularly important in the face of climate change.

During photosynthesis plants convert energy from sunlight, carbon dioxide, and water into sugar—chemical energy. Humans and animals eat the plants, making photosynthesis the primary source of energy for all life on Earth. Scientists know that the photosynthetic activity in different regions is changing due to human interaction with the environment, including climate change. And these changes make large-scale studies of photosynthetic activity increasingly important.

Until now, computer models have been the primary tools for estimating photosynthetic productivity on a global scale. They are based on estimating a measure of plant energy called gross primary production (GPP), which is the rate at which plants capture and store a unit of chemical energy as biomass over a specific time. But the accuracy of these indirect approaches has been difficult to evaluate.

The core of the new approach is a breakthrough in the use of satellite technology to measure light that is emitted by plant leaves as a byproduct of photosynthesis. The plant produces fluorescent light when sunlight excites the photosynthetic pigment chlorophyll. Instruments aboard the Japanese Greenhouse Gases Observing Satellite (GOSAT) sensed this fluorescence as the orbiter passed overhead. The technique gives researchers a direct observation of photosynthesis on a large scale for the first time.

Berry's team made observations of fluorescence from large areas of crops in the Midwestern Corn Belt and the Indo-Gangetic Plain. This new data produced values that are 50% to 75% higher than state-of-the-art carbon cycle models, indicating that the models are severely underestimating photosynthesis.

The new studies provide a new and improved tool to evaluate the comparative productivity of the breadbaskets of the world. The relationship between fluorescence measured from space and gross primary production also provides a way for researchers to assess in near real time the production of other, non-agricultural areas of the world, including vast expanses of uncultivated forests and grasslands, which will reduce uncertainties in the modeling of current and future carbon cycles. ●

(Left, top right) Carnegie's Joe Berry

Image courtesy Robin Kempster

(Left) This map shows the highest sun-induced fluorescence (SIF) for all terrestrial ecosystems. The researchers used instruments onboard the MetOp-A platform on the satellite to produce unique estimates of global cropland gross primary production. They used monthly averages from 26 measurements. The United States Corn Belt in the Midwest, for instance, has the highest reading in July and is thus colored red. The lowest values are purple.

Image used with permission from PNAS

Matter at Extreme States

Probing Planetary Interiors, Origins, and Extreme States of Matter

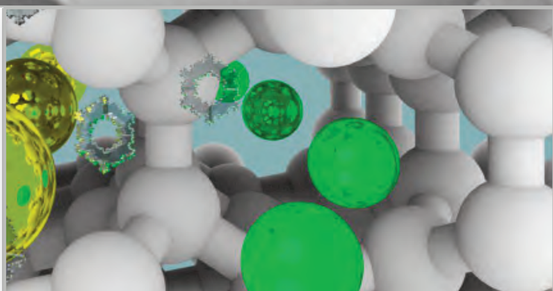


Image courtesy Duck Young Kim

Venture to Earth's Center

Anat Shahar explores the center of the Earth—from her lab. Scientists cannot sample the Earth's deep mantle or core. So Shahar blends high-pressure techniques with isotope geochemistry to study interior materials under the extreme conditions that exist there. Her goal is to understand how the Earth and other Solar System bodies formed, focusing on the composition and layering history of the Earth's core and mantle.

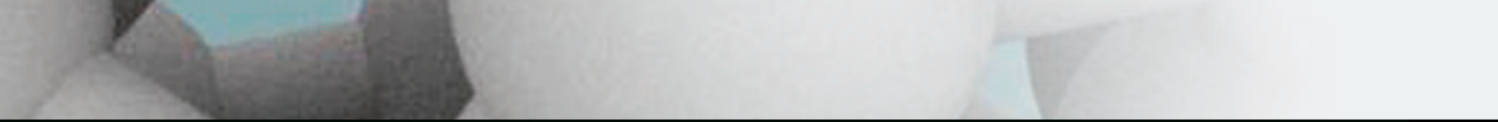
Seismic waves sent through the Earth can reveal whether deep material is liquid or solid, among other features. Such measurements suggest that the core, which is mostly iron, also contains light elements such as carbon, sulfur, oxygen, silicon, and/or hydrogen. But which ones and in what concentrations remain unknown. When the terrestrial planets formed, different materials separated out and formed layers. In the Earth, heavier elements like iron sank to the core. The chemical composition from this process depends on varying pressures and temperatures, which affect how elements and their isotopes—forms of an element with different numbers of neutrons—interact and bond.

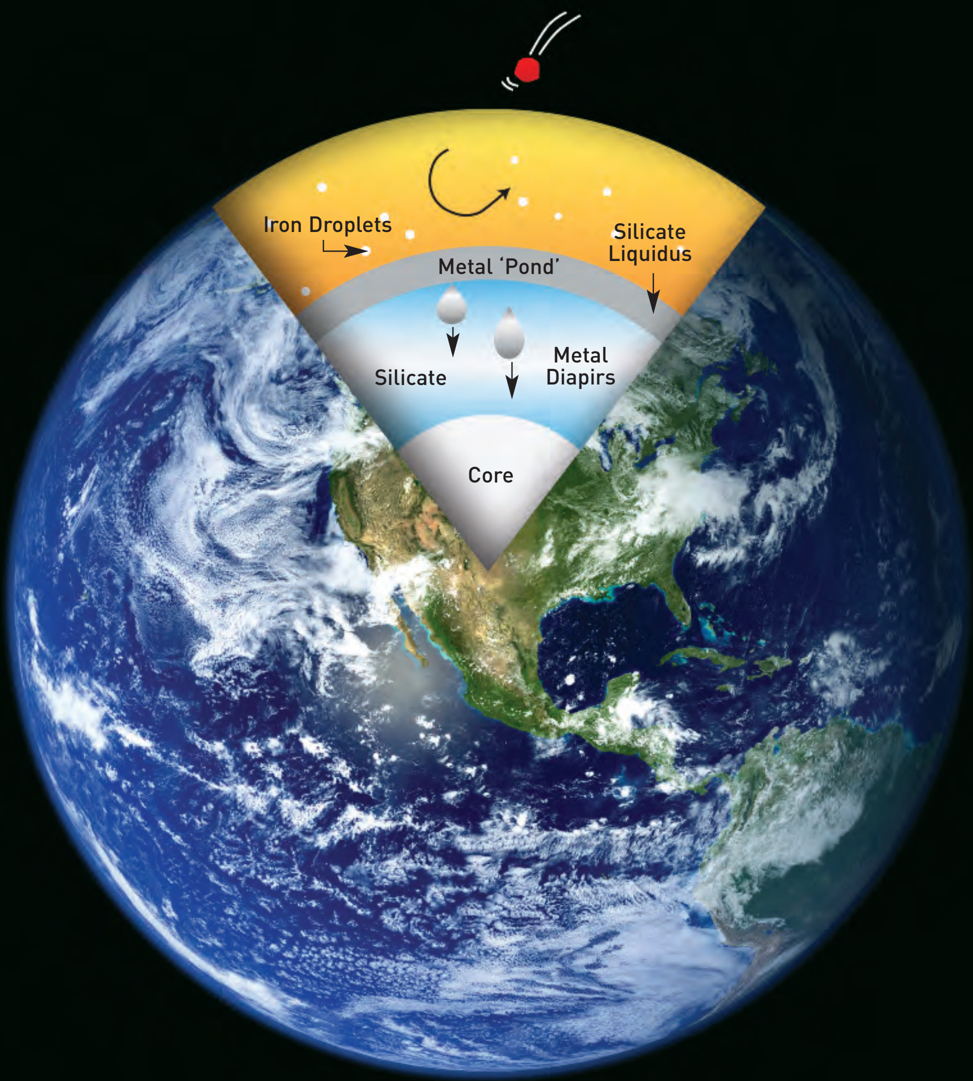
Defining the ratios of different isotopes of an element sheds light on the processes that occurred during formation and identifies the chemistry of deep interiors. Shahar's team recently conducted a series of experiments that provided the first experimental evidence that adding a light element to iron changes the isotopic ratios of the iron.

Shahar's team took mixtures of oxides and metals with varying amounts of sulfur to mimic terrestrial and Martian compositions and melted them at temperatures of about 3000°F (1650°C) and squeezed them to pressures from 10,000 to 20,000 times atmospheric pressure (1-2 gigapascals). They found that the amount of sulfur affects the bonding environment and thus varies the isotopic composition. The work is an important step to understanding how the bonding environment affects isotopes that separate from the bonded alloy and can be extended to independently determine the composition of planetary cores.

...the first experimental evidence that adding a light element to iron changes the isotopic ratios of the iron.

Shahar's work depends on a new mass spectrometer that can analyze more elements with much better precision than previous instruments. She also uses a technique adapted for high-pressure studies, called the three-isotope exchange, which better reveals the reactions taking place.



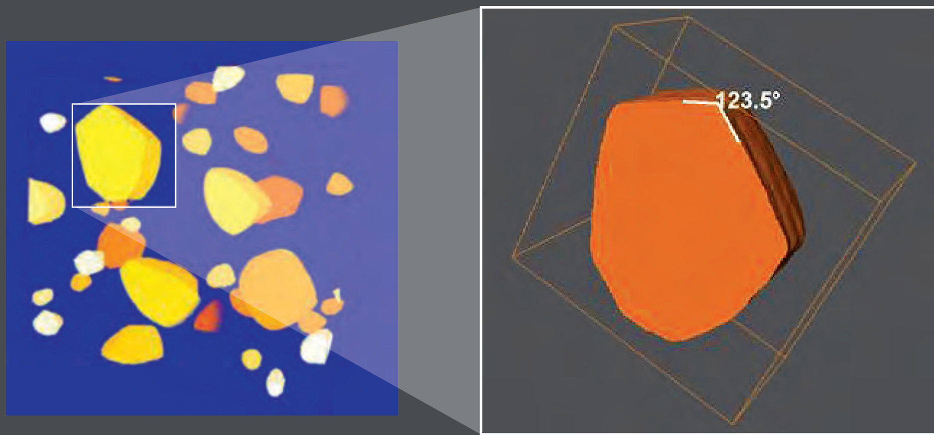


The planet Earth took tens of millions of years to build up and grow. Pressures and temperatures increase to extremes in the deep Earth. This simplified schematic shows the bombardment from small planetesimals, many of which had iron cores (cutaway). Scientists believe that the iron mixed with silicate and descended into Earth's interior, pooling in a layer. It became unstable and broke into large blobs called diapirs, which eventually fell to the core.

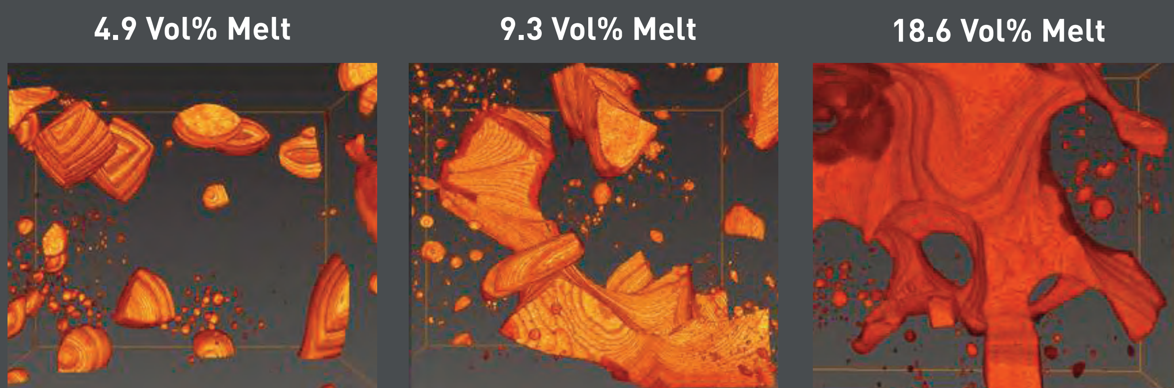
Earth image courtesy NASA Goddard Space Flight Center, Reto Stöckli, Robert Simmon, MODIS, USGS, Defense Meteorological Satellite Program; cutaway courtesy Nature 441, *June 15, 2006, p. 828, used with permission*

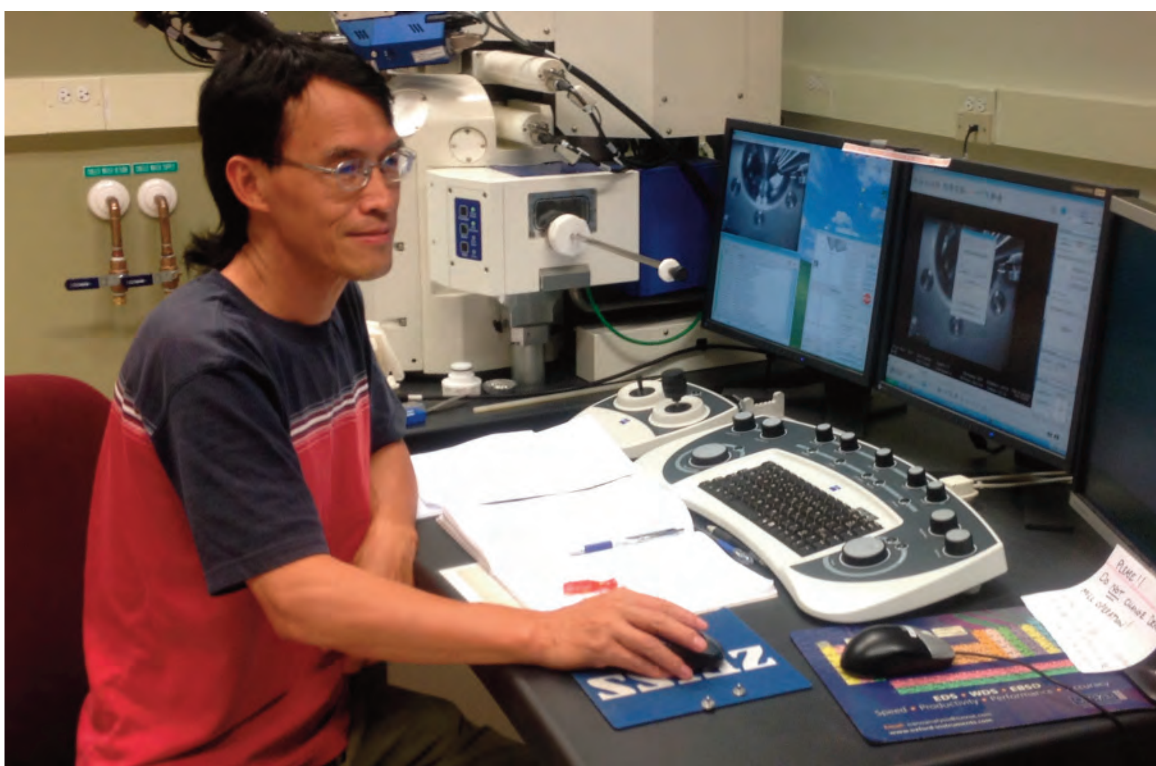
(Right) In addition to her research program, Anat Shahar provides a thriving training program for interns, undergraduates, graduates, and postdoctoral fellows. One high school intern made the Intel Science Talent Search semifinals based on this research program.

Image courtesy Anat Shahar



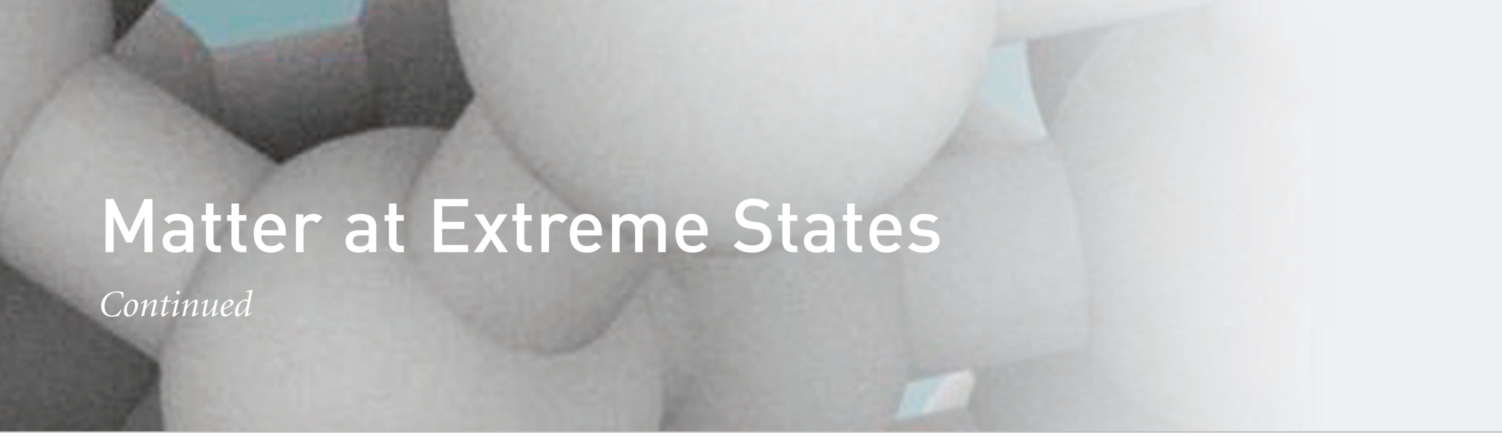
The value of the dihedral angle, left, determines whether the liquid metal forms in isolated pockets first or becomes interconnected. The liquid metal forms interconnected networks (far right below) at high ratios of metal to silicate.





Yingwei Fei uses a recently installed focused ion beam and high-resolution field emission scanning electron microscopy cross-beam instrument at the Geophysical Laboratory. The instruments create 3-D images of recovered samples from high-pressure and temperature simulation experiments.

Images courtesy Yingwei Fei



Matter at Extreme States

Continued

Percolating and Crystallizing

Earth's metallic core generates the planet's magnetic field, protecting life from harmful UV radiation. Understanding the processes of iron percolating to the center during core formation and inner core crystallization can shed light on the core's composition, thermal evolution, and the magnetic field generation. Yingwei Fei and team developed a new visualization technique enabling them to investigate these processes in unprecedented detail, representing a major milestone for studying Earth's evolution.

> Yingwei Fei and team developed a new visualization technique . . . a major milestone for studying Earth's evolution.

The composition and dynamics of terrestrial planetary cores depend on two major processes—how liquid metal percolated, or filtered, down through the solid silicate, the minerals that make up most of Earth's crust and mantle, and how the inner core crystallized as the planets cooled.

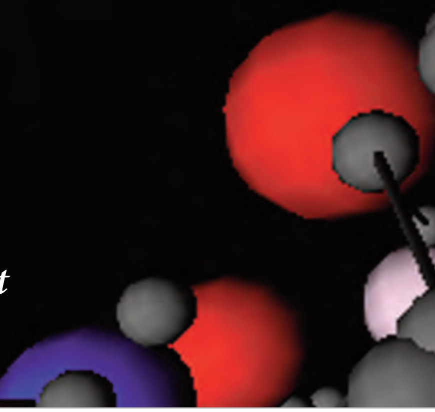
The team made detailed measurements of these processes at high pressure and temperature, relevant to the conditions of core formation. Their new imaging technique visualized the distribution of the metal into the silicate mixture in 3-D, providing a precise measurement of a key value controlling percolation.

The key value is called the dihedral angle—a geometric configuration between the solid and melt—which determines whether the melt is interconnected or forms in isolated pockets. Conventional measurements have large uncertainties in this angle.

The scientists pulverized a mixture of the silicate olivine and metallic iron powder with sulfur in varying concentrations. To simulate percolation, they heated a sample to iron-sulfide melting temperatures, leaving the silicon solid. They imaged a cooled slice using a focused ion beam and high-resolution field emission scanning electron microscopy, then processed the images with software.

The scientists found that liquid metal forms isolated pockets trapped in the silicate matrix because of the large dihedral angle. By increasing the ratio of metal to silicate, or decreasing pressure, the liquid metal can form an interconnected network, facilitating the metal and silicate separation to form a metallic core.

To understand crystallization and the element distribution between the liquid outer core and the solid inner core they used the multi-anvil apparatus to heat samples up to 4170°F (2300°C) at pressures up to 266,000 atmospheres (27 gigapascals); they used the diamond anvil cell for higher pressures. The high-resolution imaging and quantitative chemical analyses provide essential data needed to understand the steps of the crystallization process for the first time. ●



Plant Science

Characterizing the Genes of Plant Growth and Development

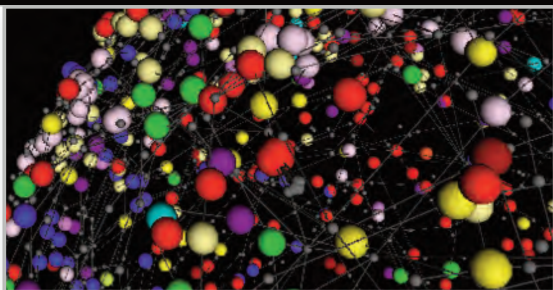


Image courtesy Taehyong Kim

Deciphering Plant Chemistry at Warp Speed

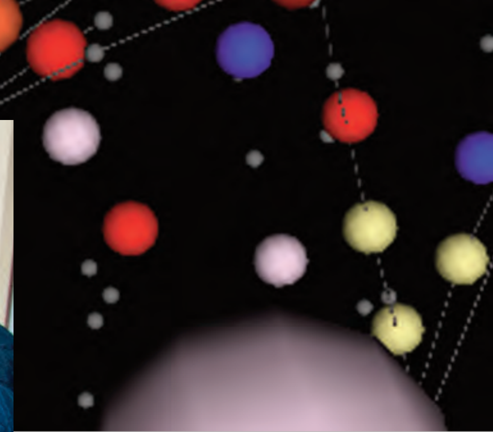
Human health and survival depend in large part on the chemistry of plant metabolism. About a quarter of our prescription drugs and half of anticancer drugs come from plants. These compounds, called specialized or secondary metabolites, are used to defend plants against pests and disease. They differ from primary metabolites, which govern cell function. Sue Rhee wants to understand how plants evolved. She developed computational tools to reconstruct species-specific metabolic networks on the genome scale and systematically analyzed these networks from functional and evolutionary perspectives. This work could dramatically impact agriculture, drug discovery, and biotechnology.

Understanding how plants evolved its vast networks of metabolic chemical reactions has been a longstanding goal in plant biology. But until now it has taken years to decades to plot a single pathway. Rhee's lab developed a high-throughput computational pipeline to predict metabolic enzymes and pathways, based on extensive libraries of data. She combined it with a semiautomated validation system and manual processes that have reduced the time to map out the steps from weeks to hours.

Rhee's team recently reconstructed and analyzed the metabolic networks for 16 species, including flowering plants, algae, and mosses. They found that genes that produce the specialized metabolites proliferated to a much greater degree and by different mechanisms than those producing primary metabolites. Specialized metabolites also showed different patterns of gene clustering—genes located in the same regions on chromosomes. The results indicate that the different types of metabolism evolved differently. These distinct patterns provide researchers with a new tool to discover previously unknown specialized metabolites, to understand how they benefit plants, and to determine other ways they could benefit people.

Rhee's lab developed a high-throughput computational pipeline to predict metabolic enzymes and pathways...

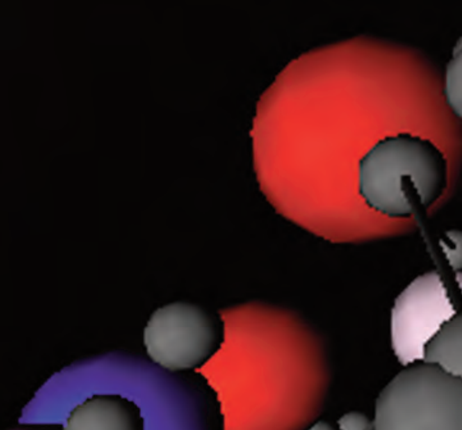
This study shapes Rhee's long-term research plan. Over the next several years, she will be identifying metabolic components and distinguishing the molecular players and processes between primary and specialized metabolism. She will also develop new possibilities for engineering these chemical networks, unraveling the origin governing gene clusters, and more.



The Rhee group congregates. From left to right: Lee Chae, lead author of the study; Jue Fan; Sue Rhee and Taehyong Kim, coauthors; and Meng Xu.

Images courtesy Robin Kempster

The Rhee team looked at the differences between so-called secondary metabolites, which are used to defend against pests and disease, and primary metabolites, which govern normal cell functions, for 16 species, including flowering plants, algae, and mosses. The group found that the two types of metabolites evolved differently. This photograph, taken by Sue Rhee, is of a flowering cactus.

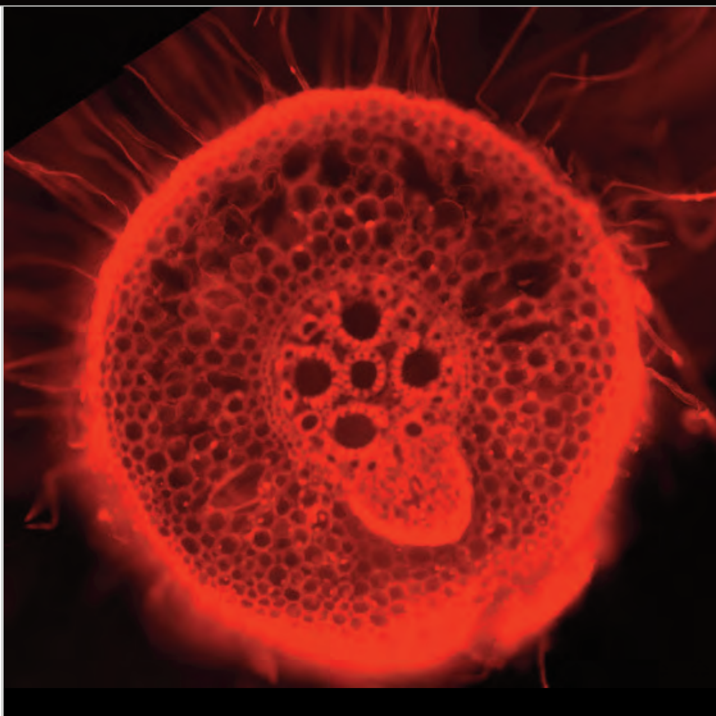


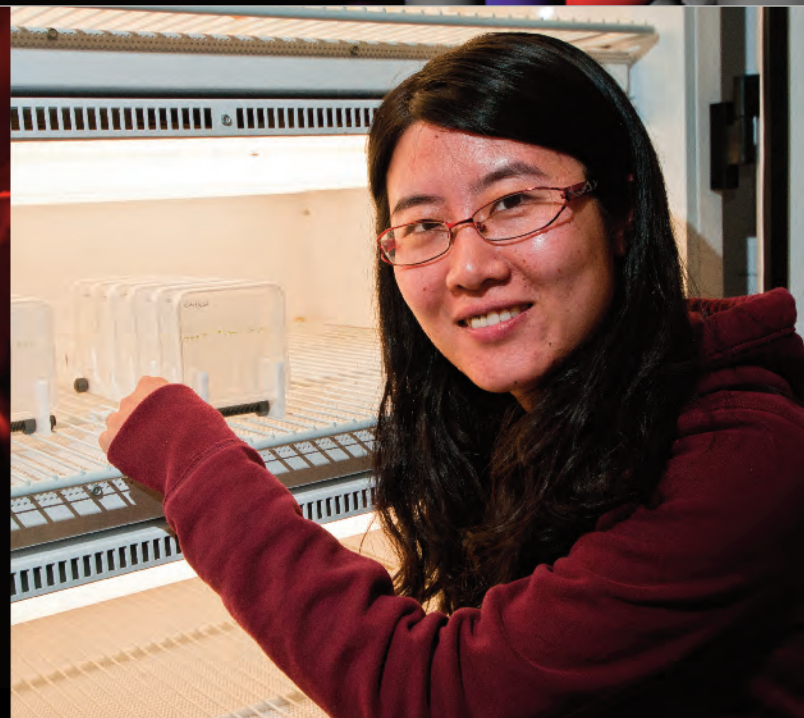
Ph. D. student from Singapore Bao Yun (top right) was first author on the study. Stanford graduate student Neil Robbins II (bottom left) was a coauthor.

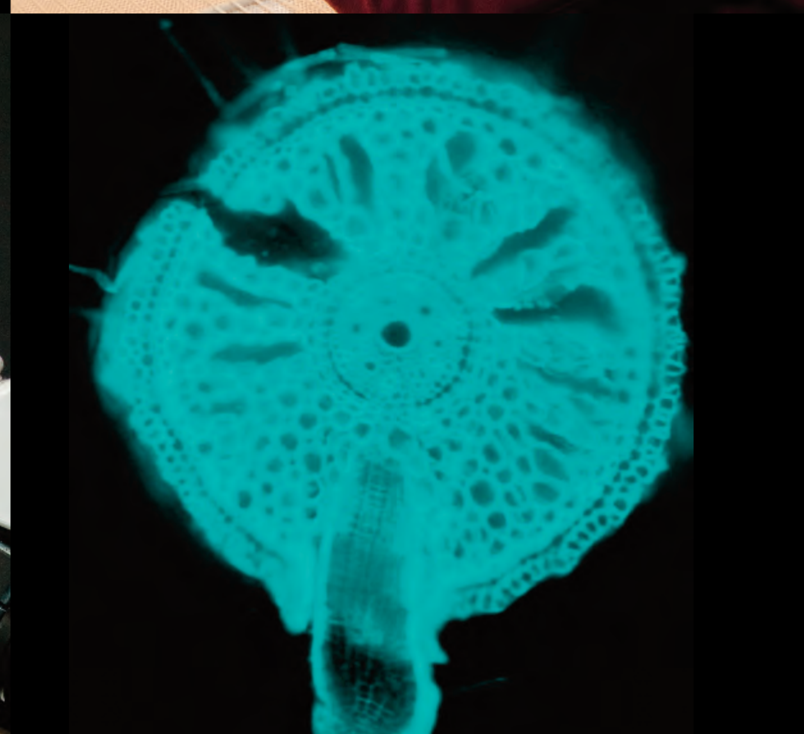
Images courtesy José Dinneny

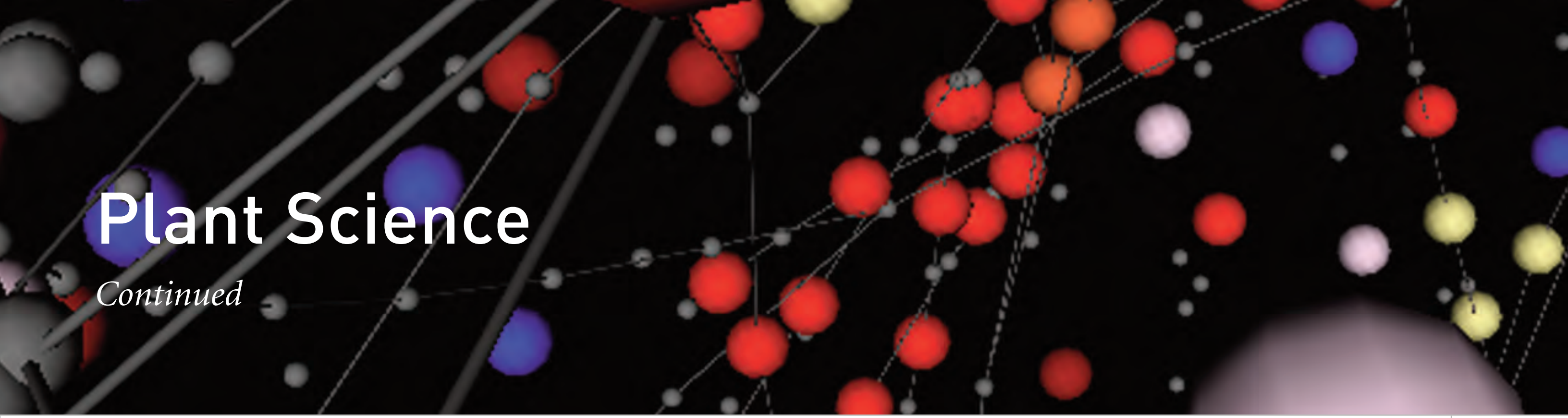
Cross sections of a maize root (top left) and rice root (bottom right) show root branches developing toward water.

Maize image courtesy Neil E. Robbins II; rice image courtesy Pooja Aggarwal



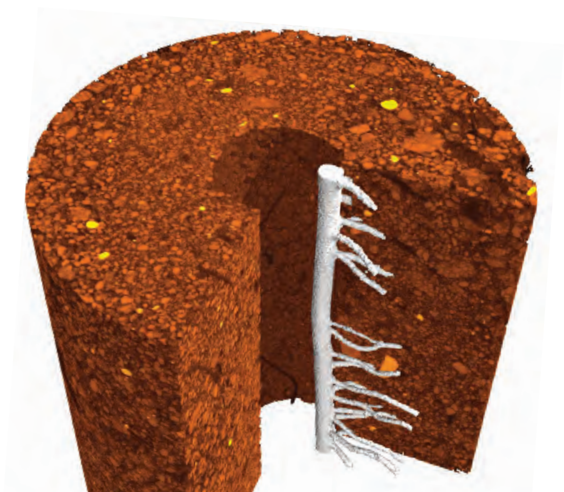






Water and Air Spawn Root Structure

Plants exploit the maze of subsurface soil particles, water, and nutrients with their branched root network. But how roots grow in response to moisture and what, if any, effect moisture has on the architecture of the root system has been unclear. Recent research led by José Dinneny showed that differences in the availability of water and air pockets around the circumference of the root creates special developmental cues that determine where lateral root branches will be located. In the experimental plant *Arabidopsis* and in rice and corn crops, root branches appear only on the side of the main root contacting water while tiny root hairs grow only in response to air pockets. An understanding of how plants control this process could be important to adapting crop roots to water-limiting conditions.



This micro-CT-generated image shows a maize seedling root contacting the soil surface.

Image courtesy Craig Sturrock, with permission from PNAS

The structure of a root system is regulated in ways to optimize soil exploration while limiting growth into water-poor regions. The research showed that root tips of these three plant species could tell the difference between a wet surface and air pockets and respond accordingly. The study suggests that the rate with which water is absorbed by a root is important to lateral root development. In addition to affecting root architecture, these conditions affect the patterning of antioxidant metabolites and the tissues that make up the internal spaces where air can circulate. The scientists dubbed this phenomena hydropatterning.

The researchers found that this sensing ability is distinct from the water stress-response system governed by the hormone abscisic acid. This points to the likelihood that hydropatterning is important for regulating root branching under non-stressful growth conditions.

Dinneny and his team developed methods for growing roots in environments where the distributions of water and air around the root were highly controlled. With colleagues, they observed early-stage lateral root markers using microscale X-ray tomography and 3-D models of roots growing in soil.

Prior to this study, researchers had underestimated the spatial acuity of this patterning system. They now find that roots can respond to environmental conditions that vary over distances as small as 100 microns—about the size of a typical soil particle. In future research they hope to discover just how the cells sense the differences in water availability when contacting surfaces.

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

Teaching the Art of Teaching Science and Math

Green Works In D.C.!

This summer the Carnegie Academy for Science Education (CASE) hosted a three-week institute on environmental literacy for some 30 Washington, D.C., K-12 teachers with funding from the D.C. Department of the Environment (DDOE). The D.C. Office of the State Superintendent for Education (OSSE) selected the teachers and Julie Edmonds and Toby Horn, codirectors of CASE, administered the program in partnership with DDOE, OSSE, and the D.C. Environmental Educators Consortium (DCEEC). The goal of the Environmental Literacy Summer Institute (ELSI) was for teachers to prepare to implement the Next Generation Science Standards developed by the National Academy of Sciences in the context of environmental literacy.

The new science standards were developed by educators in 48 states in alignment with the National Academy of Science's "Framework for Science Education." The standards are linked to the new Common Core standards for math and English. Now, science in the classroom will mirror the way science and engineering professionals approach their work in the real world where, for instance, math and science are used together, not separately. The new method also emphasizes concepts, not just topics such as how systems interact, and that reading, writing, and speaking are all part of the scientific endeavor.

The ELSI teachers learned details of the new science standards, including which concepts are taught in which grade. They developed unit plans for their courses, connecting concepts and performance tasks so students could show what they have learned. Weeks one and three were sessions at Carnegie headquarters. The second week was spent in the field looking at real-world work—on organic farms, in green buildings (of which D.C. has many), canoeing and sampling on the Anacostia River, and visiting the Smithsonian and sustainability projects to use as resources for the courses that they developed. The final week also included developing ways in which students would be evaluated. After the three-week institute, teachers continued developing their plans for eventual sharing with all D.C. teachers through the OSSE website. Once field testing is complete, the plans will be available on LearnDC.org.

> Now, science in the classroom will mirror the way science and engineering professionals approach their work in the real world.

(Above) Codirectors of CASE Julie Edmonds (front row, far left) and Toby Horn (second row, far right) hosted the three-week Environmental Literacy Summer Institute for Washington, D.C., teachers.
Images courtesy Toby Horn

(Left) CASE hosted the three-week Environmental Literacy Summer Institute for K-12 Washington, D.C., teachers (shown) to prepare to implement the Next Generation Science Standards in the context of environmental literacy.

(Above) The 2014 cohort of Math for America fellows pose on the statue of Albert Einstein in Washington, D.C., with mentor Guy Brandenburg (upper right).

Images courtesy Bianca Abrams

(Right) Two of the first Math for America DC cohort, Lindsay Mann (right) and Max Mikulec (left), are at the gala celebrating the first cohort's completion of their fellowships. They were selected to become Master Teachers.

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

Continued

First Fellows Graduate M*f*A DC!

With a May gala, the first cohort of five Math for America DC (M*f*A DC) fellows celebrated their successful completion of the five-year mathematics teaching program. The highly selective fellowship, launched in 2008, provides tuition and stipend support for a program that begins with a one-year master's degree followed by a four-year mathematics teaching commitment for 6th-12th grade students in high-need Washington, D.C., public and charter schools. Two from the first cohort of M*f*A DC teachers will become Master Teachers, another program supported by M*f*A DC.

The goal of the Master Teacher program is to establish a community of leaders in mathematics who teach the subject engagingly and mentor other fellows. The two new Master Teachers are Lindsay Mann and Max Mikulec. In 2012-13 Mann received a "Highly Effective" rating—the highest possible—and an excellent achievement for a teacher with less than four years' experience, as measured by the IMPACT system assessing D.C. public school teachers. The ranks are based on student achievement, instructional expertise, collaboration, and professionalism. Joe Herbert, from the third M*f*A DC cohort, was also ranked "Highly Effective." Both receive significant bonuses for this achievement.

Thus far, 37 fellows have participated in the program, and 28 have instructed about 2,400 high-need D.C. students. In addition to teaching, the fellows receive intense professional development. They now have a variety of 30 sessions provided by the Master Teachers from which to choose. The ultimate goal of both M*f*A programs is to continue to grow a vibrant and dynamic mathematics teaching community with teachers staying in the profession for over four years. On average, teachers stay with the profession only a couple of years. M*f*A DC's future looks very bright: The national M*f*A program has extended their support of the D.C. chapter.

Mathematics teacher Bill Day, a member of the M*f*A Master Teacher program since 2012, was awarded the Teacher of the Year 2014 prize by the Washington, D.C., mayor and superintendent of schools at a school assembly in December 2013. The award is "in recognition of outstanding teaching in the District of Columbia and professional leadership within and beyond the classroom." Day teaches at Two Rivers Public Charter School.

2013-2014 YEAR BOOK

Financial Profile

for the year ending June 30, 2014 (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.***

The Carnegie Institution of Washington completed fiscal year 2014 in sound financial condition due to the positive returns (+19.5%) 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, 2014, the endowment was valued at $980 million. Over the period 2001-2014, average annual increases in endowment contributions to the budget were 5.0%. Carnegie closely controls expenses in order to ensure the continuation of a healthy scientific enterprise.

For a number of years, under the direction of the Finance committee of the board, Carnegie's endowment has been allocated among a broad spectrum of asset classes including: equities (stocks), absolute return investments, real estate partnerships, private equity, natural resources partnerships, and fixed-income instruments (bonds). The goal of this diversified approach is to generate attractive overall performance and 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, 2014.

Asset Class	Target	Actual
Common Stock	37.5%	39.5%
Alternative Assets	55.0%	51.5%
Fixed Income and Cash	7.5%	9.0%

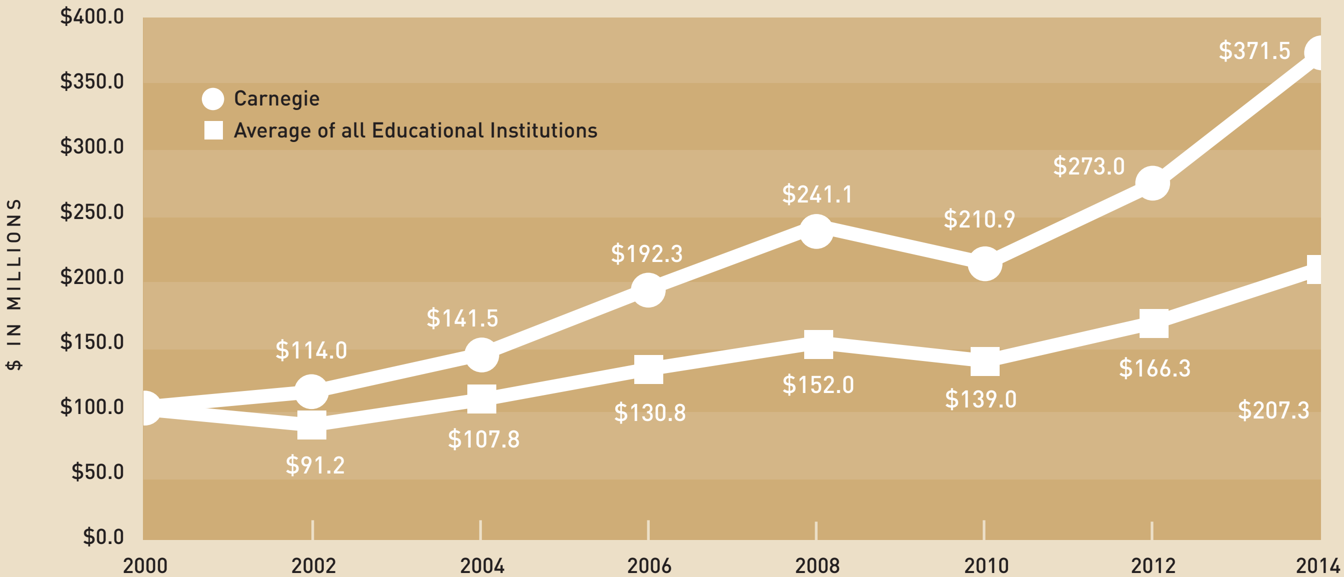
Carnegie's investment goals are to provide high levels of current support to the institution and to maintain the long-term spending power of its endowment. The success of Carnegie's investment strategy is illustrated in the following figure that compares, for a hypothetical investment of $100 million, Carnegie's investment returns with the average returns for all educational institutions for the last fourteen 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 22 years.

In fiscal year 2014, Carnegie benefitted from continuing federal support. Carnegie's federal support has grown from $24.5 million in 2006 to $28.8 million in new grants in 2014. This is a testament to the high quality of Carnegie scientists and their ability to compete successfully for federal funds in this period of fiscal restraint.

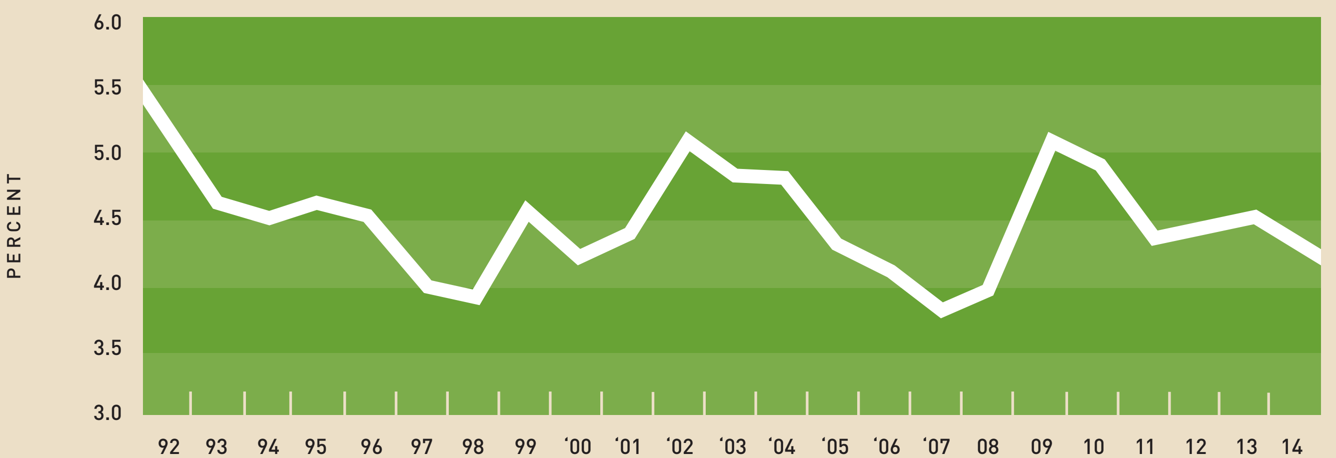
Carnegie also benefits from generous support from foundations and individuals. Funding from foundations has grown from an average of about $3 million/year in the period from 2000 to 2004 to $8 million in 2014. Within Carnegie's endowment, there are a number of "funds" that provide support either in a 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 2014 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 (2000-2014)



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.

Statements of Financial Position (Unaudited)

June 30, 2014, and 2013

	2014	2013
Assets		
Current assets:		
Cash and cash equivalents	$ 4,093,370	$ 2,131,428
Accrued investment income	11,988	17,496
Contributions receivable	11,280,393	14,100,999
Accounts receivable and other assets	9,188,678	10,423,327
Bond proceeds held by Trustee	49,414,262	15,698
Total current assets	$ 73,988,691	$ 26,688,948
Noncurrent assets:		
Investments	984,182,412	856,597,311
Property and equipment, net	140,153,915	147,278,352
Long term deferred assets	17,598,331	13,174,134
Total noncurrent assets	$1,141,934,658	$1,017,049,797
Total assets	$1,215,923,349	$1,043,738,745
Liabilities and Net Assets		
Accounts payable and accrued expenses	$ 11,234,976	$ 9,559,263
Deferred revenues	28,055,413	28,235,748
Bonds payable	115,064,362	65,685,422
Accrued postretirement benefits	23,558,628	20,356,659
Total liabilities	$ 177,913,379	$ 123,837,091
Net assets		
Unrestricted	$ 306,552,812	$ 272,816,713
Temporarily restricted	676,403,916	592,058,025
Permanently restricted	55,053,242	55,026,916
Total net assets	$1,038,009,970	$ 919,901,654
Total liabilities and net assets	$1,215,923,349	$1,043,738,745

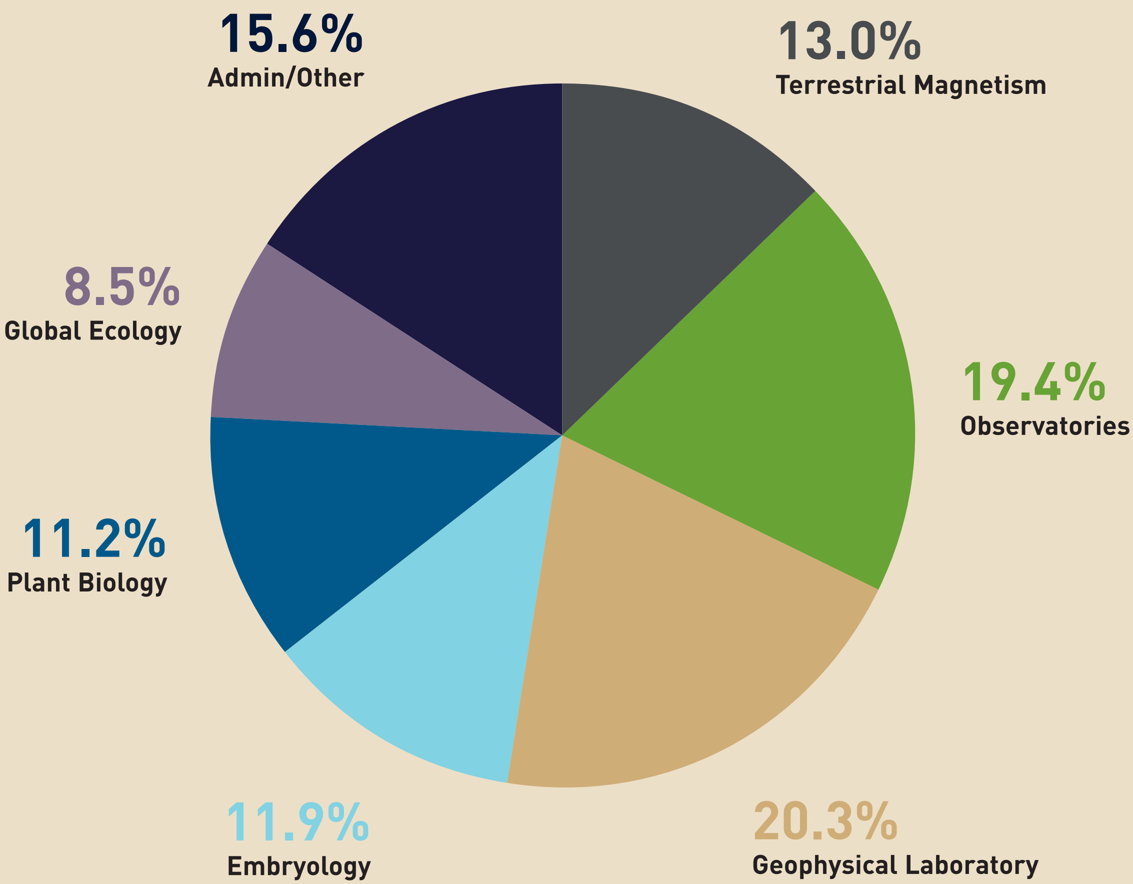
Statements of Activities[1] (Unaudited)

Periods ended June 30, 2014, and 2013

	2014	2013
Revenue and support:		
Grants and contracts	$ 35,708,599	$ 38,545,813
Contributions, gifts	10,438,061	9,916,611
Other income	2,645,768	342,775
Net external revenue	$ 48,792,428	$ 48,805,199
Investment income and unrealized gains (losses)	$ 170,662,287	$107,781,363
Total revenues, gains, other support	$ 219,454,715	$156,586,562
Program and supporting services:		
Terrestrial Magnetism	$ 12,858,902	$ 13,540,172
Observatories	19,181,747	18,733,368
Geophysical Laboratory	20,079,387	21,003,255
Embryology	11,778,108	11,643,914
Plant Biology	11,119,082	11,327,868
Global Ecology	8,432,635	8,427,241
Other programs	1,250,486	757,789
Administration and general expenses	14,205,604	14,341,283
Total expenses	$ 98,905,951	$ 99,774,890
Change in net assets before pension related changes	$ 120,548,764	$ 56,811,672
Pension related changes	(2,440,448)	512,635
Net assets at the beginning of the period	$ 919,901,654	$862,577,347
Net assets at the end of the period	$1,038,009,970	$919,901,654

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

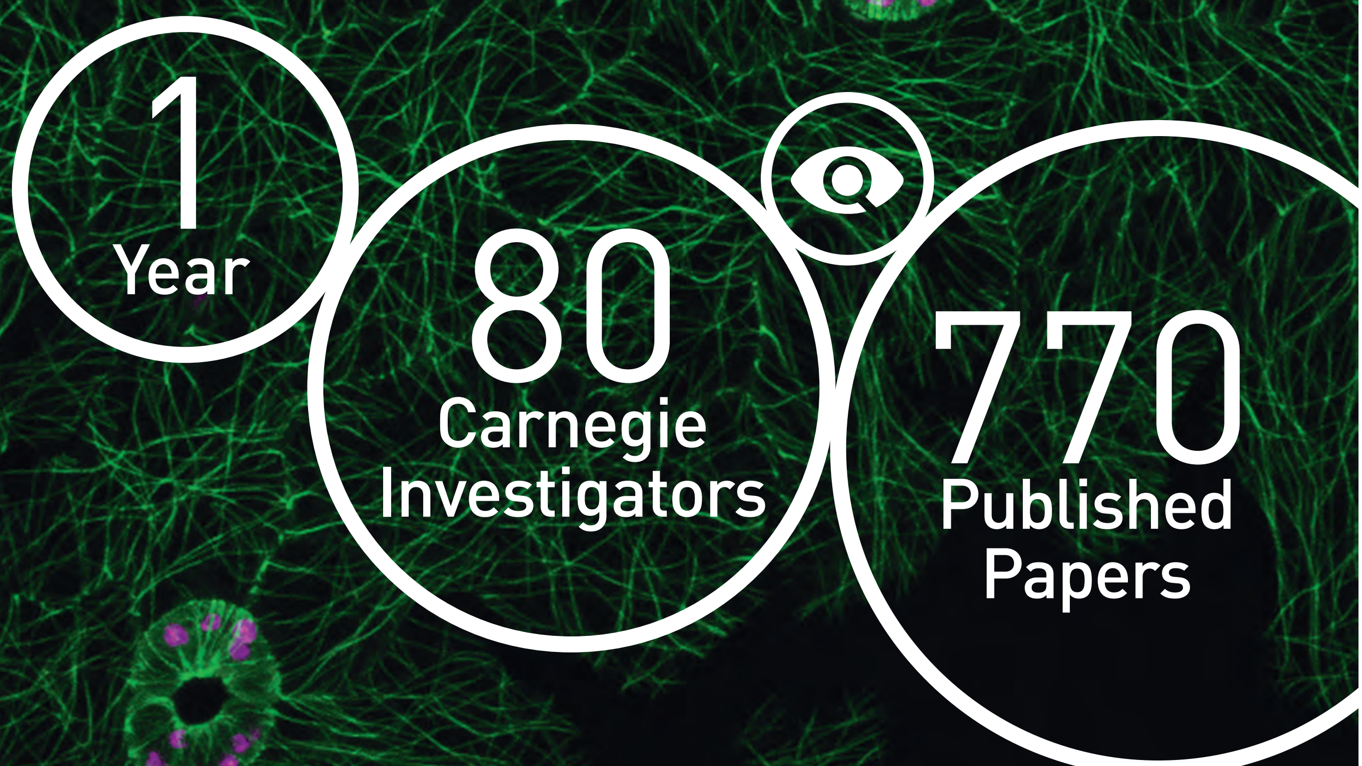
2014 Expenses by Department ($98.9 Million)



Small, Lean, and Potent

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 770 papers published in the most prestigious scientific journals during the last year. Many discoveries were widely covered by the media.

For a full listing of personnel and publications see:
http://carnegiescience.edu/yearbook2014



Carnegie Investigators IN THE NEWS

"New findings on cellular signaling offer potential implications ranging from agriculture to cancer research"

ZHIYONG WANG IN NEWS MEDICAL

"Discovery of planetoid hints at bigger cousin in shadows"

SCOTT SHEPPARD IN THE NEW YORK TIMES

"Red meat isn't very green: Study finds beef pollutes far more than pork, poultry, dairy, eggs"

KEN CALDEIRA IN THE HUFFINGTON POST

"Illegal mining in Latin America"

GREG ASNER IN THE ECONOMIST

"Hear from the scientists who saw the Ohio algae blooms coming"

ANNA MICHALAK ON PBS NEWSHOUR

"Old water in the solar system suggests possibility of life elsewhere"

CONEL ALEXANDER IN THE WASHINGTON POST

"Panel's warning on climate risk: worst is yet to come"

CHRIS FIELD IN THE NEW YORK TIMES

"Missing light crisis: Something is amiss in the universe"

JUNA KOLLMEIER IN INTERNATIONAL BUSINESS TIMES

"Ultra-thin nanothread discovery could make diamonds an astronaut's best friend"

MALCOLM GUTHRIE IN FORBES

"Characterizing photosynthesis to help biodiesel"

MARTIN JONIKAS IN DOMESTIC FUEL

"Satellite technology to measure plant energy activity"

JOE BERRY IN THE BUSINESS STANDARD

"Astronomers clue in to why binary stars are so bountiful"

ALAN BOSS IN NATIONAL GEOGRAPHIC.COM

"Newly found planet may have flowing water, astronomers report"

PAMELA ARRIAGADA IN NEWSWEEK

Carnegie Investigators

Staff Scientists

GEORGE D. CODY, Acting Director[1]
RONALD E. COHEN
YINGWEI FEI
MARILYN L. FOGEL, Adjunct[2]
ALEXANDER F. GONCHAROV
ROBERT M. HAZEN
RUSSELL J. HEMLEY, Director[3]
HO-KWANG MAO
BJØRN O. MYSEN
DOUGLAS RUMBLE III
ANAT SHAHAR
ANDREW STEELE
TIMOTHY A. STROBEL
VIKTOR V. STRUZHKIN

[1] From October 6, 2013
[2] To December 31, 2013
[3] To October 6, 2013, Senior Staff Scientist from October 7, 2013

THE GEOPHYSICAL LABORATORY »

Matter at Extreme States, Earth/Planetary Science

Front row (left to right): **Yangzheng Lin, Robert Hazen, Timothy Strobel, Russell Hemley, Ho-Kwang (Dave) Mao, Andrew Steele, George Cody, Anat Shahar, Doug Rumble, Alexander Goncharov, Pablo Esparaza.** Second row: **Kadek Hemawan, Peng Zhang, Danielle Appleby, Valery Levitas, Muhetaer Aihaiti, Irena Mamajanov, Xiao-Ming Liu, Morgan Phillips-Hoople, Valerie Hillgren, Agnes Mao, Michelle Scholtes, Jinfu Shu, Sergey Lobanov, DuckYoung Kim, Fang Huang, Stephen Elardo, Andrea Mangum.** Third row: **Craig Schiffries, Huiyang Gou, Eugene Vinitsky, Jianjun Ying, Haidong Zhang, Merri Wolf, Nicholas Holtgrewe, Shaun Hardy, Chang-Sheng Zha, Jurrien Knibbe, Ivan Naumov, Gefei Qian, Zhisheng Zhao, Hong Liu, Helen Venzon, Cecile Feuillie, Stevce Stefanoski, Ileana Perez-Rodriguez, Jihua Hao, Katherine Crispin.** Fourth row: **Yael Fitzpatrick, Stephen Hodge, Reinhard Boehler, Victor Lugo, Stephen Gramsch, Jeff Lightfield, Gabor Szilagyi, Xiaojia Chen, Jabrane Labidi, Javier Nossa, Neil Bennett, Dyanne Furtado, Charles Le Losq, Cheng Ji, Trong Nguyen, Colin Jackson, Hitoshi Gomi.**

« THE DEPARTMENT OF EMBRYOLOGY

Genetics/Developmental Biology

Front row (left to right): **Pavol Genzor, Mary Best, Mahmud Siddiqi, Tom McDonaugh, Bill Kupiec, Rafael Villagaray, Vanessa Quinlivan-Repasi, Yihan Wan, Rejeanne Juste, Lakshmi Gorrepati, Lydia Li.** Second row: **Chen-Ming Fan, Joseph Gall, Allan Spradling, Fred Tan, Yixian Zheng, Pat Cammon, Zehra Nizami, Wilber Ramos, James Thierer, Will Yarosh, Rodrigo Nicodemos, Andrew Kesner, Matt Sieber.** Third row: **Alex Bortvin, Eugenia Dikovskaia, Gaelle Talhaourne, Sveta Deryusheva, Ayse Keskus, Antara Ghosh, Jui-Ko Chang, Valeriya Gaysinskaya, Jessica Otis, Alexandria Brown, Oscar Reyes, Marnie Halpern, Michelle Macurak, Connie Jewell, Joseph Tran.** Forth row: **Michelle Rozo, Samatha Satchell, Ona Martin, Lynne Hugendubler, Allison Pinder, Dianne Williams, Ming-Chia Lee, Lei Lei, Megha Ghildiyal, Steve DeLuca, rotation student, Bob Levis, Marla Tharp, Ankita Das, Rebecca Obniski, Ethan Greenblatt.** Fifth row: **Yuxuan Guo, Carmen Tull, Haiyang Chen, Andrew Rock, Shusheng Wang, Mike Sepanski, Erik Duboué, Safia Malki, Christoph Lepper, Jen Anderson, Sara Roberson, Blake Caldwell, Tiffany Tu, Steven Ching, Zheng-An Wu.** Sixth row: **Frederick Dong, Pedram Nozari, Arash Adeli, Simen Vlasov, Marlow Minor, Abhi Subedi, Tyler Harvey, Shiying Jin, Stephanie Kuo, Jung-Hwa Choi, Dolly Chin, Zhonghua Liu, Sibiao Yue, Glenese Johnson, Teddi Schott, Earl Potts.**

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[1]
ALLAN C. SPRADLING, Director
FREDERICK TAN
YIXIAN ZHENG

Staff Associates

JEFFREY HAN[2]
CHRISTOPH LEPPER

1 To October 2013
2 To August 2013

Carnegie Investigators

Research Staff Members

ANDREW BENSON
REBECCA BERNSTEIN[1]
ALAN DRESSLER
WENDY FREEDMAN, Director[2]
LUIS HO
JUNA KOLLMEIER
PATRICK McCARTHY
ANDREW McWILLIAM
JOHN MULCHAEY, Acting Director[3]
AUGUSTUS OEMLER, JR., Director Emeritus
ERIC PERSSON
GEORGE PRESTON, Director Emeritus
MICHAEL RAUCH
FRANÇOIS SCHWEIZER
STEPHEN SHECTMAN
JOSHUA SIMON
IAN THOMPSON
RAY WEYMANN, Director Emeritus

Staff Associates

JEFFREY CRANE[4]
DAN KELSON
BARRY MADORE[5]

———

1 From November 1, 2013
2 To September 1, 2014
3 From September 1, 2014
4 Formerly listed in Postdoctoral Fellows and Associates
5 From January 14, 2014, formerly Senior Research Associate

THE OBSERVATORIES »

Astronomy

Front row (left to right): **Erica Clark, Sung-Ri Sok, Greg Ortiz, Jerson Castillo, Drew Newman, Gwen Rudie, Ning Jiang, Kaew Tinynont, David Khatami, Mansi Kasliwal, Andy Monson, Gillian Tong, Sean Johnson, Alan Uomoto, Sharon Kelly, Wendy Freedman, Andrew Benson, Alan Dressler, Irina Strelnik, Paul Collison, Victoria, Scowcroft, Christoph Birk, Laura Sturch, Edward Villanueva, Shannon Patel, Janet Colucci.** Back row: **Alessia Garafalo, Erika Carlson, Matthias Raives, Clarke Esmerian, Emilie Parent, Roozbeh Davari, Annie Hedlund, Daniel McAndrew, Beck Lynn, John Mulchaey, Beverly Fink, George Preston, Wenxiong Li, Barry Madore, Josh Simon, Robert Storts, Jiayi Sun, Tyler Holland-Ashford, Dan Kelson, Andrew McWilliam, Scott Rubel, Earl Harris, Ian Thompson, Françios Schweizer, Mark Seibert, Jeffrey Rich, Chris Burns.**

« THE DEPARTMENT OF GLOBAL ECOLOGY

Global Ecology

Front row (left to right): **Anna Michalak, Dawn Ross, Evana Lee, Leslie White, Soheil Shayegh, David Knapp, Jeff Ho.** Second row: **Chris Field, Emily Francis, Robin Martin, Yuanyuan Fang, Susan Cortinas, Katie Kryston.** Third row: **Claire Baldeck, Dana Chadwick, Yuka Estrada, Tuai Williams, Jennifer Scerri, Lester Kwiatkowski, Eva Ahbe, Kate Ricke.** Fourth row: **Jovan Tadic, Kai Zhu, Eren Bilir, Todd Tobeck, Ari Kornfeld, Xurxo Gago, Mike Mastrandrea, Garrett Huntress.** Fifth row: **Andrew Levy, David Marvin, Greg Asner, Theo van de Sande, Joe Berry, Ismael Villa, Ken Caldeira, Eric Kissel.**

Carnegie Investigators

Research Staff Members

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

Carnegie Investigators

Research Staff Members

CONEL M. O'D. ALEXANDER
ALAN P. BOSS
R. PAUL BUTLER
RICHARD W. CARLSON, Director[1]
JOHN E. CHAMBERS
LINDA T. ELKINS-TANTON, Director[2]
JOHN A. GRAHAM, Emeritus
ERIK H. HAURI
DAVID E. JAMES[3]
ALAN T. LINDE
LARRY R. NITTLER
DIANA C. ROMAN
SCOTT S. SHEPPARD
STEVEN B. SHIREY
SEAN C. SOLOMON, Director Emeritus[4]
FOUAD TERA, Emeritus
ALYCIA J. WEINBERGER

Senior Fellows

VERA C. RUBIN[5]
I. SELWYN SACKS

THE DEPARTMENT OF TERRESTRIAL MAGNETISM »

Earth/Planetary Science and Astronomy

Front row (left to right): **Pablo Esparza, Adelio Contreras, Marion Garçon, Marion Le Voyer, Selwyn Sacks, Mary Horan, Casey Leffue, Merri Wolf, Jemma Davidson, Robin Dienel, Wan Kim, Amanda Lough, Shaun Hardy, John Graham.** Second row: **Alycia Weinberger, Pamela Arriagada, Jianhua Wang, Scott Sheppard, Lara Wagner, Steven Golden, Timothy Mock.** Third row: **Gary Bors, Jessica Donaldson, Jared Marske, Erik Hauri, Richard Carlson, Ben Pandit, Johanna Teske, Nathan Kaib, Timothy Rodigas.** Fourth row: **Alan Boss, Brad Foley, Conel Alexander, Sergio Dieterich, Janice Dunlap, Steven Shirey, Paul Butler.**

---

[1] From May 10, 2014
[2] To May 9, 2014
[3] Retired September 30, 2013
[4] Leave of Absence
[5] To May 6, 2014

CIYB14_63-72F2_0506_3/FIN45-67F.qxd 2/3/15 8:08 AM Page 71

« THE DEPARTMENT OF PLANT BIOLOGY

Plant Science

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, José 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, Munevver 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.**

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
ZHIYONG WANG

Adjunct Staff

DEVAKI BHAYA
MATTHEW EVANS
EVA HUALA[1]
RICHARD JORGENSEN[2]

Young Investigator

MARTIN JONIKAS

---

[1] To June 30, 2014
[2] From August 1, 2013, to May 31, 2014

A Gift for the Future

One of the most effective ways of supporting the work of the Carnegie Institution is to include the institution in your estate plans. By doing so, you can support cutting-edge, independent scientific research well into the future.

Estate gifts are a tangible demonstration of your dedication to the Carnegie Institution and can potentially generate significant tax savings for your estate. These gifts can be directed to support fellowships, chairs, specific research projects, or other programs, and can be additions to the endowment.

For additional information, please contact Rick Sherman at rsherman@carnegiescience.edu, or (202) 939-1114.

CARNEGIE SCIENCE

For Additional Information

See the Carnegie Website:
www.CarnegieScience.edu/support

Or Call:
The Office of Advancement
202.387.6400

Or Write:
Rick Sherman
The Office of Advancement
Carnegie Institution
1530 P Street N.W.
Washington, DC 20005-1910