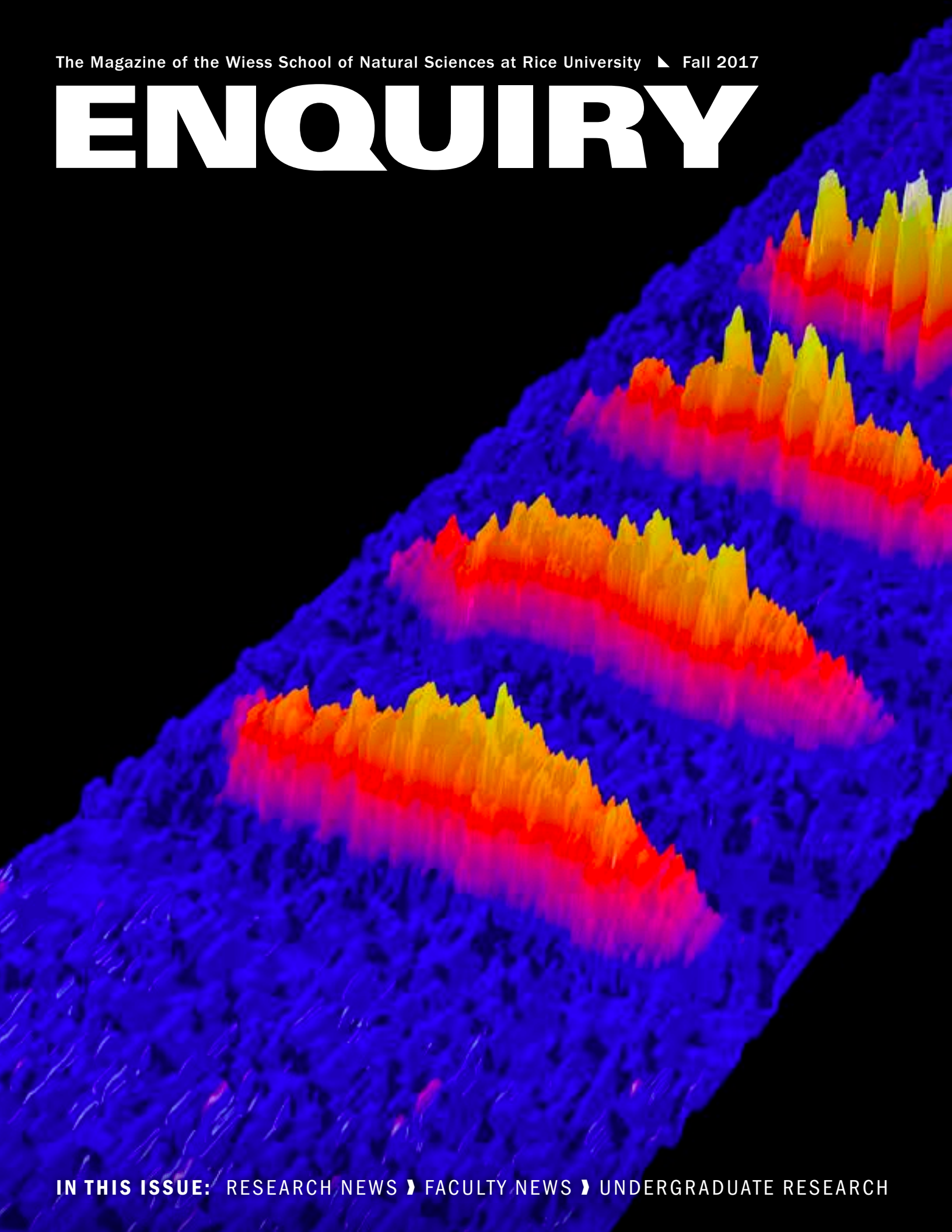


The Magazine of the Wiess School of Natural Sciences at Rice University ▶ Fall 2017

# ENQUIRY



IN THIS ISSUE: RESEARCH NEWS ▶ FACULTY NEWS ▶ UNDERGRADUATE RESEARCH

## A LETTER FROM THE DEAN

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**PETER J. ROSSKY**  
Dean, Wiess School of Natural Sciences

“AS YOU LOOK THROUGH  
THE STORIES, I HOPE THAT  
EACH OF YOU CAN SHARE IN  
THE CURIOSITY THAT FUELS  
OUR FACULTY AND STUDENTS  
TO STRIVE TO UNDERSTAND  
NATURE AT ITS DEEPEST  
LEVELS.”

Dear Friends of the Wiess School,

I am delighted to welcome you to this issue of ENQUIRY, the magazine of the Wiess School of Natural Sciences at Rice University. Within the pages of this issue, you will find stories of discovery — examples of the frontier scientific explorations and the trailblazing scientists that make up this exceptional school. As you look through the stories, I hope that each of you can share in the curiosity that fuels our faculty and students to strive to understand nature at its deepest levels.

The investigations in the natural sciences highlighted here span not only a remarkable breadth of science but also a range of length and time scales that is nearly unfathomable, from watching the quantum motion of individual atoms close to the absolute zero of temperature, to controlling individual genes in bacteria, to tracking the impact of climate change on the propagation of native plants, to witnessing the birth process of a new solar system more than 30 million times farther away from us than our own sun.

I am also proud to have this opportunity to share with you the national and international academic recognitions received by our faculty and students during the past year. Amazing Rice students, from across the schools, have also been the primary authors of the magazine’s content. I urge you to take the opportunity to read about our accomplished contributors.

All of the faculty, staff and students in the Wiess School join me in welcoming you to these pages and wish you an exciting journey through these highlights.

Best wishes,

A handwritten signature in black ink, appearing to read 'Peter J. Rossky', written over a light blue rectangular background.

Peter J. Rossky

## ENQUIRY

**EDITOR**  
Lauren Kapcha

**COMMUNICATIONS ADMINISTRATOR**  
Pamela Jones

**PHOTOGRAPHY, DESIGN AND EDITORIAL  
BY THE OFFICE OF PUBLIC AFFAIRS**

For information about supporting the natural sciences at Rice, please contact Jerry Haus at 713-348-4263 or [jerry.haus@rice.edu](mailto:jerry.haus@rice.edu).

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Photo: L. Simkins

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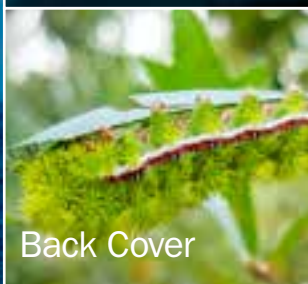
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Image: B. Saxton,  
NRAD/AUI/NSF



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Photo: Jankowsky Lab



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**On the cover:** The orange and yellow stripes in this composite image depict matter waves from different experimental runs in the Hulet Lab. The stripes show how matter waves change due to rapid magnetic shifts that bring about modulational instability. The left line shows a matter wave before magnetic switching. Subsequent images (to right) show how repulsive to attractive fluctuations become amplified in the wave. Clear signs of deviations from the initial solid shape can be seen in the third image, and the peaks and valleys in the far right image show how the wave morphs into a soliton train, a set of standing waves. (Image courtesy of Jason Nguyen)

# CONTRIBUTORS



## SAMANTHA CHAO '20

("Helping an Award-Winning Chef Support Local Farms") is a sophomore English major and business and biochemistry and cell biology double minor at Jones College. She enjoys writing, singing and playing the guitar, and she hopes to attend medical school.



## NATALIE DANCKERS '17

("Sex-Specific Responses to Climate Change") graduated this past May with a psychology and English double major and a business minor. Science literacy is extremely important to Danckers, who believes that research should be accessible to everyone, regardless of their scientific background. She was an editor for Catalyst.



## CAROL ANN DOWNES '17

("A Cost Reducing Flow for Transport Networks") graduated this past may with a Ph.D. in mathematics, completed under the supervision of Robert Hardt. She loves paper notebooks and can always be found with her research notebook and her pocket commonplace book. Downes is now a member of the faculty in the mathematics department at Hendrix College.



## ELAINE HU '19

("Developing a Quantum Dot Tagging Method for Tadpoles") is a junior at Sid Richardson College double majoring in ecology and evolutionary biology and art history. She is an editor for Catalyst and enjoys playing tennis and reading. Hu plans to become a physician.



## AMANI RAMIZ '19

("A One-Step Process to Create Carbon-Nitrogen Bonds") is a junior at Brown College, majoring in cognitive sciences. She is the director of communications for Catalyst and hopes to attend medical school and pursue global health research.



## JENNY REN '18

("Designing Synthetic Gene Regulatory Networks in E. coli") is a senior biochemistry and cell biology and economics double major at Jones College. She is an editor for Catalyst and enjoys dancing and drinking chai lattes. Ren plans to become a physician.



## EVAN SHEGOG '18

("Nascent Solar Systems Reveal Details of Planet Formation") is a senior at Hanszen College, majoring in ecology and evolutionary biology. Shegog is a member of Rice EMS and of the Rice Lads club soccer team. He is a writer for Catalyst.



## JACKSON STILES '20

("The Unexpected Intersection of Art and Science") is a sophomore earth science major and environmental science minor at Duncan College. He has a passion for paleontology and paleoclimatology and plans to attend graduate school to study in one of these fields. Stiles enjoys playing soccer and watching bad science fiction movies. He is a writer and editor for Catalyst.



## AJAY SUBRAMANIAN '18

is a senior materials science and nanoengineering major at Wiess College. He is co-editor-in-chief of Catalyst and served as Catalyst's liaison for this issue of Enquiry. Subramanian is involved in undergraduate research, participates in intramural sports and orchestra, and is a member of the a cappella group Basmati Beats.



## RISHI SURESH '17

("Gas Sensors Yield Secrets of Soil Microbes") graduated this past May with a cognitive sciences major. Suresh is passionate about music; plays the violin, guitar and banjo; and is a member of the a cappella groups Basmati Beats and Nocturnal. He was a writer for Catalyst.



## NICHOLAS ZAIBAQ

("Twenty Years Later: Carbon-Based Nanoscience Research at Rice") is a fourth-year graduate student, pursuing a Ph.D. in chemistry under the supervision of Lon Wilson. Zaibaq writes for Rice Magazine and enjoys attending musicals and plays, TED talks, folkloric dance and learning more about public science communication.

\*Catalyst is the undergraduate science research journal at Rice. The publication is edited and published by students with the goal of providing a voice for undergraduate researchers in the natural sciences. ■

## Accolades

### PRIZES AND AWARDS



Bonnie Bartel

### NATIONAL ACADEMY OF SCIENCES

Biochemist and plant biologist **Bonnie Bartel**, the Ralph and Dorothy Looney Professor of Biochemistry and Cell Biology, has been elected to the National Academy of Sciences. Her groundbreaking research in plant biology has led to a new and deeper understanding of how plants produce and use hormones and how they sequester oxidative metabolism in subcellular compartments known as peroxisomes. Bartel's group specializes in finding and exploring the genes involved in building, maintaining and destroying these essential cellular compartments.



Christy Landes

### ACS EARLY CAREER AWARD IN EXPERIMENTAL PHYSICAL CHEMISTRY

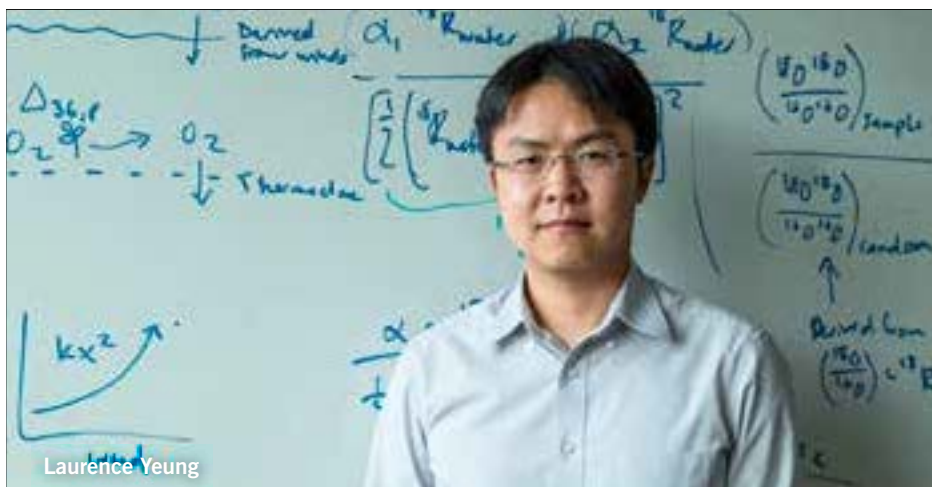
**Christy Landes**, professor of chemistry and of electrical and computer engineering, won the 2016 Early Career Award in Experimental Physical Chemistry from the American Chemical Society. The society cited Landes "for integrating super-resolution single-molecule techniques and information theory to contribute new discoveries in biological and chemical separations at the molecular scale."



Peter Wolynes

### INDIAN NATIONAL SCIENCE ACADEMY

**Peter Wolynes** has been elected a foreign fellow of the Indian National Science Academy, an honor bestowed on fewer than 100 scholars worldwide. Wolynes is the Bullard-Welch Foundation Professor of Science, a professor of chemistry and a senior scientist with Rice's Center for Theoretical Biological Physics. His research focuses on many-body phenomena in biology, chemistry and physics, and he is one of the foremost experts on protein folding.



Laurence Yeung

### GEOCHEMICAL SOCIETY F.W. CLARKE AWARD

**Laurence Yeung**, assistant professor of earth, environmental and planetary sciences, was the 2016 winner of the F.W. Clarke Award. The Clarke Medal is given annually by the society to an early career scientist for a single outstanding contribution to geochemistry or cosmochemistry. The award recognizes Yeung's efforts to develop, through experimentation and theory, a new set of tracers based on how often rare isotopes are found "clumped" together in the same molecule.

## SCHOLARLY SOCIETIES

### ACCADEMIA DEI LINCEI

**Albert Bally**, the Harry Carothers Wiess Professor Emeritus of Geology and Geophysics, was elected as a member of the Italian science academy Accademia dei Lincei.

### AMERICAN CHEMICAL SOCIETY

The American Chemical Society has presented **Rice University** the Citation for Chemical Breakthroughs Award in recognition of the discovery of C60, or the buckyball, at Rice in 1985. The buckyball discovery was recognized with the 1996 Nobel Prize in chemistry, which Rice's Robert Curl and Richard Smalley shared with the University of Sussex's Harold Kroto.

### AMERICAN PHYSICAL SOCIETY

**Matteo Pasquali**, chair of the Department of Chemistry and the A. J. Hartsook Professor of Chemical and Biomolecular Engineering and of materials science and nanoengineering, has been elected a fellow of the American Physical Society.

### HUMBOLDT FOUNDATION

The Alexander von Humboldt Foundation awarded **Emilia Morosan**, professor of physics and astronomy, of chemistry, and of materials science and nanoengineering, a Humboldt Research Award.

## MATERIALS RESEARCH SOCIETY

**Peter Nordlander**, professor of physics and astronomy, of electrical and computer engineering, and of materials science and nanoengineering, has been named as a fellow of the Materials Research Society.

## NATIONAL SCIENCE FOUNDATION

The National Science Foundation named **Matthew Foster**, assistant professor of physics and astronomy, as a recipient of an Early Career Award.

## PRESIDENTIAL EARLY CAREER AWARD FOR SCIENTISTS AND ENGINEERS

**Wei Li**, assistant professor of physics and astronomy, has been named a recipient of the Presidential Early Career Award for Scientists and Engineers, the government's highest honor for people who have recently begun their research careers.

## ROYAL DANISH ACADEMY OF SCIENCES AND LETTERS

**Janne Blichert-Toft**, a Wiess visiting professor in the department of earth, environmental and planetary sciences, was elected as a member of the Royal Danish Academy of Sciences and Letters.

## FELLOWSHIPS

### SOCIETY IN SCIENCE BRANCO WEISS FELLOWSHIP

Postdoctoral research associate **Idse Heemskerk** has been named a 2016 winner of the Society in Science Branco Weiss Fellowship. The award will support up to five years of research by Heemskerk, who works in the lab of Aryeh Warmflash, assistant professor of biosciences.

## STUDENT ACCOMPLISHMENTS

### FULBRIGHT GRANTS

**Beatrice Herrmann '16**, **Erin Rieger '16** and **Spencer Seballos '16** were awarded 2016 Fulbright Grants to study, teach and/or conduct research in France, Norway and Laos, respectively.

### GOLDWATER SCHOLARSHIP

**Henry Bair '17** and **Austin Cao '18** were named Goldwater Scholars for the 2016–2017 academic year.

## NATIONAL SCIENCE FOUNDATION

**Razan Alnahhas**, graduate student in biochemistry and cell biology; **Nicole Carrejo**, **Lauren McCarthy** and **Sarah Rehn**, graduate students in chemistry; **Andrew Moodie**, graduate student in earth, environmental and planetary sciences; **David Zong**, graduate student in systems, synthetic and physical biology; and undergraduate students **Thomas Carroll '16**, **Brittany Cavazos '16**, **Elli Ronay '16** and **Caleb Voss '16** were selected for the 2016 National Science Foundation Graduate Research Fellowship Program.

### TRUMAN SCHOLARSHIP

**Anjali Bhatla '17** was among 54 college students nationwide named a 2016 Truman Scholar.

### WATSON FELLOWSHIP

**Kira Clingen '16** was awarded a 2016 Thomas J. Watson Fellowship.

## New Faculty



Melodie French

### MELODIE FRENCH

**Assistant Professor of Earth, Environmental and Planetary Sciences**

Melodie French studies the physics of earthquakes and deformation along tectonic plate boundaries. She also studies the fracture mechanics of rocks with applications to geological engineering. Her research is primarily experimental; she measures and models the physical processes that occur in rocks at high temperatures and pressures. A component of her work also consists of studying the rocks recovered from faults, both currently active faults that have been cored at kilometers depth and ancient faults that have been exhumed to Earth's surface.

Prior to joining the Rice faculty, Melodie received her Ph.D. in geophysics from Texas A&M University and was an NSF Earth Sciences Postdoctoral Fellow at the University of Maryland at College Park.



Milivoje Lukic

### MILIVOJE LUKIC

**Assistant Professor of Mathematics**

Milivoje Lukic's main field of research is spectral theory. Spectral theory does for differential operators what linear algebra does for matrices, and the mathematical notion of spectrum is an extension of physical notions, such as the set of frequencies of a vibrating string or the set of allowed energies of a quantum system. He is also interested in connections with integrable systems. This includes nonlinear equations which can be solved by an inverse scattering transform — just as many linear systems are solved by a Fourier transform.

Lukic graduated from the University of Belgrade, Serbia, and completed a M.Sc. in physics and a Ph.D. in math at the California Institute of Technology. He was an Evans Instructor at Rice and then a postdoctoral fellow at the University of Toronto before rejoining Rice as a member of the faculty.

## Faculty Retirements

### ED BILLUPS

**Chemistry**

A native of West Virginia, W. E. (Ed) Billups earned a bachelor's degree from Marshall University and, after a period in industry as a research chemist, a Ph.D. in chemistry from Pennsylvania State University. He joined the faculty at Rice in 1970 as an assistant professor in the chemistry department. He served as the chair of the chemistry department from 1985 to 1991.



Ed Billups (left) with Bruce Brinson

Billups is best known for his early work dealing with the synthesis of hydrocarbons of theoretical interest, including the synthesis of elusive hydrocarbons like methylenecyclopropene, spiropentadiene and bicycloprop-2-enyl, a valence isomer of benzene. His work in nanotechnology includes the development of routes to soluble carbon nanomaterials. More recent research interests include energy and the science for developing asphaltene chemistry.

Billups is the author of more than 200 research papers and holds over 10 patents. He has mentored more than 30 doctoral students who now hold influential positions in academia and industry. Billups is the recipient of awards that include an Alexander von Humboldt Senior Scientist Award, Alfred P. Sloan Fellowship, Lilly Grantee in Organic Chemistry Program and the 2003 Award of the American Chemical Society, Greater Houston Section of the American Chemical Society. He now is professor emeritus of chemistry.

# In Memoriam



**MARJORIE CORCORAN**  
**Professor of Physics and Astronomy**

Rice physicist and beloved faculty member Marjorie Corcoran died unexpectedly Feb. 3, 2017. She was 66.

Corcoran studied experimental particle physics to better understand the most elementary constituents of matter. She came to Rice in 1980, but she had already begun her research at Fermilab while a graduate student at Indiana University. Her research focused on CP violation, tests of fundamental symmetries and searches for physics beyond the Standard Model of particle physics that has been successful in describing all known experimental results.

An advocate for women in science, Corcoran supervised a number of Rice graduate students' theses and dissertations. She was a fellow of the American Physical Society and served on its division of particles and fields executive committee. Corcoran received the Distinguished Scientist Award from the University of Wisconsin physics department. She worked tirelessly with students and educators and created the ongoing Quarknet high school teacher program in 2004. In January 2015, the American Physical Society named Corcoran Woman Physicist of the Month and noted that she was "a leader in the particle physics community and a great role model for women in physics."



**HANS AVÉ LALLEMANT**  
**Professor Emeritus of Earth Science**

Hans Avé Lallemand died Nov. 14, 2016. He was 78.

A pioneer in the rheology of the mantle and the structural evolution of mountain belts all over the world, Avé Lallemand traveled across the globe — from Alaska to southeast Asia to the Caribbean — for his field work.

He was one of the first to calibrate a rheologic law for the ductile deformation of mantle rocks. He studied the significance of transpression and transtension in mountain belts and developed new models for the exhumation of high pressure rocks in accretionary prisms.

Born in Indonesia, Avé Lallemand was educated in the Netherlands, where he earned a doctorate in geology from the University of Leiden. He then moved to the United States and in 1970 became a professor in Rice's Department of Earth Science, where he taught structural geology and field mapping. He retired in 2006.





### ROBERT HAUGE

**Distinguished Faculty Fellow in Chemistry and in Materials Science and Nanoengineering**

Robert Hauge, 77, died March 17, 2016, after a long illness. He had recently celebrated his 50th year at Rice University, nearly all of them as a faculty fellow.

A native of Sun Prairie, Wisc., Hauge earned a bachelor's degree at Loras College in 1960 and a Ph.D. at the University of California at Berkeley in 1965.

Hauge joined Rice as a postdoctoral researcher at the invitation of chemist John Margrave. Hauge contributed to groundbreaking work in spectroscopy, fluorine chemistry and high-temperature inorganic chemistry. He remained at Rice as a faculty fellow, rising to distinguished faculty fellow in 1992.

Hauge was renowned at Rice for his love of collaboration, a quality that led to his status as one of the most highly cited chemists in the world, according to an ISI/Thomson Reuters ranking that placed him at No. 13 on a 2011 list of the 100 top chemists of the previous decade. He worked with and co-authored papers with scores of Rice researchers.



### HALLY BETH POINDEXTER

**Professor Emeritus of Kinesiology and Department Chair of Kinesiology**

Hally Beth Walker Poindexter '47 died July 19, 2016. She was 88.

Poindexter's lifelong commitment to promoting women — especially in sports — at Rice spanned more than 50 years. She served on the faculty from 1965 through 1998. During her 20-year tenure as chair of the Department of Kinesiology, Poindexter managed club sports, maintained the care and use of the gym, and volunteered her time organizing and coaching the first women's sports teams.

As a vocal member of the Faculty Council, Poindexter was active in the cause of equality for women in varsity sports and instrumental in weaving Title IX into the fabric of Rice Athletics. She was inducted into the Rice Athletics Hall of Fame in 2015.

In addition to having a B.A. from Rice, Poindexter had a B.S. from the University of Houston, an M.A. from the University of Northern Colorado and an Ed.D. from Columbia University.



### WILLIAM VEECH

**Edgar O. Lovett Professor of Mathematics**

William Austin Veech died unexpectedly Aug. 30, 2016, at age 77.

Veech joined the faculty of Rice University in 1969. He served as mathematics department chair from 1982 to 1986 and held an endowed chair since 1988, the Milton Brockett Porter Chair from 1988 to 2003 and the Edgar Odell Lovett Chair since 2003.

Veech obtained his B.A. from Dartmouth College in 1960 and earned his Ph.D. in 1963 under the supervision of Salomon Bochner at Princeton University. He is the namesake of Veech surfaces, simple polygonal billiard tables whose dynamical properties induce subsets of the heavily studied Riemann's moduli space of curves with astonishing properties. The study of such surfaces has become one of the most active topics in mathematics today.

Veech was an inaugural fellow of the American Mathematics Society. He worked at the Institute for Advanced Study during his numerous visits there during the 1960s, 1970s and 1980s. His publications spanned more than 50 years.

# Colossal Antarctic Ice-Shelf Collapse Followed Last Ice Age

BY JADE BOYD

In a study that provides clues about how Antarctica's nation-sized Ross Ice Shelf might respond to a warming climate, U.S. and Japanese oceanographers have shown that a 100,000-square-mile section of the ice shelf broke apart within 1,500 years during a warming period after the last ice age.

The Ross Ice Shelf is the world's largest ice shelf, a vast floating extension of the West Antarctic Ice Sheet that is about the size of France. But at the end of the last ice age, it extended much farther north and covered the entire Ross Sea. Rice oceanographer John Anderson, postdoctoral research associate Lauren Simkins, graduate student Lindsay Protho and colleagues at the University of Tokyo detailed how the ice shelf shrank during a period of climate warming following the ice age.

"At the height of the last ice age, we know that the sheet of ice covering the Antarctic continent was larger and thicker than it is today," said Anderson, Rice's Maurice Ewing Professor of Oceanography and professor of earth, environmental and planetary sciences. "This continent-enveloping ice sheet extended all the way to the continental shelf, and in western Antarctica it filled the entire Ross Sea basin."

While people typically think of continents as landmasses that rise above the sea, the margins of all continents, including Antarctica, extend well beyond their shores to include continental shelves, subsea aprons that are far more shallow than the deep ocean abysses that mark the continental boundary.



**Left:** The NSF research vessel Nathaniel B. Palmer prepares to dock at McMurdo Station, Antarctica. **Right:** A sediment core from the Ross Sea floor is raised onto the deck of the research vessel. Photos: L. Simkins

In western Antarctica, the Ross Sea is characterized by a continental shelf that extends nearly 1,000 miles from the coast and is as much as 3,500 feet deep. Anderson said the geologic record shows that as recently as 18,000 years ago the entire Ross basin was filled with ice that was so thick and heavy it was grounded on the seafloor all the way to the edge of the continental shelf.

“We found that about 10,000 years ago, this thick grounded ice sheet broke apart in dramatic fashion,” Anderson said. “The evidence shows that an armada of icebergs — each at least twice as tall as the Empire State Building — was pushed out en masse. We know this because this part of the Ross Sea is about 550 meters (1,804 feet) deep, and the icebergs were so large and so tightly packed that they gouged huge furrows into the sea floor as they moved north.”

Researchers measured the furrows using a seafloor mapping system — the most sensitive ever employed in the Antarctic — during a 2015 cruise by the U.S. research vessel Nathaniel B. Palmer, which is operated by the National Science Foundation.

Simkins, who helped gather data during the 56-day cruise, said other features preserved on the seafloor, formed by the retreating ice, showed that the margin of the grounded ice sheet retreated rapidly after the initial collapse and fell back hundreds of miles in stair-step fashion.

The Ross Ice Shelf appeared after the breakup of the ice sheet. An ice shelf is the floating, seaward extension of an ice sheet and marks the point at which the ice is thin enough to float.

“The grounding line is the location where the ice actually sits on the seafloor,” Simkins said. “Following ice-shelf breakup, the ground-

ing line is left exposed to marine processes, such as ocean warming, which can erode the grounding line and cause it to move back toward the shore.”

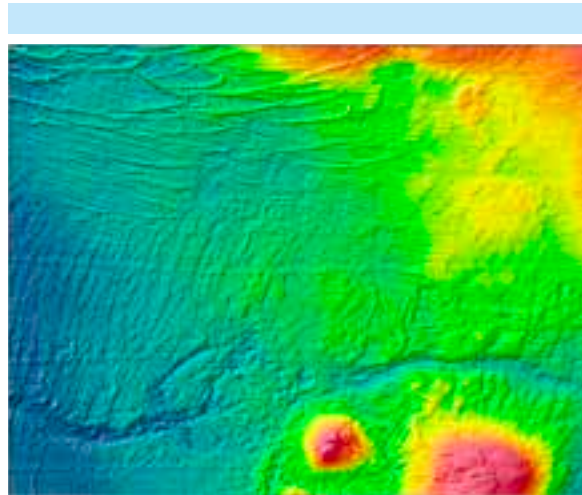
The retreat was halted when the grounding line reached a series of shallow banks that acted as anchors and stabilized the ice shelf for about 5,000 years.

Anderson said, “Throughout this period, the ice shelf was pinned atop these shallow banks. On the surface, ice still covered large portions of the Ross Sea, but there was open water beneath the ice shelf.”

The researchers know the times when the seafloor was partially or fully ice-covered, thanks to painstaking geochemical analyses of seafloor sediments that were overseen by Yusuke Yokoyama, a professor at the University of Tokyo who was also a Wiess Vis-

iting Professor in Rice’s Department of Earth Science in 2014–2015. The geochemical analyses also relied on evidence gathered by the Palmer, which is capable of drilling and recovering sediment cores from the seafloor. Such cores contain a geological record that can extend thousands of years, and Yokoyama’s team used Ross Sea core samples that were recovered during a 1999 Palmer cruise as well as 2015 cores and seafloor imagery to pinpoint the timing of the ice-shelf breakup.

“The really big breakup began about 3000 B.C.,” Anderson said. “We believe it was similar, in many respects, to the breakup of the Larsen B Ice Shelf in 2002. The Larsen is far smaller than the Ross Ice Shelf, but satellite imagery that year showed the Larsen dramatically breaking apart in just a few weeks. We believe the large breakup of the Ross Ice Shelf occurred at roughly

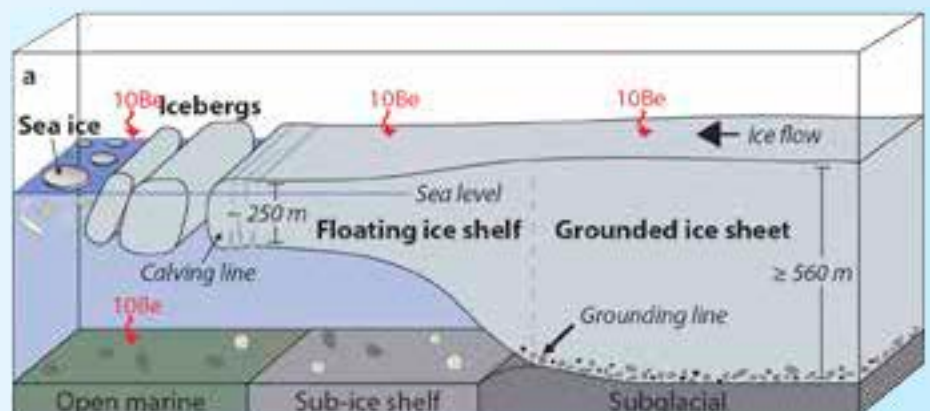


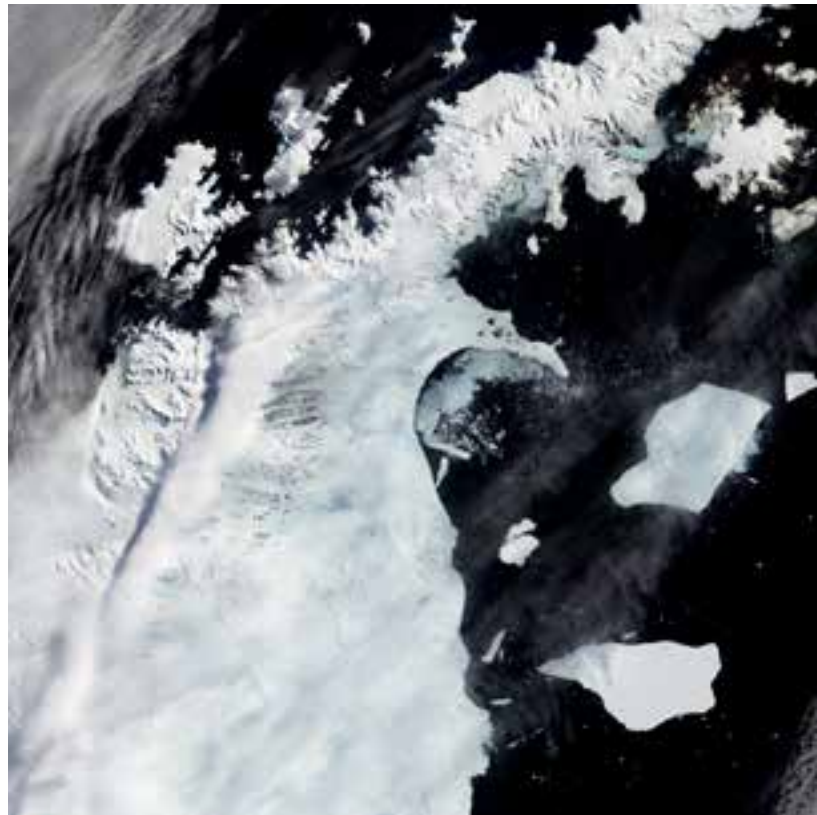
Glacial landforms preserved a record of past Antarctic Ice Sheet retreat from the continental shelf on the seafloor. The linear ridges were deposited at former ice margin positions, i.e., the position where the ice shelf meets the sea. The spacing of these ridges indicates rhythmic ice margin retreat. The v-shaped ridges that partially bury the linear ridges mark a local re-advance of the ice margin. Image: L. Simkins

### AN ICE SHEET (RIGHT) IS A LARGE MASS OF GLACIAL ICE THAT COVERS THE SURROUNDING TERRAIN. In

places, the Antarctic Ice Sheet reaches down to 2,500 meters below sea level, resting on terrain that would otherwise be seabed. An ice shelf (center) is a thick, floating platform of ice that forms where a glacier meets the sea. The boundary between the floating ice shelf and the grounded ice sheet is called the grounding line. The open sea is partially covered by ice that is much thinner than the ice shelf (left). The isotope beryllium-10 (<sup>10</sup>Be) forms in the atmosphere and does not fall to the seafloor beneath ice shelves or ice sheets.

Image: L. Simkins





Jan. 31, 2002

Feb. 17, 2002

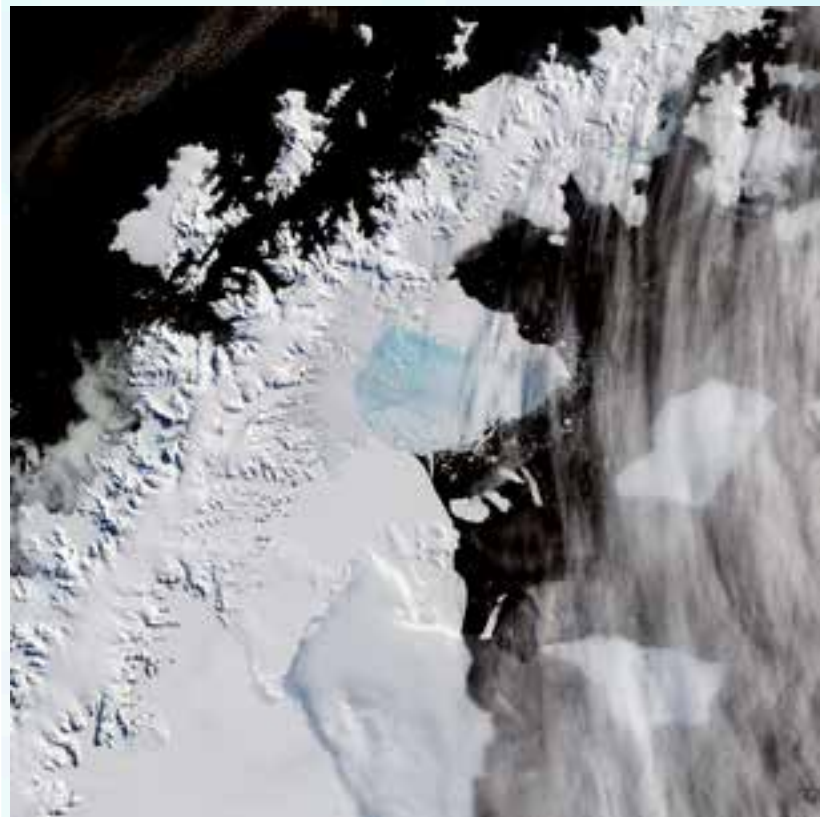
**In 2002, a piece of the Larsen B ice shelf, about the size of Rhode Island disappeared in six weeks.** These true color images show dark blue melt ponds starting to show on the surface Jan. 31 and Feb. 17. Thousands of icebergs (silver) and a large area of very finely floating ice (light blue) were all that remained of the former shelf in March. Image courtesy of Ted Scambos, National Snow and Ice Data Center, University of Colorado, Boulder, based on data from MODIS.

this same pace, but the area involved was so much larger — about the size of the state of Colorado — that it took several centuries to complete.”

By 1500 B.C. the breakup had exposed about 100,000 square miles of the Ross Sea that had been either wholly or largely ice-covered for many millennia, Anderson said.

To pinpoint the timing, Yokoyama’s team used two novel geochemical approaches: measurement of the isotope beryllium 10, which forms in the atmosphere and does not fall to the sea-floor beneath ice shelves, and “compound-specific radiocarbon

**“The really big breakup began about 3000 B.C. We believe it was similar, in many respects, to the breakup of the Larsen B Ice Shelf in 2002. The Larsen is far smaller than the Ross Ice Shelf, but satellite imagery that year showed the Larsen dramatically breaking apart in just a few weeks.”**



March 5, 2002



March 17, 2002

dating,” a painstaking technique that involves identifying and ascertaining the age of specific organic molecules in sediments. Yokoyama said each compound-specific radiocarbon dating measurement took several weeks to perform, and more than a dozen were needed for the study, which marked the first systematic use of the technique in Antarctic science.

“Our radiocarbon dating work alone took more than a year to complete,” Yokoyama said. “The results of those tests, as well as the beryllium tests, provided conclusive evidence that the main breakup of the ice shelf occurred between 5,000 and 3,500 years ago.”

Anderson said knowledge about the past behavior of the ice sheet and ice shelf, in particular their rate of response to atmospheric and oceanic warming, informs scientists about how present-day ice sheets and ice shelves may respond to future warming.

“There are similarities to what we see the modern Ross Ice Shelf doing,” Anderson said. “The farthest boundary of the ice shelf extends nearly 1,000 kilometers (621 miles) from the grounding line, where the ice sheet is grounded in about 800 meters (2,625 feet) of water. That’s a condition that most glaciologists consider unstable, and it is not unlike the situation that existed prior to the big breakup that began 5,000 years ago.”

The present Ross Ice Shelf is about 500 miles wide and several hundred feet thick. Because the ice shelf is already floating, its breakup and melting would not, by itself, pose a risk of raising

global sea level, Anderson said. However, he pointed out that the ice shelf acts as a brake to dozens of Antarctic ice streams and outlet glaciers, and ice flowing into the ocean from those would contribute to global sea level rise.

“The ice shelf slows the flow of grounded ice from the glaciers, and as we saw after the Larsen B breakup, once you pull the stopper out of the bottle,” Anderson said, “the glaciers move much faster, in some cases about 10 times faster.” ■



# Designing Synthetic Gene Regulatory Networks in *E. coli*

BY JENNY REN

Bands of cyan and yellow fluorescence flash and swirl around each other in synchrony, like the bright headlights of cars zooming by. The colored lights seem to communicate, turning each other on and off in a microscopic imitation of the aurora borealis.

This curious, yet dazzling, phenomenon is a circuit created by Matthew Bennett, associate professor of biochemistry and cell biology, and his synthetic biology lab at Rice University. But this circuit is not made of silicon chips, and it definitely does not conduct electricity. Instead, Bennett and his lab construct gene circuits in bacteria.

Bennett's work with gene circuits is a major component of synthetic biology. At its core, synthetic biology involves the design and construction of new biological entities — such as enzymes, genetic pathways and organisms — or the redesign of existing natural biological systems. At the forefront of this field, Bennett's lab creates gene circuits to study naturally occurring gene relationships as well as new, artificial cellular functions.

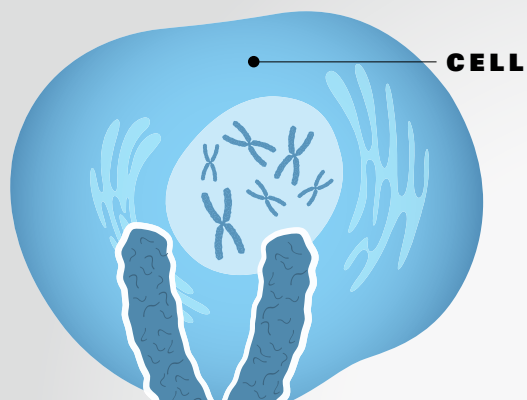
So how exactly do you go from DNA and genes to coordinated flu-

orescent bacteria? Every organism begins with the same building blocks of life: the four DNA bases (A, T, C and G). Genes are short segments of DNA that act as recipes for the various characteristics and functions of an organism; they encode proteins, which carry out biological processes in the cell. "Genes are not static," said Bennett. "They are active, malleable things that regulate one another." Some genes encode regulatory proteins, also known as transcription factors, that can turn other genes on (activation) and off (repression), forming a complicated web of interaction called a gene network. Synthetic biologists like Bennett then assemble and rewire these networks, harnessing the activation and repression interactions to engineer novel genetic circuits that can be studied in bacteria, yeast or other model cells. Bennett uses synthetic circuits to study the underlying

"Genes are not static.

They are active, malleable things

that regulate one another."



**DNA BASES:**

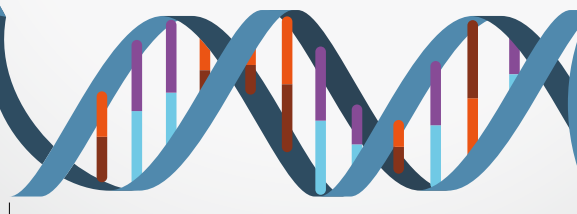
- A** ADENINE
- C** CYTOSINE
- G** GUANINE
- T** THYMINE

The wide diversity of life on our planet arises from different sequences of the four bases in a strand of DNA: adenine (A), cytosine (C), guanine (G) and thymine (T).

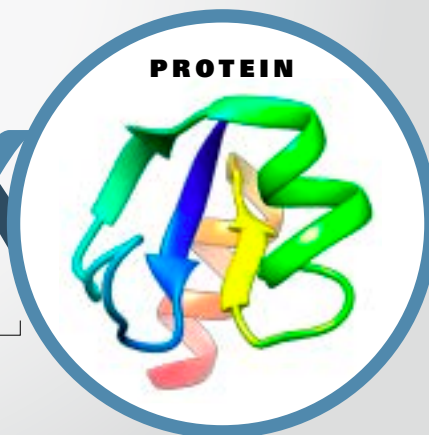
DNA is found in the nucleus of our cells, tightly wound into structures called chromosomes.

Sections of DNA, called genes, contain the instructions to build proteins, molecules that are essential to the structure and performance of all organisms.

**CHROMOSOME**



**GENE**



**PROTEIN**

principles governing gene networks and regulation.

The spectacle of bright cyan and yellow bacteria is two populations of *E. coli*, each carrying a synthetic gene circuit engineered by Bennett and his lab. The team created the colorful, fluorescent bacterial circuit by utilizing quorum sensing genes that naturally occur in other bacteria. Quorum sensing genes help bacterial colonies sense and signal their size. *E. coli* do not possess these genes, so Bennett's lab spliced quorum sensing genes into the two populations of *E. coli* bacteria. One strain — the activator — stimulated specific gene expression, while the other strain — the repressor — inhibited that same gene's expression. The activator strain produced a signaling molecule that further activated its own signal production in a positive feedback loop as well as triggering the repressor strain. When prompted, the repressor strain produced another molecule that mitigated itself and the activator strain. Both strains also produced an enzyme that degraded the signaling molecules, preventing accumulation of unnecessary signal.

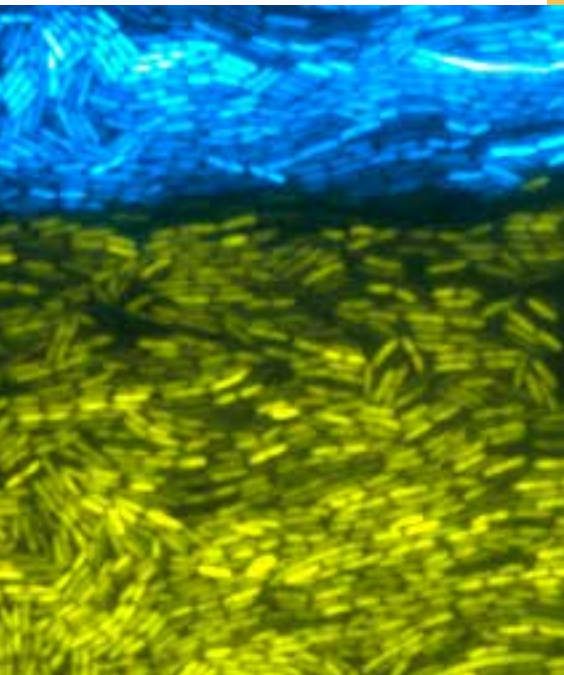
With the 12 genes in the network, Bennett also included genes to express fluorescence. Upon activation, each strain produced a fluorescent molecule: cyan for the activator and yellow for the repressor. When grown together, both populations were activated and repressed in synchrony, causing aesthetically pleasing oscillations across the bacterial populations. However, when only one strain was grown in isolation, no fluctuations were observed at all. The alternating fluorescence clearly demonstrates the oscillating protein expression and communication between the two *E. coli* strains, providing visual evidence for even the most untrained eye.

Now, Bennett's lab has progressed much farther than observing genetic circuits

in very small, confined spaces. In small chambers like those in the original *E. coli* studies, signaling is basically instantaneous. But what if those same bacterial populations are placed in a larger area, where chemical signals from one side never reach the other? "This is much more akin to what happens with large multicellular systems like us," explained Bennett. "Chemical signaling just doesn't always reach from side to side." Additionally, the two strains compete for space, causing disorganized heterogeneity in the system. "And yet," mused Bennett, "somehow during development things coordinate with each other." Through further gene circuit engineering and fluid mechanics, Bennett and his team have discovered a way to grow different bacterial strains that can reach homeostasis in larger reaction chambers. "After a transient period, the two strains line up with each other to create this striped pattern," Bennett said. "Everything is synchronized."

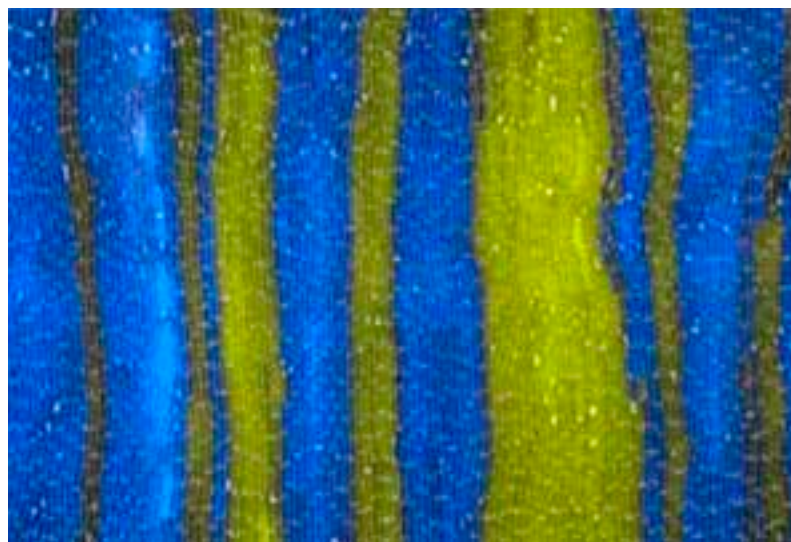
The implications of these results are endless. Future applications could range from biological computation to biofuel production and medical treatment. Bennett's lab now is investigating the possibility of treating tumors via the gut microbiome, the bacterial populations living in our intestines. Physicians could prescribe a patient with some sort of yogurt, for example, that could interact with other bacteria in the digestive tract or bloodstream. The injected bacteria could then congregate at the tumor site, and after receiving a signal the physician administers, the injected bacteria will start producing some drug at the site of the tumor. Ideally, the physician could specifically initiate bacterial drug production, the tumor shrinks, and the immune system eventually clears the bacteria.

Many of the projects in Bennett's lab



**Above:** Two strains of synthetically engineered bacteria cooperate to create multicellular phenomena. Their fluorescence indicates that the engineered capabilities have been activated.

**Right:** After some time in a larger chamber, the two strains of synthetically engineered bacteria reach an equilibrium, lining up with each other to form this striped pattern.





aim to understand the basic dynamics of gene regulation. He and his team use experiments and mathematical theories to answer questions such as how long it takes for one gene to regulate another or how pathways occur in natural systems. A second research goal is somewhat larger. “We’re working on something called synthetic microbial consortia,” said Bennett. “It’s a very long-term goal of getting cells to work with one another to create multicellular systems.” A lot of previous work focuses on successful gene networks and circuits in single cells. However, Bennett aims to understand more about communication systems. “We want different strains to talk to each other,” he said, “to communicate, to bring about emergent phenomenon that you wouldn’t see in isogenic strains alone.”

When asked about his motivation, Bennett’s answer is at once simple, strange and inspiring: the cuttlefish. Along with concentrating on immediate applicable results of synthetic biology and genetic circuits, Bennett also declares much loftier ambitions. “I want to build a cuttlefish. They’re these tiny things, but they’re the masters of stealth. They can morph their bodies into any shape, any color, instantly. It’s pretty amazing. How do I build these wonderful things? How can I go from a simple thing like an *E. coli* to a cuttlefish? I want to understand that process. I want to do it from the ground up.” Bennett is by no means an idealist — he understands that this most likely will not happen within his lifetime. Nevertheless, Bennett aims to contribute to the utmost understanding of how life is made. For Bennett, “That’s the grand prize of synthetic biology.”

Ultimately, Bennett’s main goal is to understand how genes bring about complicated organisms like us. He takes a reductionist approach, trying to understand the complicated process of building organisms from the bottom up. “It’s a challenge,” Bennett admits, “but I know it’s an accomplishable challenge because nature’s already done it.” ■

**Cuttlefish** are masters of camouflage, able to rapidly change the color, pattern and texture of their skin to communicate with other cuttlefish, blend in with their surroundings and warn off predators.



# A Cost Reducing Flow for Transport Networks

BY CAROL ANN DOWNES

Snapshots of the flow acting on a transport path where one central supply location ships one item to each of 24 equally spaced destinations.  $M^\alpha(T)$  is the cost of each transport network.

$$\alpha = 0.5$$

$$\mu^+ = 24\delta_{(0,0)}$$

$$\mu^- = \sum_{i=1}^{24} \delta_{(1, i\pi/12)}$$

$$T \in \text{Path}(\mu^+, \mu^-)$$

$$M^0(T) = 24$$

$$M^1(T) = 21.42$$

$$M^2(T) = 19.85$$

**A PRACTICAL QUESTION THAT ARISES IN BUSINESS OPERATIONS IS HOW TO MINIMIZE THE COST OF SHIPPING GOODS TO CONSUMERS.**

To help answer this question, classical transport theory — as in the Monge-Kantorovich problem — focuses on minimizing transportation cost by optimally allocating or distributing goods. Here, the cost does not account for the actual path traveled by the goods. Instead, each good is assumed to be traveling along a straight line from source to destination, and the length of the journey determines the cost.

While this model allows for easier cost analysis, it is not always realistic. The cost of transportation in real applications is rarely determined solely by the distances between sources and destinations. This is most clearly seen in nature (e.g., tree root systems and cardiovascular systems), where we find examples of ramified, or branching, paths that use overlapping structures for efficiency of shared transport. In the same vein, we often see efficiencies of scale in economics, i.e., the cost per pound for transporting freight decreases as the amount of freight increases, that encourage ramified networks. In other words, “Y-shaped” paths can be more cost effective than “V-shaped” ones when sending goods from one supply location to two demand locations.

To overcome the limitation in the Monge-Kantorovich model, we can use concave functions to incorporate efficiencies of scale into transportation models. First, we associate a capacity to each edge of the transport network, representing the amount of mass (i.e., goods) traveling along that edge. Then, we define the cost of transporting the associated mass along an edge as the length of the edge multiplied by the amount of mass raised to a fixed power between zero and one. The total transport cost of the network is then the sum of these values over all edges in the network. Defining transport cost in this way makes shared transport, and thus, ramified structures, advantageous when searching for a minimal cost transportation network between fixed sources and destinations.

However, finding this optimal branch structure proves difficult, especially when studying transportation between complicated supply and demand distributions. In fact, algorithmically finding optimal concave cost networks, even with a finite number of supply and demand distributions, is an NP-hard problem — a difficult problem in computer science. So, instead of solving this optimization problem outright, I created a cost reducing flow to evolve transportation networks.

Instead of restricting the flow to transportation networks, I generalized it for reducing an appropriately defined mass of real-valued, k-dimensional flat chains, which may be considered as generalized, oriented surfaces with densities. Moreover, the constructed flow is continuous in time with respect to the typical norm on flat chains. I can flow an initial transport path to a local minimum by viewing transportation networks as 1-D, real-valued flat chains and their transport costs as their masses. In this context, we say that the flow is a continuous evolutionary process that moves an

**The cost of transportation in real applications is rarely determined solely by the distances between sources and destinations.**

initial network in such a way to decrease the cost of transportation. In fact, this flow allows for changes in the topology of the network, meaning that the network can evolve to include more branching points for cost-efficient overlapping. Concretely, when the flow is applied to a simple transport network with one source sending goods to two destinations, we can see the network evolve, through a “zipping up” mechanism, from a “V-shaped” initial path — goods follow two linear routes from the source to two destinations — to the optimal “Y-shaped” path — goods share a single route for some distance before separating toward their destinations.

For future research, the generalized definition of the flow allows for exploration into other areas of application outside of optimizing transport networks. For example, the flow seems readily applicable to continuously reduce noise in large data sets in arbitrary dimensions. Additionally, the flow may prove to be valuable in modeling directed self-assembly of matter. ■



# EXPLORING THE QUANTUM WORLD WITH ULTRACOLD ATOMS

BY LAUREN KAPCHA

**Imagine that you are playing a game of pool, and you've lined up your winning shot to pocket the eight ball. You contact the cue ball and send it on its way, anticipating that perfect collision. But, there's no impact at all. The cue ball passes right through the eight ball completely unchanged in shape or speed. In the classical world where we live, this would never happen. However, in the quantum world that Randall Hulet, the Fayed Sarofim Professor of Physics and Astronomy at Rice, studies in his lab, this type of interaction is expected.**

Hulet's group uses lasers to cool lithium atoms down to one microkelvin, or just one-millionth of a degree above absolute zero. "We produce atoms that are colder than anything else in the universe — a million times colder than deep space," said Hulet. The laws of quantum mechanics govern atoms at these low temperatures: objects behave as both particles and waves and everything is ruled by probabilities. One of the curious occupants of the quantum realm that Hulet's group studies is the matter wave soliton.

To understand what a matter wave soliton is, let's break this down piece-by-piece starting with the matter wave. Quantum mechanics tells us that all matter can show wave-like behavior, yet this isn't what we experience in daily life. Atoms act like tiny billiard balls at room temperature. They have a well-defined mass and position and don't appear to be wave-like at all. If particles also act like waves, why is this the case? It has to do with the wavelength of an atom. At high temperature, like room temperature, the wavelength of an atom is so short that its wave-like properties aren't very obvious. As the temperature gets lower, the wavelength of the atom gets longer, and the particle's location starts to get a little bit blurry. As long as the blurriness is smaller than the separation between atoms, you can still track individual blurry billiard balls. But at low enough temperatures, the waves of neighboring atoms overlap making it impossible to distinguish one atom from the next. The group of atoms forms one giant matter wave, called a Bose-Einstein condensate.

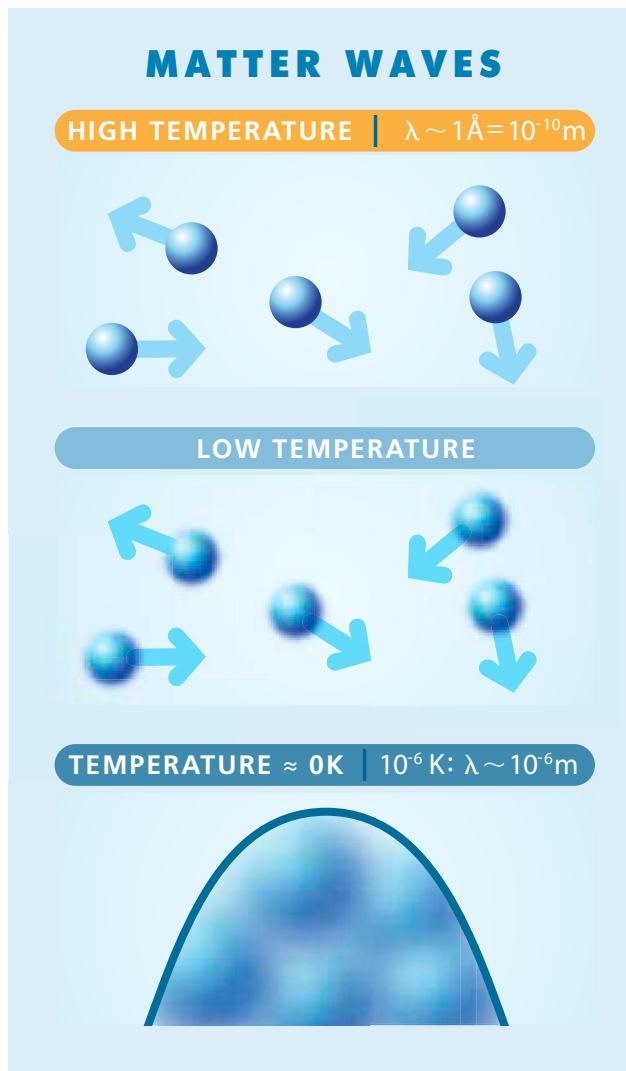
Now, let's address the second part: what exactly is a soliton? "One of the most interesting wave phenomena is something called a soliton, which is an object — a wave, a wave packet, a group of waves together — that can propagate without changing shape, without changing velocity, without spreading," said Hulet. If you think about how a typical wave behaves, you'll see how special this is. When you drop a rock into a pond, the rock pushes water away, producing a circular wave that spreads out. This spreading out is known as dispersion, and it is why the ripples die out before covering the entire pond. Under just the right conditions, other forces acting on the wave can exactly cancel the dispersion. When this happens, the wave packet's shape will not change over time: you have a soliton. If dropping that rock in the pond formed a soliton, the ripples would advance across the pond until they reached the edge — unchanging in size or speed.

John Scott Russell documented the first soliton in the 1830s while conducting experiments

along Scotland's Union Canal. When one of the horse-drawn barges came to an abrupt stop, he observed a solitary wave that continued on without changing shape or speed. He followed the wave on horseback for a couple of miles before it dissipated. He termed this a "wave of translation" and went on to study its properties in a wave tank he built at his home. Solitons are actually found all over the place: in the fiber optics we depend on for information transmission, in the collective motions of proteins and DNA, in Jupiter's great red spot, and in ocean waves. Astrophysicists even suggest that solitons may be able to describe the expansion of the universe.

In 2002, Hulet and his coworkers made a new type of soliton: a matter wave soliton. First, they cooled down a gas of lithium atoms to one microkelvin to form a Bose-Einstein condensate. Next, they tuned the interactions between atoms to be attractive, exactly balancing the forces that typically cause a wave to spread out. This allowed them to create anything from a single matter wave soliton to a "train" of up to 15 solitons side-by-side. Hulet and his group study both soliton trains and collisions of individual solitons to learn more about the fundamental nature of the matter wave soliton.

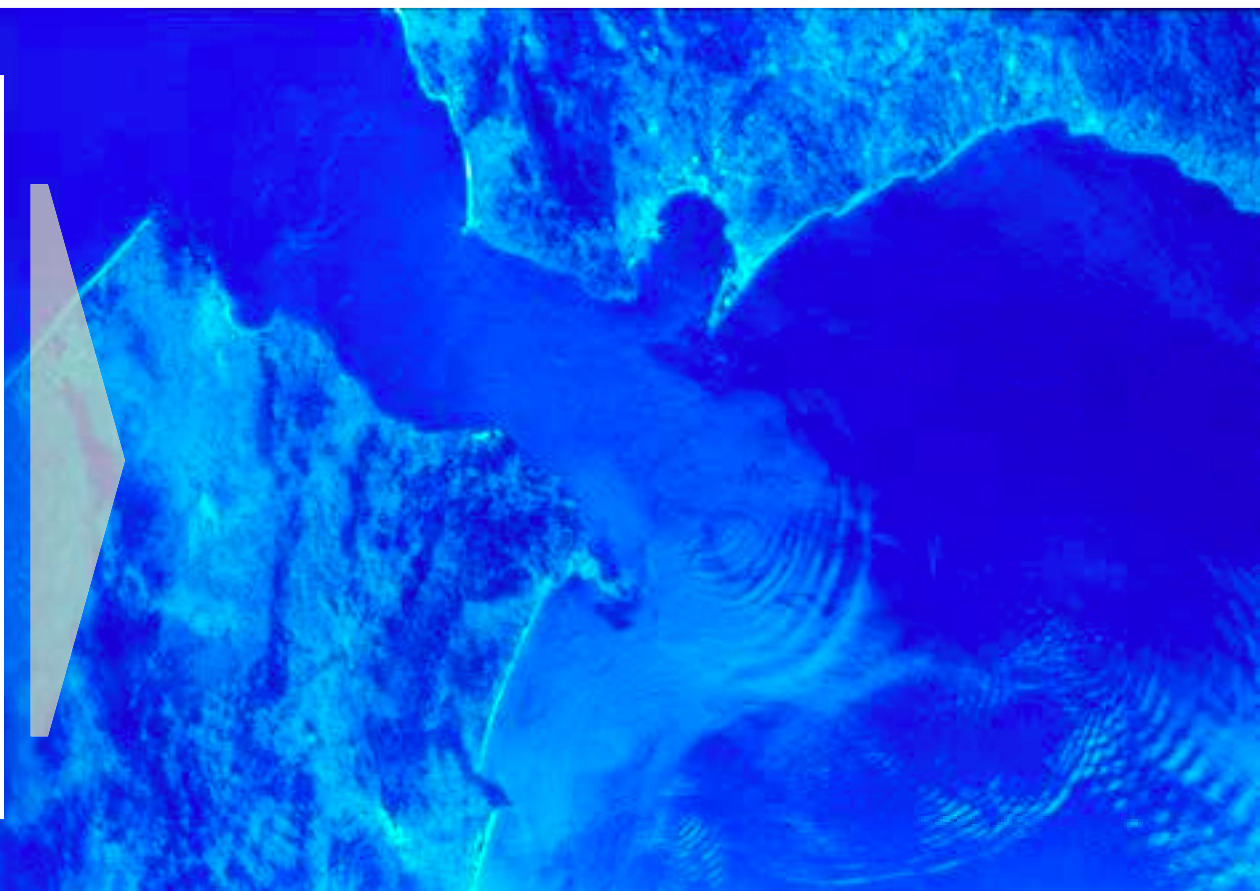
Like the confined water wave solitons Russell studied in his backyard wave tanks, Hulet's group also confines matter wave solitons for their investigations. Instead of a large water tank, Hulet, research scientist Jason Nguyen and graduate student De "Henry" Luo use a



Matter waves are an example of the quantum mechanical concept of wave-particle duality that says all matter exhibits wave-like behavior. The wavelength of a particle is given by the de Broglie equation, which relates wavelength ( $\lambda$ ) to momentum ( $p$ ):  $\lambda = h/p$ , where  $h$  is Planck's constant. Since particle momentum depends on temperature, as the temperature gets lower, the atoms' wavelengths get longer.

At high temperature, the wavelength of a particle like the lithium atoms used in these experiments is so small that no wave-like properties are observable. When the temperature is low enough, the atoms' wavelengths are longer than the distance between neighboring atoms. They become a Bose-Einstein condensate, acting as a single matter-wave.

Ocean solitons propagating from the Strait of Gibraltar, captured by oceanographer-astronaut Paul Scully-Power. The soliton is produced by water flowing into the Strait from the Atlantic Ocean. Internal wave sets are generated at the interface between the lighter, less salty Atlantic and the denser, saltier Mediterranean water. Here, you can see a series of solitons produced by the eastward flowing tide followed by a stretch of water where no solitons have been produced after the tide turns. Three tidal cycles are shown, with about 60 kilometers separating one group of solitons from the next. Image: STS-41G, October 1984. Picture #17-34-081



## ONE OF THE DEFINING FEATURES OF A SOLITON IS THAT THEY ARE SUPPOSED TO BE ABLE TO PASS THROUGH ONE ANOTHER AND EMERGE UNFAZED.

laser to create a 1-dimensional (1-D) parabolic track that lets the solitons oscillate back and forth. “We make two of them on opposite sides of a 1-D track, and we shoot them at each other and see how they scatter and how they interact,” said Hulet.

“One of the defining features of a soliton is that they are supposed to be able to pass through one another and emerge unfazed,” Hulet said. “Some of the collisions are consistent with that.” Indeed, sometimes two solitons collide, emerge unchanged and continue on their oscillating cycle. Other collisions, however, seem to show the solitons approaching each other, leaving a small gap between them and bouncing off each other. “When we saw the initial data we said, ‘This doesn’t make sense,’ because solitons are always supposed to pass through one another and these look like they’re bouncing instead.”

In order to understand what’s happening here, we need to think about the properties of waves again. When two waves meet, they interact with each other in a process called interference. If the crests and troughs of the two waves align, the waves are in phase and the interference will result in one wave with a larger amplitude than either of the original waves. However, if

the crests and troughs are out of alignment, the waves are out of phase and the resulting wave will have a smaller amplitude than the original waves — possibly even zero.

This is exactly what is happening with the solitons that seem to be bouncing away from each other. “Think of them as waves that can have a positive or negative amplitude. One of the solitons is positive while the other is negative, so they cancel one another,” Hulet explained. “The probability of them being in the spot where they meet is zero. They pass through that spot, but you never see them there.”

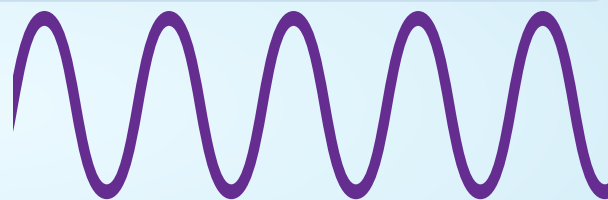
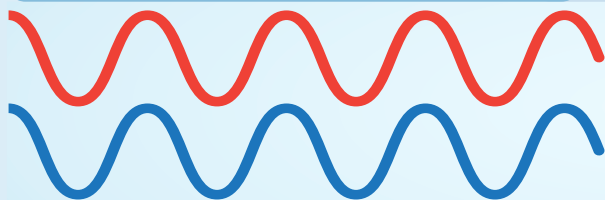
The group confirmed this was the case by devising a way to “tag” the individual solitons by making one larger than the other. “Where it appeared that they had been bouncing off of each other, we still saw the gap but we also saw the larger soliton emerge unfazed on the other side of the gap,” said Hulet. The out-of-phase solitons do, in fact, pass through one another; they only appear to bounce away from the collision.

Interesting things happen for in-phase soliton collisions in these experiments as well. In-phase solitons also undergo wave interference when they collide. In this case, the solitons are both positive, so instead of canceling each other out, they experience a huge density spike during a collision. The strength of this interaction is so large, that it sometimes results in annihilation of the solitons. The soliton pair implodes, the lithium atoms heat up, blow out of the track and are never seen again. Other times, in-phase soliton collisions result in a merger where only a single soliton persists after the collision. In contrast, out-of-phase collisions are robust and can survive more than 20 collisions without undergoing fusion or annihilation.

### WAVE INTERFERENCE

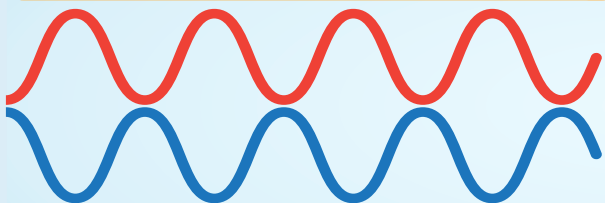
#### CONSTRUCTIVE INTERFERENCE › IN PHASE

Resulting amplitude is larger than either wave in the incident pair



#### DESTRUCTIVE INTERFERENCE › OUT OF PHASE

Resulting amplitude is zero compared to the incident pair

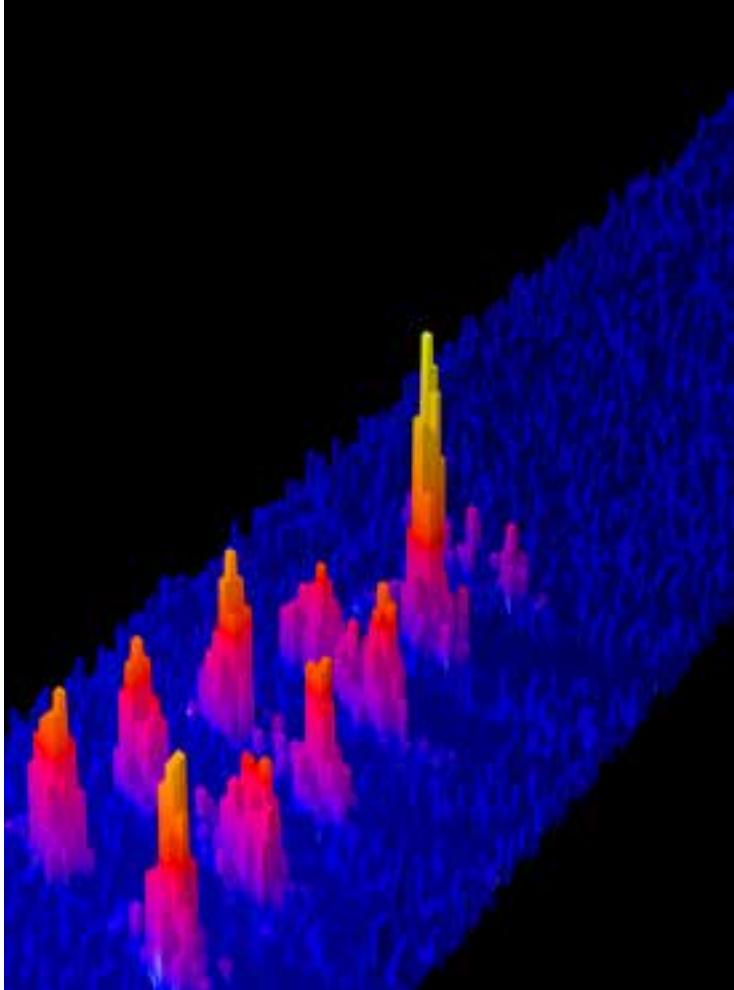


When two waves interact, they form a single resultant wave in a process called wave interference. The principle of superposition tells us that when two or more waves are present at the same point, the amplitude of the resultant wave is determined by adding the amplitudes of the incident waves.

When the crests and troughs of the incident waves are perfectly aligned, or in-phase, constructive interference occurs. The resultant wave has an amplitude that is larger than either incident wave.

When the crests of one incident wave perfectly align with the troughs of the second incident wave, or are out-of-phase, destructive interference occurs. The resultant wave has an amplitude of zero if the incident waves are exactly out-of-phase.

If the difference between phases is somewhere between perfectly in-phase and perfectly out-of-phase, the resultant wave will have an amplitude that is the sum of the amplitudes of the incident waves, which will fall between these maximum and minimum values.

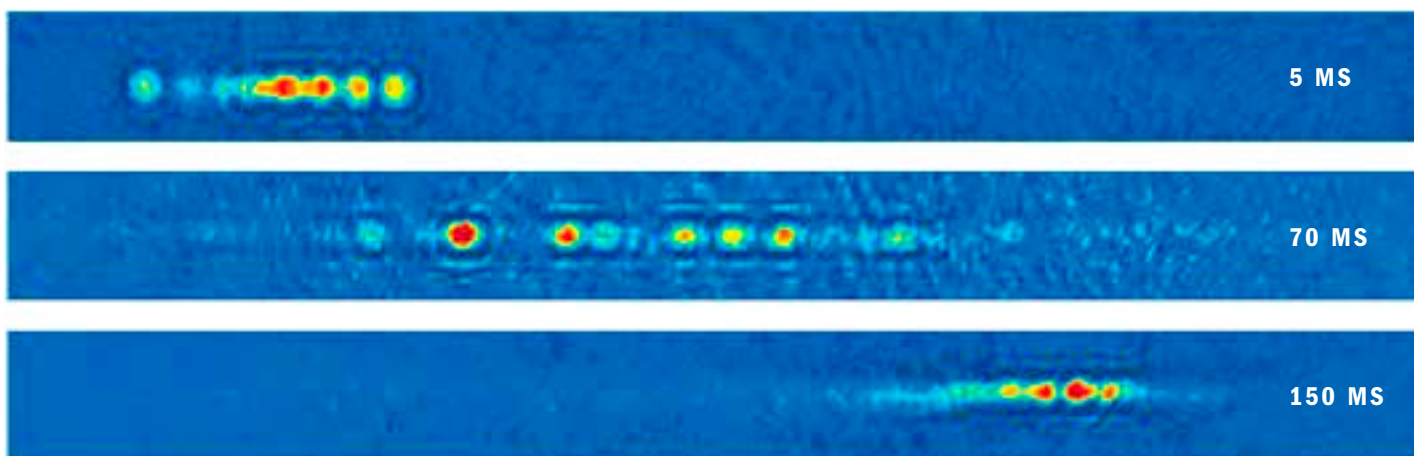


A collision of two in-phase matter wave solitons results in their annihilation. This collection of time-lapse images follows the collision and annihilation from start to finish (left to right). During the collision, the density exceeds a critical value, precipitating the implosion of the soliton pair. Hot remnants can be seen immediately following the implosion.

Phase also turns out to play an essential role in the stability of soliton trains, groups of up to 15 solitons lined up end-to-end that persist for several seconds — a very long lifetime for a matter wave soliton. In early experiments, Hulet's team was surprised to find repulsive interactions between adjacent solitons: the solitons spread out at the bottom of the parabolic track and bunched back up at the top. It turned out that adjoining solitons were out-of-phase and their interference produced this short-range repulsive force between them.

Hulet's group found that soliton trains always have an alternating positive-negative-positive-negative phase structure, but they didn't know why. Do soliton trains form with this alternating phase structure in place or do they evolve into this structure through annihilations or mergers of in-phase neighbors? Recent follow-up experiments have provided an answer to this long-standing question: soliton trains are born with the alternating phase. Nondestructive imaging techniques that let Hulet's team watch the evolution of soliton trains over time showed that the solitons interact repulsively from the moment the soliton train first emerges. These repulsive interactions are a clear indication that the alternating phase structure is present from the very beginning.

Now, Hulet's group is working on making an interferometer



These three images show a soliton train near the two turning points and near the center of oscillation in the 1-D parabolic track. The solitons in the train are seen to bunch up at the turning points and spread out at the center of oscillation, which results from repulsive forces between neighboring solitons.

out of solitons. Interferometry involves splitting a wave — here a matter wave soliton — into two parts that travel a different path before being recombined at the detector having undergone different phase shifts on their individual paths. Using what they've learned about soliton interactions and collisions, this quantum atomic interferometer will provide the opportunity to further probe the borderline between the quantum and classical worlds.

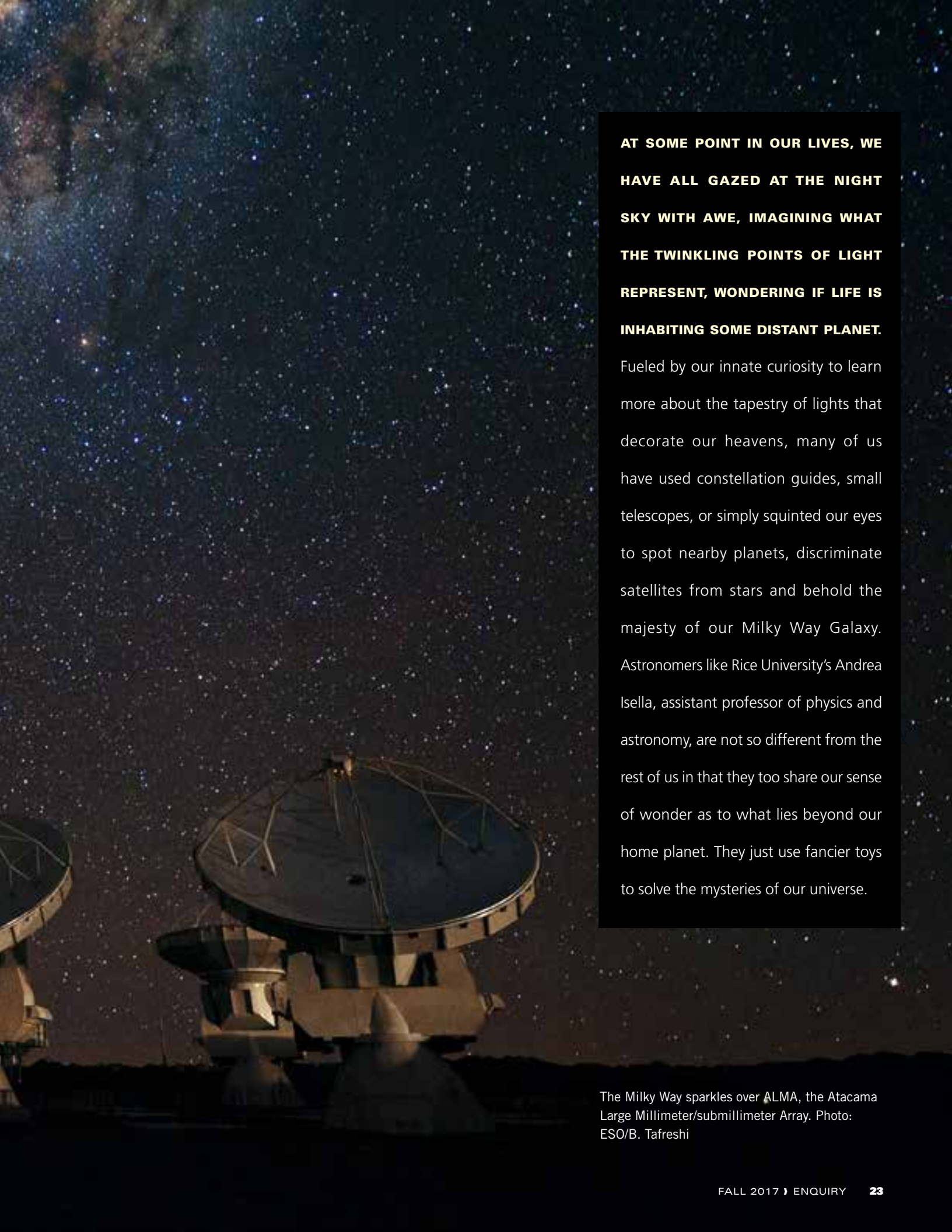
"Fifty years ago, no one imagined that lasers would be used to transmit information via an internet or scan our food at the grocery store checkout," said Hulet. "We're in a similar situation now. We're getting our first glimpses of a wondrous and sometimes surprising set of dynamical quantum phenomena, and there's no way to know exactly what may come of it." ■

# NASCENT SOLAR SYSTEMS

**REVEAL  
DETAILS OF  
PLANET  
FORMATION**

BY EVAN SHEGOG





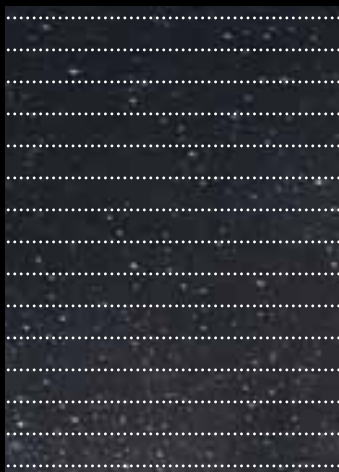
**AT SOME POINT IN OUR LIVES, WE  
HAVE ALL GAZED AT THE NIGHT  
SKY WITH AWE, IMAGINING WHAT  
THE TWINKLING POINTS OF LIGHT  
REPRESENT, WONDERING IF LIFE IS  
INHABITING SOME DISTANT PLANET.**

Fueled by our innate curiosity to learn more about the tapestry of lights that decorate our heavens, many of us have used constellation guides, small telescopes, or simply squinted our eyes to spot nearby planets, discriminate satellites from stars and behold the majesty of our Milky Way Galaxy. Astronomers like Rice University's Andrea ISELLA, assistant professor of physics and astronomy, are not so different from the rest of us in that they too share our sense of wonder as to what lies beyond our home planet. They just use fancier toys to solve the mysteries of our universe.

The Milky Way sparkles over ALMA, the Atacama Large Millimeter/submillimeter Array. Photo: ESO/B. Tafreshi



**“Currently, we are looking at stars forming about 500 light-years away from us. We are looking at these baby stars surrounded by donuts of gas and dust because it is in these disks where planets form.”**



For Isella, it was the Italian sky that sparked his passion to pursue a career in astronomy. He spent his childhood examining the moon with his rudimentary telescope, a simple optical lens that allowed for basic magnification. Yet, through this basic telescope, he was able to see the moon and stars in a way that he had never seen them before. This sparked his dream of one day becoming an astronomer. Isella went to school in Italy to study physics, astrophysics and applied physics and began to gain access to fancier toys. He was no longer using simple optical lenses to study the moon, but rather he was using sophisticated instruments to study planet formation.

As a postdoc at the California Institute of Technology, Isella had the opportunity to use a newly developed, large radio interferometer in his research. “Interferometry involves using multiple telescopes, and then combining the signals of all these telescopes to get a much sharper picture,” Isella said. “This new telescope gave us a new ability. With it, we began to take more detailed pictures of newborn stellar systems, looking for evidence of planet formation.” Technological advancements continued to improve telescopes that initially produced smudged images due to pixel size. As telescopes became better and better, pixel sizes shrank and images became more defined. With the aid of these improved instruments, Isella is now able to advance his own research at Rice, which is focused on the question of how planets form — and their potential habitability.

Astronomers cannot really use Earth as their only example when studying planet formation. “Since our solar system is 4.5 billions of years old, the surface of the Earth has been significantly reprocessed, so there is no real information present about its formation,” Isella said. As an alternative, astronomers examine other objects, such as meteorites. Even then it is important to keep in mind that for every piece of information that is gathered from the solar system, one has to extrapolate it back 4.5 billion years. To complement the evidence that Earth and meteorites can supply regarding planet formation, Isella studies planets that are forming in our universe right now.

When a new star forms, a gaseous disk surrounds it that may, under certain circumstances yet unknown, give rise to planets.

Small particles of dust and ice in this so-called protoplanetary disk interact and stick together, eventually forming aggregates that are thousands of kilometers in size. If the disk is big enough, runaway aggregations begin to form planets roughly the size of our moon. These newborn planets are difficult for astronomers to see because they are small, faint and embedded in the disk of dust and ice. Advances in instrumentation have only recently made it possible to observe planetary systems in the act of forming.

While Isella was observing the sky from California, an international project with a goal of mapping planet-forming systems was underway on a large plateau in the Atacama Desert of Northern Chile to construct the Atacama Large Millimeter/submillimeter Array (ALMA). ALMA consists of 66 12-meter and 7-meter diameter radio telescopes providing unprecedented opportunities to study star and planet formation. “These telescopes all operate using interferometry, and radio waves are used to measure mass, temperature and many other variables of distant objects,” Isella pointed out.

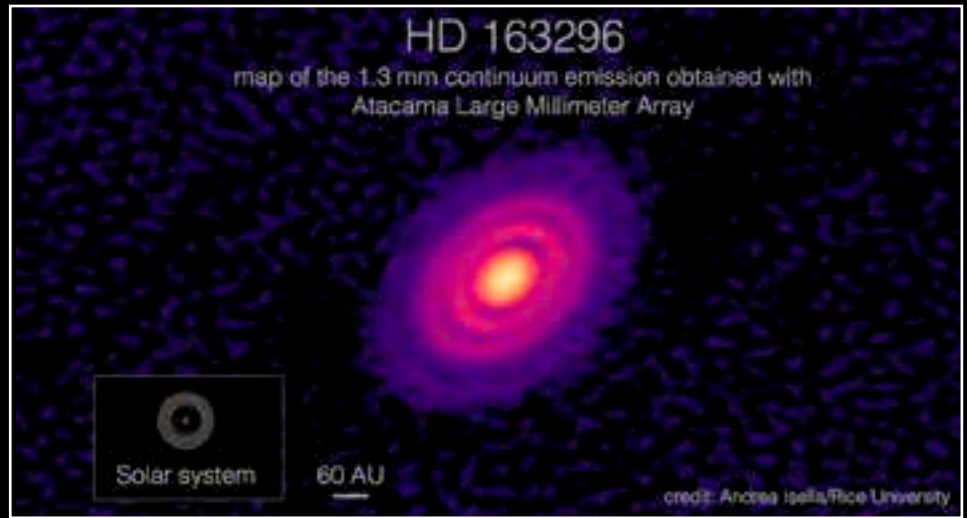
“Currently, we are looking at stars forming about 500 light-years away from us,” said Isella. “We are looking at these baby stars surrounded by donuts of gas and dust because it is in these disks where planets form. The disks are made from dust and gasses, such as hydrogen and carbon monoxide, which will eventually be inherited by the new planets.” Fortunately, from an observational standpoint, nature is such that carbon monoxide emits a lot of microwaves that in turn can be used to determine the density, temperature and velocity of gas. By studying the dust and gas in these disks, astronomers can infer the chemical composition of newborn planets and their implications for supporting life. This data in turn provides integral information regarding our own planet’s formation.

ALMA uses slightly different wavelengths of light to see dust and gas separately, which is an important tool for scientists hoping to decipher the mysteries of planet formation. Forming planets will suck up or push away all the materials around them, including both dust and gas, creating large voids in the protoplanetary disk. Turbulence within the disk, on the other hand, affects dust and gas in different ways. In order for sci-

entists to really know about the presence or absence of planets, they must be able to see both components.

Using ALMA, Isella and his team were able to image both the dust and gas in the disk surrounding a distant star at unprecedented resolution. Their images show three distinct gaps partially depleted of gas and dust in the disk surrounding the star HD 163296. The two outer gaps are equally depleted. Isella is confident that planets, probably two Saturn-sized gas giants, are responsible for sweeping these rings clear. Researchers do not yet know, however, what is creating the inner gap, which has far more carbon monoxide than the outer two. “The inner gap is mysterious. Whatever is creating the structure is removing the dust, but there’s still a lot of gas,” Isella said. HD163296 is a young star — just 5 million years old — and the planets causing the observed rings are still in formation. “You can think of this image as a picture of a baby solar system,” said Isella. “The analysis of these observations provides direct information about the physical processes related to the formation of planets.”

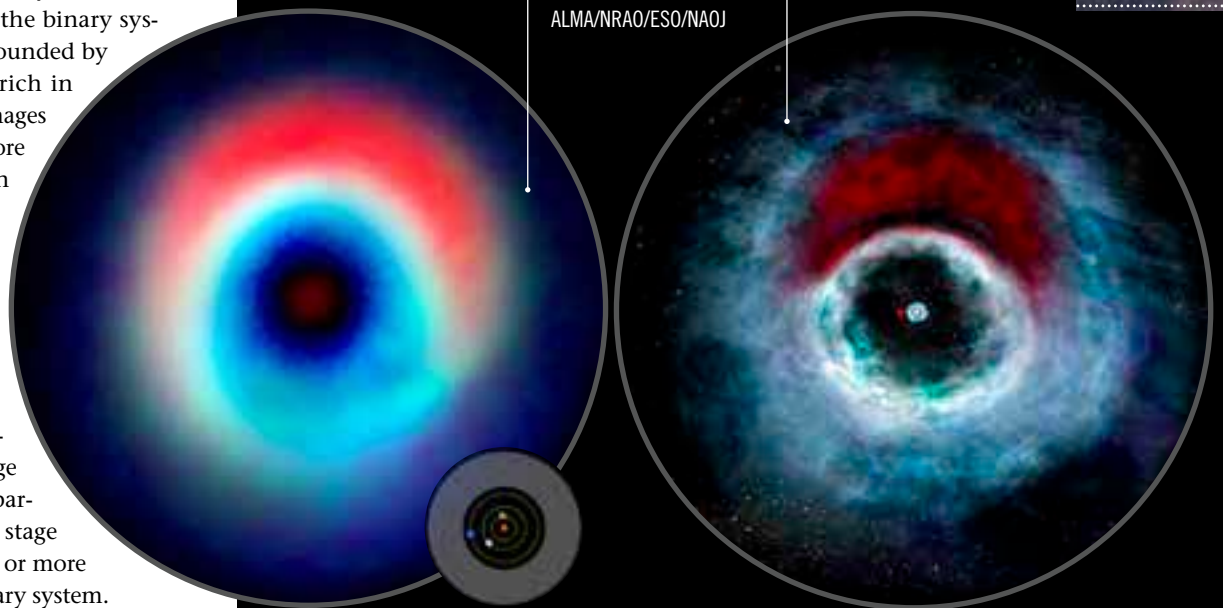
These same techniques have also made it possible to study something that until recently astronomers thought wouldn’t exist: planets in binary (two star) systems. “Previous thinking has concluded that planets would not form around binary systems, due to radical orbits, and unstable forces,” explained Isella. “Then people started to discover planets around binary stars, so clearly they had to tweak the theory.” Astronomers have long known that the binary system HD 142527 is surrounded by a protoplanetary disk rich in dust and gas, but new images from ALMA provided more detail for analysis than ever before. The images show a broad ring around the binary star and huge arc where the density of dust is largely enhanced compared to that of carbon monoxide molecules. Scientists believe that this large concentration of dust particles might be the first stage of the formation of one or more planets around this binary system.



**Above:** A composite image of the young star HD 163296. The inner pink area shows dust in the protoplanetary disk. The larger purple area shows the carbon monoxide in the system. The two outer gaps are free of both dust and gas, suggesting two planets are forming there. Photo: ALMA (ESO/NAOJ/NRAO); A. Isella; B. Saxton (NRAO/AUI/NSF)

**Below:** A composite image of the HD 142527 binary star system from data captured by the Atacama Large Millimeter/submillimeter Array shows a distinctive arc of dust (red) and a ring of carbon monoxide (blue and green). The red arc is free of gas, suggesting the carbon monoxide has “frozen out,” forming a layer of frost on the dust grains in that region. Astronomers speculate this frost provides a boost to planet formation. A representation of Earth’s solar system at bottom right is to scale. Image: Andrea Isella/Rice University; B. Saxton/NRAO/AUI/NSF; ALMA/NRAO/ESO/NAOJ

**Below:** An illustration shows the HD 142527 binary star system from data captured by the Atacama Large Millimeter/submillimeter Array. The red body orbiting the center represents the low-mass companion star. Image: B. Saxton/NRAO/AUI/NSF



**“Habitability is ultimately the driving force for looking at new planets and their formation.”**



Studying the properties of protoplanetary disks will take years to complete. However, a new space telescope is scheduled to launch in October 2018, and scientists hope that this successor to the Hubble telescope will expedite the process of discovery and provide much clearer images. “Habitability is ultimately the driving force for looking at new planets and their formation,” said Isella. Habitability is not just about the presence of water or other factors, but it is also about space physics, proximity to stars, and the magnetic sphere of the planet. “It is these properties that enable life,” he emphasized.

“We do not know how Earth was formed, we do not know how our solar system was formed, and we cannot explain the incredible diversity of life that our planet supports. There are, however, thousands of objects in the sky that we can observe and study that may shed some light on these fundamental questions,” concluded Isella. Peering into his favorite telescope, Isella is doing just that; he is looking up at the sky, searching for answers. ■



**(Top)** This famous Hubble visible-light snapshot, dubbed the Pillars of Creation, shows large columns of dust and gas in the Eagle Nebula. The dust obscures the view of the stars forming deep within these structures. **(Bottom)** Here, the same pillars are seen in infra-

red light, piercing through the dust and gas to show the baby stars forming within the pillars. NASA's new telescope will offer unprecedented sensitivity in the infrared range. Image: NASA, ESA/Hubble and the Hubble Heritage Team (STScI/AURA)



# Twenty Years Later:

## Carbon-Based Nanoscience Research at Rice

BY NICHOLAS ZAIBAQ



In November 2016, Rice celebrated the 20th anniversary of the Nobel Prize in chemistry awarded jointly to Robert F. Curl '54, Sir Harold W. Kroto and Richard E. Smalley for their discovery of fullerenes. Their discovery of C<sub>60</sub>, or buckminsterfullerene, changed the face of science and technology, pioneering the field of nanotechnology. Here, we first look back at their C<sub>60</sub> discovery and then highlight a few of the wide-ranging current Rice research efforts that trace their origins back to Curl, Kroto and Smalley's inspired work.

In C.S. Lewis's "The Lion, the Witch and the Wardrobe," Lucy finds the magical land of Narnia in the most unlikely of places: an old wardrobe. Lucy then brings her three siblings into Narnia, where the four of them have many grand adventures. Something similar happened at Rice, although no wardrobe was involved. Rice's Robert Curl and Richard Smalley and the University of Sussex's Harold Kroto discovered a new form of carbon and brought the rest of the scientific community along to investigate new problems as they helped launch the fields of nanoscience and nanotechnology.

The story begins in 1984 when chemists and friends Kroto and Curl saw each other at a conference. Curl, Rice's Kenneth S. Pitzer-Schlumberger Professor Emeritus of Natural Sciences, told Kroto of the recent results he and Smalley had generated using an apparatus of Smalley's design and construction. Dubbed AP2 (pronounced app-two), the instrument used an intense laser pulse to blast atoms off of a sample and then swept the clusters formed as the vaporized atoms cooled into a mass spectrometer for analysis.

Kroto wanted to use the instrument to study carbon chain molecules formed by stars. Smalley, however, was less interested in deviating from his ongoing work studying semiconductor clusters with Curl. A year later, Smalley finally agreed to give Kroto time on AP2. Kroto came to Rice to run his experiment with Curl, Smalley, and graduate students James Heath, Sean O'Brien and Yuan Liu.

The team (L-R) back in the 80s. Robert F. Curl (standing) Sean O'Brien, Richard E. Smalley, Harold W. Kroto and James Heath.

Within 10 days, the research team had all the data Kroto needed. They had found the carbon chain molecules Kroto was hoping to find. But, there was an unexplainable feature in their data.

"There was something peculiar about C60. It was almost like it said, 'Look at me,'" Curl recalled about seeing an unexpected peak in the mass spectrum, which showed the number of carbons in the molecules AP2 produced. They had found a previously unknown form of carbon, but what was the structure of these extremely stable 60 atom carbon clusters?

"A great deal of conversation ensued, and the conclusion was that the reason C60 was special was probably because it didn't have any dangling bonds that are easily attacked by other smaller carbon molecules," said Curl. "And so, we got to talking about Buckminster Fuller, because Fuller's structures [geodesic domes] looked like they might be made into something close, but we couldn't find the book to say exactly how that worked."

This led to individual brainstorming sessions among the teammates. Heath tried unsuccessfully to make a model from toothpicks



The Fuller dome in Montreal that researchers state as inspiration for the C60 structure.

and gumdrops. Kroto remembered making a star dome for his kids long ago, but couldn't remember exactly how it was made, although he was confident a similar structure could be the one they were looking for. Smalley turned to paper, scissors and tape, cutting up hexagons and pentagons and piecing them together, which naturally formed a sphere. Throughout these discussions, Curl's attention to detail stopped any conjectures from getting

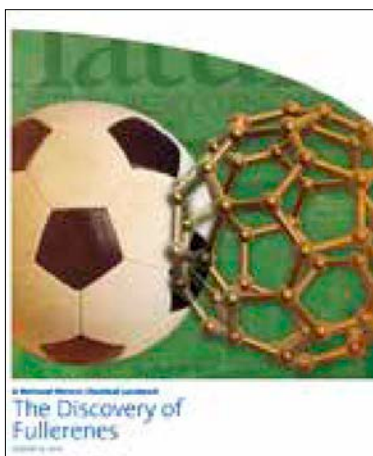
too wild. The following Monday — just one day before Kroto was set to return to England — the team met again, studied Smalley's paper soccer ball and spent the rest of the week writing a short publication to announce their findings. The rest is history.

Like Lucy in Lewis' novel, buckminsterfullerene opened the door to a vast, new, exciting world of science. The discovery led many scientists — both at Rice and around the world — to quickly convert their labs to focus on applications-based and fundamental research of C60 and other materials (such as carbon nanotubes and metal nanoparticles) that have unique properties at the nanoscale that are not present in larger samples.

Smalley began collaborating with other faculty on campus, including Bruce Weisman, professor of chemistry and of materials science and nanoengineering. "After the isolation of C60 [in mass quantities] in 1991, there was a great explosion of activity in this field," said Weisman. Smalley soon jumped from C60 research to carbon nanotubes — cylindrical fullerenes. "It was truly remark-

**"I could explain this to you in a number of ways, but what you've got there, boys, is a soccer ball."**

— William Veech



The American Chemical Society honored the discovery of fullerenes as a National Historic Chemical Landmark in 2010.

able. I'd never seen as many people in the scientific community drop what they were doing and work whole hog on fullerenes. But, Rick was able to turn on a dime. So, he decided no more fullerenes. He was just going to work on nanotubes," said Bruce Johnson, distinguished faculty fellow in chemistry.

One of the major projects Smalley championed was the Center for Nanoscale Science and Technology (CNST), now called the Smalley-Curl Institute. As the first university-based research institute dedicated to nanotechnology in the U.S., the CNST changed the research landscape at Rice. Lon Wilson, professor of chemistry, remembered that Rice was less collaborative before the C60 discovery. "There really was no central theme around which everyone could rally," Wilson said. "With the CNST, it was a way to unite everyone under a common tent." Nanotechnology was soon at the forefront of research in many areas of science and engineering. The original studies on fullerenes and carbon nanotubes are still being cited today, and Rice researchers are still very active in carbon-based nanoscience with Pulickel Ajayan, Matteo Pasquali and James Tour making significant contributions to the field in addition to those researchers whose work is featured here. "Rick had succeeded in making nanotechnology and nanoscience a force for Rice," said Johnson.

The discovery of C60 brought together people from different countries and disciplines, and it was aptly named not after a scientist, but an architect who was known for innovation. Current graduate students even borrowed the molecule's nickname for their annual winter formal — the Bucky Ball. In his Nobel lecture, Kroto eloquently summarized the effect of this new form of carbon that can still be seen today: "this elegant molecule with a charisma that has fascinated scientists, delighted lay people, and infected children with a new enthusiasm for science ... has given chemistry a new lease of life."

# 20 Twenty Years Later

## Carbon-Based Nanoscience Research at Rice

# TODAY

## Lon Wilson



Wilson recalls how he began working on fullerenes: "Rick Smalley went to everyone in the [chemistry] department with a vial of C60 and said, 'Here, do something interesting with this.'" Wilson did just that. "The first experiment we tried with the fullerene was simply looking at the electrochemical properties of C60," Wilson said. "We presented that work at the Electrochemical Society meeting that year, which est-

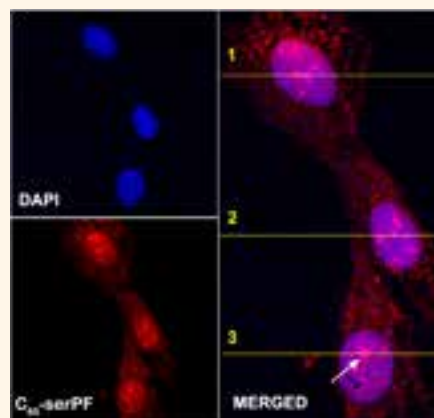
ablished a whole new symposium at the conference specifically for nanocarbons research."

A question from Wilson's first graduate student, who was working on gadolinium-based MRI contrast agents in industry, further influenced his decision to transition his research efforts to nanomaterials. "My former student asked, 'What would happen if you put a gadolinium ion inside a fullerene?' And I said, I have no idea," recalled Wilson.

His group has come a long way since then, shifting from bioinorganic chemistry to producing MRI and PET contrast agents using fullerenes and ultra-short carbon nanotubes. This method proved very fruitful, since encapsulating metal ions inside the nanoparticles greatly enhanced the contrast agent efficacy, out-performing all known

clinical agents by up to an order of magnitude.

Throughout much of his career, Wilson focused on introducing nanotechnology into the clinic. One landmark study showed that fullerenes synthesized in his lab could pass through all known biological barriers, including the blood brain



A nuclear stain (blue) and fluorescently-labeled fullerene (red) localize to the nucleus of liver cancer cells.

barrier, making C60 an attractive candidate for drug delivery applications. Recently, Wilson and his collaborators at Baylor College of Medicine, have been looking at how fullerenes move through the blood vessels in a tumor. Using a powerful microscope, they have imaged fullerenes in real time in a live mouse model. Due to its small size, C60 can exit "leaky" tumor blood vessels into cancerous tissue faster than it can exit from normal blood vessels, adding

to its potential as a platform for cancer drug delivery.

Despite fullerenes having been extensively studied for potential clinical applications, Wilson notes that graphene is carbon nanotechnology's new kid on the block. "Graphene has really taken over the carbon nanomaterials field, not so much for medicine and biology, but for solid state electronics, quantum computing and more," he said. Wilson also recognizes the importance of being adaptable with research projects, since so much is unknown at the start of an experiment. "In research you have to be willing to move the goal post, add new components, and see what happens, otherwise a field may not realize its full potential. Whether or not a new material will come along and challenge graphene, we have yet to see."



# Junichiro Kono



Ever since the inception of nanotechnology, it has been difficult to create large, centimeter-sized structures out of organized nanoparticles because of the millions of incredibly small particles that must be manipulated in a very specific way. This is a challenge because nanoparticles have very unique properties that only occur at that small scale, but scientists would like to incorporate these particles in larger devices, such as films or wafers, and retain their unique properties. Efforts to overcome this challenge

have drawn together a group of experimental physicists, material scientists and chemists led by Rice scientist Junichiro Kono.

Kono, professor of electrical and computer engineering, of physics and astronomy, and of materials science and nanoengineering, describes carbon nanotubes (CNTs) as fascinating objects, where a small change in the twist, or chirality, of the nanotube, drastically changes its electrical and optical properties. Sorting CNTs into unique sets of a single chirality has been a growing field in the realm of carbon materials research. Another area where progress has been made is in the global alignment of CNTs in the same direction, so that the individual anisotropic properties of CNTs can be maintained on a much larger scale. "Something people still haven't done, is to combine the two," said Kono. That is, to separate CNTs by chirality and then assemble them into a 3-D architecture of aligned nanotubes, all with the same unique property. "If we can do this, we are approaching the dream where we have a large single crystal of aligned nanotubes, consisting of just one chirality," he said. "Then you can prepare different crystals with different chiralities, and they all would have different properties."

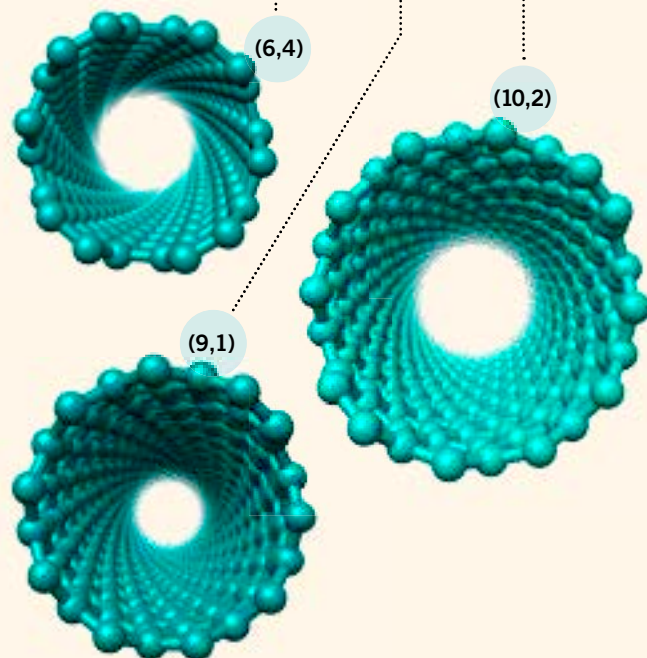
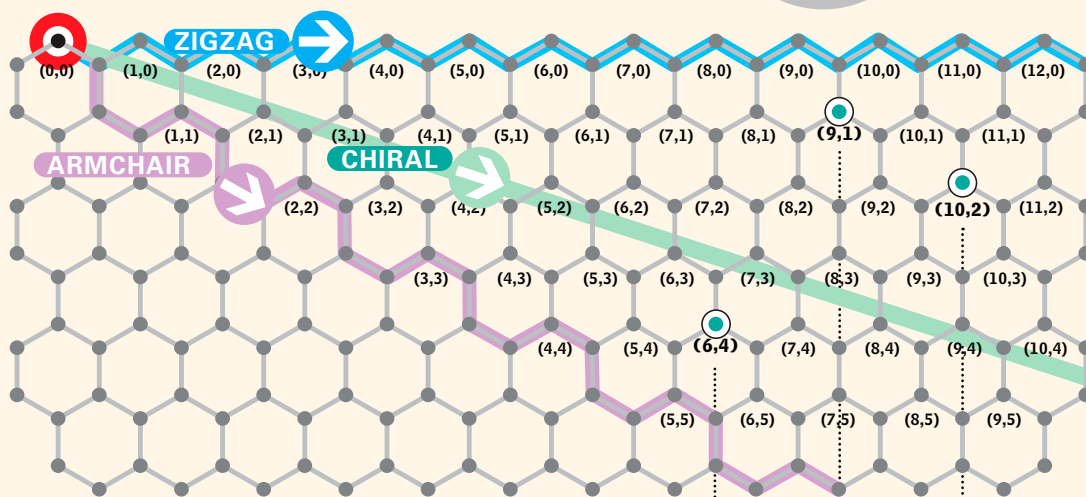
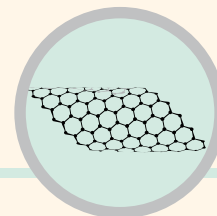
Recently, Kono and his colleagues have made a "giant step" toward this dream. Two researchers in his group made a fortunate mistake when preparing a CNT film. They found that a certain set of conditions led to the CNTs spontaneously aligning in a favorable pattern: the nanotubes were globally aligned and very densely packed, making them extremely stable. What's more is that almost all of the CNTs in the film were of the same chirality. These films have shown the highest degree of anisotropy in electrical conductivity and optical absorption of any reported macroscopic CNT sample.

Kono admits that the carbon nanotube community has decreased in size due to the rise of a variety of other families of nanomaterials, but he believes that there is still a number of outstanding problems and questions to be answered regarding the basic properties of interacting 1-D electrons in CNTs. "We are still working on CNTs very actively, both from fundamental and applied interests. We are also combining CNT films with other 2-D materials and making more complicated structures," he said. The challenge is that it is very difficult to control nanotubes and make high-purity samples more available, and while there are still basic issues to be solved, Kono is confident that CNT films can replace existing optoelectronic devices and become the material of the future.

**A carbon nanotube (CNT) is formed by rolling up a sheet of graphene.** Rolling the graphene up in different ways can form three different kinds of CNTs: armchair, zigzag or chiral.

To form a chiral CNT, the graphene is rolled so the red circle position lands on any of the atoms between the blue and purple lines.

The three sample images below show different chiral CNTs: (6,4), (9,1) and (10,2) illustrate what these different twists look like.



## Paul Cherukuri '08



"I was restless and curious," said Paul Cherukuri '08, the executive director of Rice's Institute for Biosciences and Bioengineering and former graduate student of Richard Smalley, when describing how his experiments with a home-built Tesla coil started. "I built the first version of this machine in my garage," he said. "It was a curiosity-driven, self-funded project that I worked on at night and on weekends. And only a handful of people believed it would actually work."

The goal of his experiment was to move matter remotely and make carbon nanotube wires using the electric field generated by a Tesla coil. Cherukuri and his team reported that nanotubes self-assemble into long wires in the presence of an electric field, at quite long distances from the instrument itself (> 30 cm). The self-assembled nanotube wires even acted as antennas that remotely lit LEDs in a small circuit. The team hopes their work will open the door to more research on remote-controlled assembly of nanomaterials and wireless energy. Cherukuri coined the term "Teslaphoresis" to describe the phenomenon, as a new word from Rice, just as his mentor Smalley coined the term "buckyball."

The hardest part of the project was not actually carrying out the experiments. "As scientists, that's what we're trained to do," Cherukuri said. "The trickiest part was communicating the results in such a way that it was clear and easily reproducible." He recalled Smalley teaching his students to do just that: to present the science clearly to allow others to reproduce and challenge it. Cherukuri was inspired by the clarity of the original buckyball publication, and described how when discovering something new, the report must be extremely compelling. His paper on Teslaphoresis is now one of the most read articles ever published by ACS Nano and is in the top 5 percent of all science related social media.

Another aspect of Smalley's legacy that Cherukuri cherishes and implemented in his study was how the project was student-driven and collaborative. "If I didn't have my amazing team, I don't think this would have been as interesting. I was incredibly fortunate to find intensely creative people at Rice that worked remarkably well together around an innovative idea," he said. That creativity is something that Cherukuri believes Rice fosters and encourages. But some of that innovative spirit within him comes from someplace other than Rice. "In the paper, I thanked my kids, Adam and John, as well as Bob Dylan. Both my children and Dylan's music kept me inspired to create something special," said Cherukuri. "And Rice is a very special place where you can do just that, which is why Teslaphoresis was born."



Nanotube-LED circuits self-assemble and are wirelessly powered under the influence of a directed electric field from a Tesla coil.



# Boris Yakobson

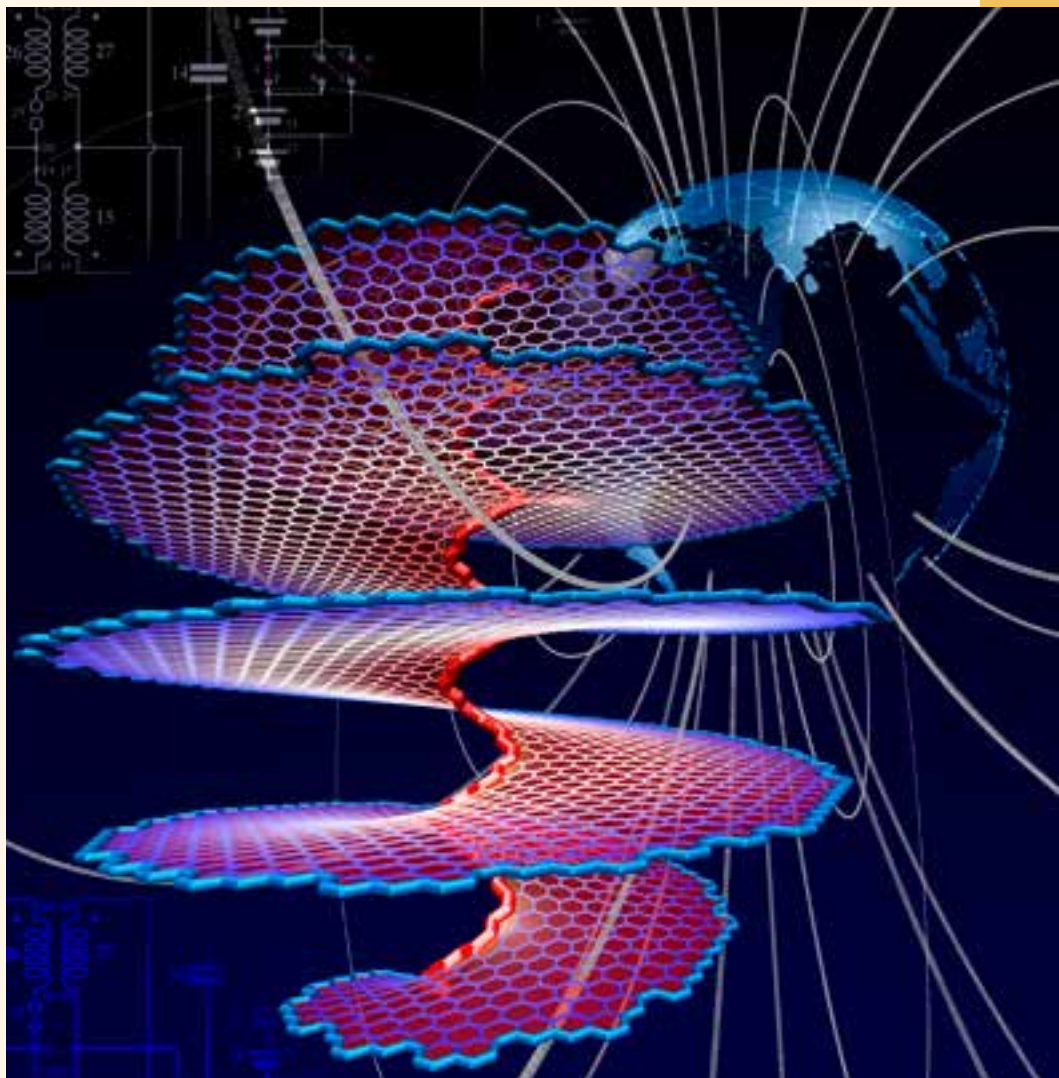


Boris Yakobson, Rice's Karl F. Hasselmann Professor of Materials Science and NanoEngineering and of Chemistry, has a black and white picture hanging in his office of a coal miner that was given to him as

a gift after a lecture in Kentucky. "It represents for me, old carbon and [this work] is new carbon, so it's old and new carbon together," he said. Embodying the theme of the photograph, a man digging deeper into carbon, Yakobson and his colleagues recently studied carbon nanoparticles found in common coal. The team focused on spirals of atom-thin graphene known as screw dislocations that occur naturally in anthracite, a type of coal with high carbon content.

The project began in collaboration with Ed Billups, professor emeritus of chemistry, who was analyzing anthracite samples and found screw dislocations. Yakobson and his team decided to study how these screw dislocations could pass current through the carbon-carbon bonds in a spiraling manner. "One of the challenges of this study," Yakobson said, "was determining how to terminate the edges [of the graphene] because the results would change depending on the shape of the edge." Another challenge was not just to study current, but also to quantitatively determine the magnetic field that is produced as a result of the current spiraling through the screw. Yakobson's computer models predict that the screws should produce a rather large magnetic field around 1 tesla, about the same as the coils found in a loudspeaker. The group believes these graphene screw dislocations could act as nanosolenoids and continue the large shift toward miniaturizing electronic devices.

Although he has ongoing projects with carbon nanotubes, graphene and carbon fibers, Yakobson is moving away from solenoids and from carbon in general — but he's not moving too far. "We have a lot of exciting work with boron [which is right next to carbon on the periodic table], for example, 1-D chains of boron, and we've done some recent work on boron fullerenes [atomic cages of boron, similar to the carbon fullerenes]," said Yakobson. But he is still excited to see what new things happen with carbon and he suggests that 1-D carbyne nanowires (atomic strings of carbon) may be the next material that spurs new discoveries. "Carbon will surprise you," he said.



If voltage is applied to graphene heli-coils, electrical current must flow helically. Near the center of the helix, this produces strong magnetic fields orders of magnitude greater than Earth's magnetic field. Image: E. S. Perv and H. Yu.



## Developing a Quantum Dot Tagging Method for Tadpoles

With climate change altering weather cues at an alarming rate, the timing of species' lifecycles has been shifted, potentially decoupling established predator-prey relationships. Shannon Carter, a Rice graduate student in the group of Volker Rudolf, associate professor of ecology and evolutionary biology, studies the interactions between tadpoles and their predators — salamanders and dragonflies — to quickly yet effectively predict how climate change is affecting these species' interactions so that appropriate conservation tactics may be applied.

To simulate predator-prey interactions, Carter creates artificial ponds. She introduces organisms to these experimental environments at different times and developmental stages to mimic conditions predicted under future climate scenarios. One challenge is the question of how to tag or mark each tadpole so that individuals can be distinguished from one another.

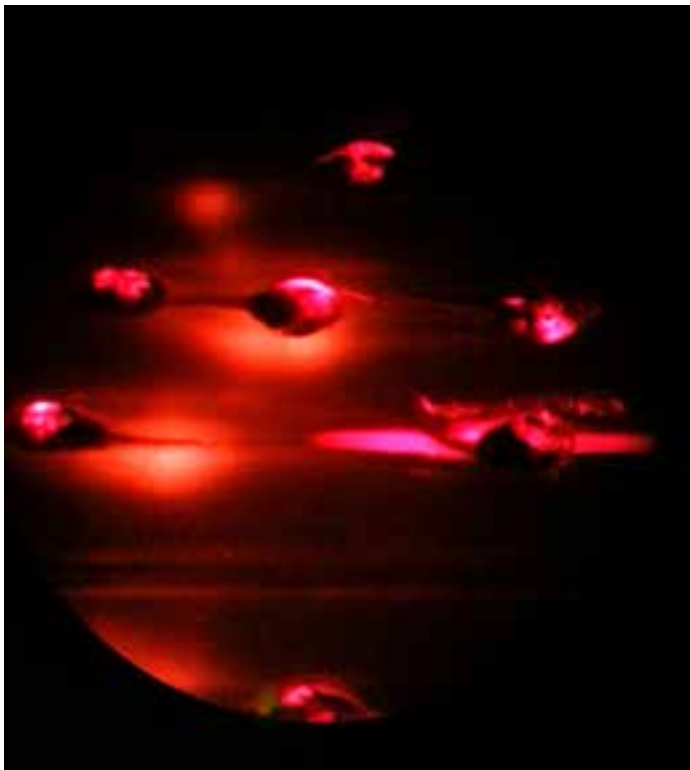
“We can conduct experiments without tagging the tadpoles individually,” Carter remarked, “but it is helpful to know exactly which tadpoles are exposed to which conditions. Tadpoles are especially challenging when it comes to tagging for several reasons: they are aquatic, delicate and metamorphose, all of which are factors that make traditional external tagging methods impractical.” Because of these limitations, she strove to find an internal tagging method that would allow her to distinguish tadpoles from one another without harming the tadpoles' development or fitness.

Carter found potential in biologically inert fluorescing particles known as quantum dots. Because of their minuscule size, spectrum of possible colors and resistance to fading under sunlight exposure, quantum dots would hypothetically be small enough to not have negative impacts on tadpole development and survival, yet

remain visible under UV light throughout the tadpoles' lifespans. Using microinjections to test the viability of quantum dots as a tag, Carter explored whether the tadpoles could withstand being injected with variable amounts of the particles. While the tadpoles survive the microinjection process, unfortunately the injected tadpoles have not yet survived for more than a few days.

Despite the momentary setback in finding an effective tadpole tagging method, Carter is not at all deterred from her principal goal of predicting how tadpole and predator populations will change and interact with one another in their altering natural environment. After all, there is so much more data to gather and analyze before these animals and the rest of their ecosystem can be effectively preserved. ■

— ELAINE HU



Tadpoles micro-injected with tiny volumes of fluorescent quantum dots have a normal appearance to the naked eye but glow brightly under a fluorescent microscope.

“Tadpoles are especially challenging when it comes to tagging for several reasons: they are aquatic, delicate and metamorphose, all of which are factors that make traditional external tagging methods impractical.”

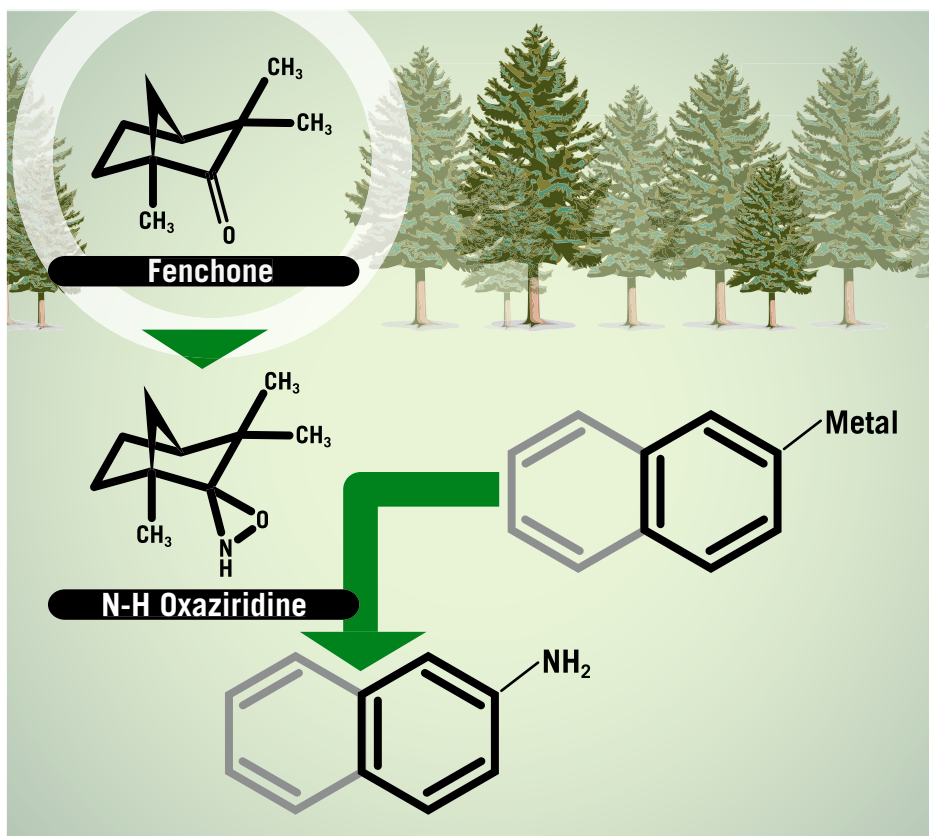
# A One-Step Process to Create Carbon-Nitrogen Bonds

"I take on projects most people think are impossible to achieve. We have failed many times, but if you're willing to take big risks, then you will be rewarded," László Kürti, associate professor of chemistry, said with a smile. His risks have paid off with his recent discovery of a way to create carbon-nitrogen (C-N) bonds (i.e., amination) without a catalyst in a single step starting from abundant aromatic Grignard reagents.

C-N bonds are prevalent in the pharmaceutical and agrochemical industries, especially aromatic amines (i.e., anilines) which are present in more than one-third of commercialized compounds. Given the widespread inclusion of nitrogen, there are surprisingly few ways to make the crucial C-N bonds.

To create anilines, an amine and an aromatic compound must react at high temperature usually in the presence of a toxic and often expensive transition metal catalyst. The product of such a reaction is usually contaminated with metal residue. Metal residue in agrochemicals can cause environmental damage and in pharmaceuticals can lead to harmful side effects for humans. Currently, multiple costly purification techniques are employed to remove transition metal contamination. Rather than changing the purification technique, Kürti wanted to remove the transition metal from the process of creating anilines altogether. At the outset, such a goal seemed unachievable, but Kürti didn't let that stop him. "If people think it won't work, that is the kind of problem I want to attack," he said.

The problem was how to preserve the integrity of strongly basic and moisture-sensitive Grignard reagents in amination reactions. Grignard reagents are often directly used to make C-C bonds, but very rarely for making C-N bonds. In attempts to create C-N bonds directly, the strongly basic Grignard reagents were found to deprotonate the acidic nitrogen source (i.e., the nitrogen-hydrogen bond) and were destroyed before amination could take place. Kürti approached this issue with a sterically congested NH-oxaziridine,



Scientists at Rice University and their colleagues have enabled the direct transfer of primary amino groups to arylmetals in a scalable and environmentally friendly fashion, meeting a formidable synthetic challenge.

a molecule in which oxygen, nitrogen, and carbon atoms are connected in a triangle. The steric bulk of the oxaziridine prevents Grignard reagents from deprotonating the N-H bond, allowing a direct substitution reaction on the oxaziridine nitrogen to create a C-N bond instead. This reaction is irreversible, cleaving a weak N-O bond that cannot be regenerated and creating a much stronger C-N bond in a single step. Kürti achieved the impossible, proving that C-N bonds can be created directly and efficiently with Grignard reagents.

Not only is this innovative process cheaper and simpler, but it is also environmentally friendly. Transition metal catalysts are nonrenewable, expensive and leave toxic residues in the products. The bulky NH-oxaziridine reagent is derived from naturally abundant terpenes that are produced by pine trees. Since Kürti's amination reaction produces a nontoxic

byproduct that is derived from a natural source, it will easily undergo biodegradation.

The implications for this discovery translate not just to the environment, but to the field of medicine. The current pharmaceutical chemist must create about 10,000 molecules in order to find one molecule that is effective. Kürti and his group serve as tool-makers, allowing chemists a cheaper, simpler way to create medicine-like molecules that contain these important C-N bonds.

Kürti hopes to expand the current amination method to create more complex substituted amines. Reflecting on his recent discovery, he said, "It is the initial key discovery in how to make C-N bonds in a simple way. Going forward, I want to translate this simplicity even further." ■

— AMANI RAMIZ

# Gas Sensors Yield Secrets of Soil Microbes

Soils are a key part of the environment that humans interact with daily. They are central to the generation of food and the purification of drinking water, and microbes within soil interact symbiotically with crops and degrade chemicals in soils that would otherwise pollute our environment.

Despite their ubiquitous presence in our everyday lives, the behavior of microbes within soil has been difficult to study as it is hard to image dynamic activity inside soil at the micron scale. A Rice University team led by biogeochemist Caroline Masiello, professor of earth, environmental and planetary sciences; biochemist Jonathan Silberg, associate professor of biosciences; and microbiologist George Bennett, the E. Dell Butcher Professor of Biochemistry and Cell Biology, has created a sensor system that allows them to “see” what microbial communities are doing within soils.

In many settings, green fluorescent protein (GFP) can be used to report on protein expression and other behaviors that could be occurring in a microbial population.

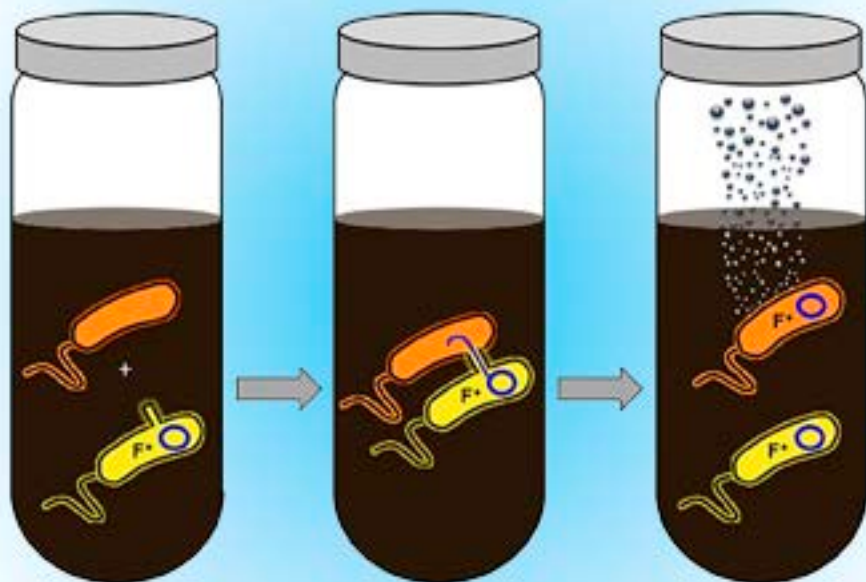
But, GFP has key limitations for use in monitoring soil systems. Specifically, GFP does not function in the oxygen-depleted conditions found in most soils, and its characteristic green color is not observable through the soil matrix. To overcome these issues in the lab, the research team programmed microbes to release low-activity gasses as a way of reporting on their various activities that occur within the soil. These new microbial tools are designed for use in the lab, and replace tedious, expensive mechanical approaches to detection of microbial behavior.

The researchers tested this new tool’s ability to study horizontal gene transfer, in which organisms transfer genetic information without having a parent-child relationship. “The process of horizontal gene transfer controls a lot of processes that are important to humans either because they are good — it’s how rhizobia trade the genes they need to fix nitrogen and support plant growth — or they’re bad — it’s how bacteria trade antibiotic resistance in soils,” said Masiello. The

team used synthetic biology to program microbes to release gasses whenever they underwent horizontal gene transfer. While previously, researchers were only able to evaluate the impacts of a given process on the microbial environment after disturbing the sample, this new tool allows researchers to look at changes occurring in the soil’s microbial communities in the lab in real-time, even in oxygen-depleted conditions.

Though this technology is just starting to be developed, the team hopes to apply it to better understand a wide host of phenomena, including antibiotic resistance, gene transfer in nutrient-deficient environments, microbial communication, and microbial response to osmotic stress. “There are other technologies that will build on this,” said Silberg. “Now we want higher-resolution information about other types of biological events by creating more sophisticated genetic programs using synthetic biology.” ■

— RISHI SURESH



Rice scientists programmed bacteria to serve as gas sensors to help them “see” into soil and learn about the behavior of the microbial communities within. When an engineered bacterium receives genetic information from another, it releases a gas to “report” the transaction. Image by: J. Silberg and S. Cheng

“The process of horizontal gene transfer controls a lot of things that are important to humans either because they are good — it’s how rhizobia trade the genes they need to fix nitrogen and support plant growth — or they’re bad — it’s how bacteria trade antibiotic resistance in soils.”

## Sex-specific Responses to Climate Change

Nestled high up in the Rocky Mountains, the wildflower *Valeriana edulis* has more scientific significance than first meets the eye. Using data dating back to the 1970s, Thomas Miller, the James and Deborah Godwin Assistant Professor of Ecology and Evolutionary Biology, and his fellow researchers examined how the changing sex ratio of this flower reflects the warming climate.

While some plants are hermaphroditic, *V. edulis* is a gendered species: some individuals carry stigmas while others carry anthers. This sex specificity meant that Miller and his fellow researchers could examine the sex characteristics of the plant. The major difference between genders is their spatial distribution: a proportionately greater number of females exist at higher elevations while males thrive at lower elevations.

With this in mind, the team began the challenging process of collecting data. Will Petry, formerly of the University of California at Irvine, spent months trekking through mountainous terrain to track around 2,500 *V. edulis* individuals. Once the data were collected, the team also had to ensure that it could be accurately compared to data from the 1970s. “We wanted to make a rigorous comparison. There were some tricky ways we had to approach the analysis,” Miller said.

By comparing data from the 1970s with more recent data, the team found that males are now present in greater numbers at higher elevations due to the climate becoming warmer and drier. “The big finding was that there have been changes in the sex ratio across time that parallel the changes that we see in space,” Miller said. The changing sex ratio of *V. edulis*, which is likely to continue given climate trends, gives rise to concerns of climate change disrupting species and entire ecosystems.

While the shift in *V. edulis*'s gender ratio is problematic, it also presents a promising way to more quickly track climate change. Studying a population's change in trait characteristics instead of its change in habitat location could allow scientists to



**Left:** A female valerian plant growing at an elevation of 3,790 meters where 75 percent of all individual plants are female. **Right:** A male valerian plant growing at an elevation of 3,790 meters. The occurrence of male plants at higher elevation has increased as conditions become hotter and drier. Photos: W. Petry

“The big finding was that there have been changes in the sex ratio across time that parallel the changes that we see in space,”

detect the effects of climate change earlier. “These compositional changes are more subtle. I hope that more people will start to look at the subtleties of not just tracking where species are but what types of individuals are there,” Miller said. In the future, other characteristics such as size and age of the individuals could be used to track how climate change is affecting various populations. ■

— NATALIE DANCKERS

# New Tools Join Breast Cancer Fight

An international team, including José Onuchic, Rice's Harry C. and Olga K. Wiess Chair of Physics and co-director of the Center for Theoretical Biological Physics, and Rice postdoc Fang Bai has discovered a way to fight the overexpression of a protein associated with the proliferation of breast cancer. Dialing down the level of the protein NAF-1 and the activity of the iron-sulfur clusters it transports may be key to halting tumor growth.

The researchers suggest a drug that is typically used to treat type 2 diabetes, pioglitazone, has proven effective at controlling NAF-1 levels. They also discovered that a single mutation to NAF-1 almost completely blocked the ability of cancer cells to proliferate, a result they said supports the idea that lowering NAF-1 expression can help stop tumors.

NAF-1 is a member of the NEET family of proteins; these proteins transport clusters of iron and sulfur molecules inside cells. The clusters help regulate processes in cells by controlling reduction-oxidation (redox) and metabolic activity. They naturally adhere to the outer surface of the mitochondria, the "power plant" that supplies cells with chemical energy.

Experiments demonstrated that the overexpression of NAF-1 in breast cancer tumors enhanced cancer cells' ability to tolerate oxidative stress. That enhancement allowed the tumors to become much larger and more aggressive.

Treating tumors with pioglitazone stabilized the iron-sulfur clusters in NAF-1, reducing the tumors' tolerance to oxidation. The team also discovered that expression of an NAF-1 protein that carried a single point mutation had a similarly toxic effect on cancer cells and prevented tumor proliferation.

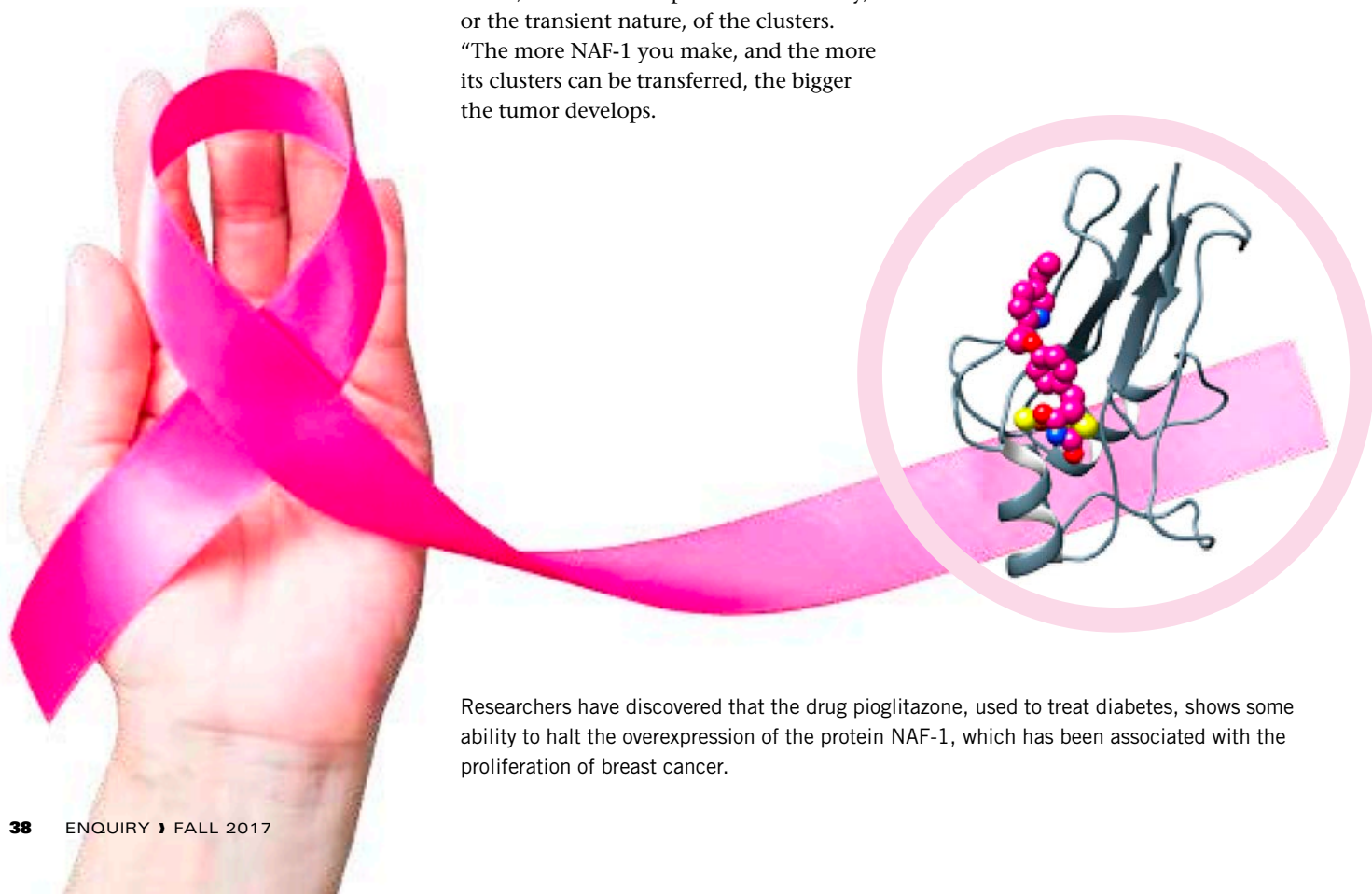
Study co-author Rachel Nechushtai, a professor at the Hebrew University of Jerusalem, said tumors depend on the lability, or the transient nature, of the clusters. "The more NAF-1 you make, and the more its clusters can be transferred, the bigger the tumor develops.

"We knew from previous studies that pioglitazone stabilizes the cluster. With the mutant, we hardly got any tumors and didn't see angiogenesis (the process through which new blood vessels form). We thought, 'How do we connect this to the clinics?' The only connection was to try a drug that, like the mutation, also stabilizes the cluster," she said. "Fang showed in her simulations where the binding site is and why the drug stabilizes the cluster."

"This is where the initial results from Fang are very nice, because she can show exactly how to modify the drug," said Onuchic. "That way, one can computationally design the drug before trying to make the real drug. It's a much less expensive way to come up with possibilities."

Bai said, "We can design selective drugs that only bind to NAF-1 and not to other proteins to reduce their side effects." ■

— MIKE WILLIAMS



Researchers have discovered that the drug pioglitazone, used to treat diabetes, shows some ability to halt the overexpression of the protein NAF-1, which has been associated with the proliferation of breast cancer.



# UNDERGRADUATE RESEARCH

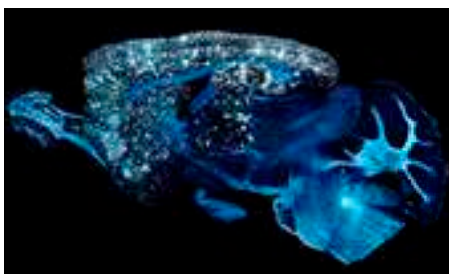
## The Unexpected Intersection of Art and Science

Kira Chen '19 is huddled over a large, white microscope. She is seated at a typical lab desk, orderly and clean. On the surface, there is nothing unique about this image. Chen could be at any lab space in the world, but what makes this one special is what she is looking at. Peering into the ocular lens, Chen is analyzing something incredible: a web of neurons. Thanks to high-powered fluorescence microscopes, scientists are now able to view webs of neurons and image whole planes of a sample layer by layer. Chen uses this type of microscope to image neurons stained with green fluorescent proteins, which light up when a certain cell expresses a desired trait. This results in a beautiful image: what looks like neon roots of a tree system, spreading out and all interconnected.

Chen works with Joanna Jankowsky in the Department of Neuroscience at Baylor College of Medicine, focusing on the pathogenesis of Alzheimer's disease, the major cause of dementia in middle-aged and elderly people. Jankowsky's group studies the onset and progression of Alzheimer's disease and explores possible therapeutic treatments. They use mice as a model system to reproduce certain symptoms of the disease in order to better understand the underlying biology of Alzheimer's disease.

Amyloid plaques, one of the hallmarks of Alzheimer's disease, are formed when amyloid- $\beta$  peptides clump together, effectively blocking synapses and impairing neuron connections. As part of Jankowsky's group, Chen is helping to determine how amyloid- $\beta$  leads to the cognitive decline of Alzheimer's disease. One of Chen's main tasks is producing images of mouse brain slices where amyloid plaques are present. After being treated with different compounds, the parts of the mouse brain that accumulate amyloid plaque glow due to the activation of green fluorescent dyes. Chen uses a microscope to focus on different parts of the brain affected by amyloid and produces images for display and further study.

It was a serendipitous turn of events



High density (top) and low density (bottom) amyloid plaques in silver stained mouse brain, sagittal cut. Courtesy of the Jankowsky Laboratory, Baylor College of Medicine.

that led to Chen working in this lab. "When I originally applied [for a lab position], the project description was about worms," Chen said. She and another applicant were the top two choices for the spot. In order to work with both students, Chen was instead given this project working with mice. "When I was in high school," she said, "Alzheimer's disease was always one of the topics I wanted to research. So it's really cool that I get to do something that my high school self wanted to do."

This newly assigned project proved to be an especially good fit for Chen, who has been interested in the arts since high school and is pursuing a double major in biological sciences and visual and dramatic arts. As a premed student, she has struggled at times to find the balance between taking art classes and remaining a competitive STEM student. With her research in the Jankowsky Lab, she managed to find a project that combined her love of art and her passion for science.

In Chen's work, art and science meet both in the imaging of expressive neural webs and in the communication of the importance of her research. "[The intersec-

Kira Chen '19



tion is] most obvious in the microscopy images part of my research. It's also apparent when you publish your research. Not only are you actually publishing the hard results, but the way you talk about the results and present the data — the images, graphs, and diagrams you use — you need to make sure it communicates what you want it to."

Chen plans to continue conducting research with Jankowsky during her remaining years at Rice and hopes to attend medical school. She is overjoyed that she is contributing to the work being done to understand Alzheimer's disease. This, combined with the sense of family she finds in the lab, provides an experience Chen greatly enjoys. Of her future in the lab, she said, "It's not just the research I'm doing but the people I'm doing it with that makes me want to stay in this lab." ■

— JACKSON STILES

## Helping an Award-Winning Chef Support Local Farms

When Tareck Haykal '19 first signed up for his laboratory courses as a freshman, he had no idea that it would be the start of a partnership with Chris Shepherd, the James Beard award-winning chef and owner of the Houston restaurant Underbelly. The restaurant's mission is to translate the diverse culture of Houston into food by sponsoring local farms, typically buying out their produce for use in the restaurant. To prevent waste, any surplus is converted into functional products. One method is to ferment extra grapes and pears into alcohol and then convert them into vinegar.

Underbelly tried to produce vinegar through spontaneous acetification, which involves storing large vats of wine in wooden crates and waiting for natural cultures of bacteria within the wine to turn the wine into vinegar. However, this method was not only slow and inefficient, it also failed to produce a satisfactory vinegar taste even though the alcohol had clearly converted to acid. Shepherd and Rice lecturers Sandra Bishnoi and Michelle Gilbertson encouraged students in Natural Sciences 120 and honors general chemistry to investigate this problem.

Haykal's group was tasked with unraveling this mystery and providing an alternative method of producing vinegar. They first learned how the alcohol in wine is oxidized into acetic acid, a key component of the acidity and taste of vinegar, through the metabolic processes of an acetic acid bacteria, *Acetobacter*. "We looked at the alcohol, acidity and sugar," said Haykal. "We found that their vinegars are extremely alcoholic, more than the average wine." This implied that there were no bacteria to convert the alcohol into acetic acid. After nearly a semester of hard work, they had a breakthrough. They found that the acidity obtained through the Underbelly production method was not acetic acid, but rather lactic acid, a waste product of bacterial fermentation that imparts the spoiled flavor of sour milk. The students found that the simple addition of mother



Meeting to discuss the findings are, from left, Underbelly owner and chef Chris Shepherd, Rice lecturers Michelle Gilbertson and Sandra Bishnoi, Tareck Haykal '19 and Underbelly cook Chris Bednorz.

of vinegar, which contains the needed *Acetobacter*, increases the amount of acetic acid in as little as two weeks.

Haykal made so much progress during the year that he was invited to continue working on the project as an Underbelly employee during the summer. Under Shepherd's guidance, he quickly learned to navigate the restaurant, managing his own timeline and learning real-world skills that can be applied to any profession. "I worked from an office right inside the kitchen, next to the chefs and sous chefs." Haykal said. "I was doing the same procedures [as in a traditional lab setting], but the feel of it was different. I got to study science in an environment I really enjoyed."

Haykal hopes others recognize the broader applications of Underbelly's projects beyond the creation of fine food. Through Shepherd, Underbelly has been a huge driving force of the local econo-

my for years by buying massive amounts of food locally. He gives this food right back to the community, first adding value through his renowned cooking to foster a sense of communal warmth. "There is a lot of potential for [the vinegar] project," Haykal said. "It aims to give waste purpose and bring these items with new value to areas where people do not have access to food." This philosophy of maximum utility provides an important social contribution to Houston.

For Haykal, this is what makes Underbelly unique. "I was immersed in this collaborative environment that had such energy and passion, making something to meet a concrete goal that had a true impact [on the community]," he said. "It was impossible not to dream bigger." ■

— SAMANTHA CHAO

# Contributed From Catalyst

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# G M O



## HOW SAFE IS OUR FOOD? BY ANU DWARUMPUDI

For thousands of years, humans have genetically enhanced other living beings through the practice of selective breeding. Sweet corn and seedless watermelons at local grocery stores as well as purebred dogs at the park are all examples of how humans have selectively enhanced desirable traits in other living creatures. In his 1859 book *On the Origin of Species*, Charles Darwin discussed how selective breeding by humans had been successful in producing change over time. As technology improves, our ability to manipulate plants and other organisms by introducing new genes promises both new innovations and potential risks.

Genetically modified organisms (GMOs) are plants, animals, or microorganisms in which genetic material, such as DNA, has been artificially manipulated to produce a certain advantageous product. This recombinant genetic engineering allows certain chosen genes, even those from unassociated species, to be transplanted from one organism into another.<sup>1</sup> Genetically modified crops are usually utilized to yield an increased level of crop production and to introduce resistance against diseases. Virus resistance makes plants less susceptible to diseases caused by insects and viruses, resulting in higher crop yields.

Genetic enhancement has improved beyond selective breeding as gene transfer technology has become capable of directly altering genomic sequences. Using a “cut and paste” mechanism, a desired gene can be isolated from a target organism via restriction enzymes and then inserted into a bacterial host using DNA ligase. Once the new gene is introduced, the cells with the inserted DNA

(known as “recombinant” DNA) can be bred to generate an advanced strain that can be further replicated to produce the desired gene product.<sup>1</sup> Due to this genetic engineering process, researchers have been able to produce synthetic insect-resistant tomatoes, corn, and potatoes. Humans’ ability to modify crops has improved yields and nutrients in a given environment, becoming the keystone of modern agriculture.<sup>2</sup> Despite these positive developments, skepticism still exists regarding

## GMO: PLANT, ANIMAL OR MICROORGANISM IN WHICH GENETIC MATERIAL, SUCH AS DNA, HAS BEEN ARTIFICIALLY MANIPULATED TO PRODUCE A CERTAIN ADVANTAGEOUS PRODUCT

the safety and societal impact of GMOs. The technological advancement from selective breeding to genetic engineering has opened up a plethora of possibilities for the future of food. As scientific capabilities expand, ethics and ideals surrounding the invasive nature of the production of GMOs have given rise to concerns about safety and long-term impacts. According to the Center for Food Safety, GMO seeds are used in 90 percent of corn, soybeans, and cotton grown in the United States.<sup>2</sup> Because GMO crops are so prevalent, any negative ecological interactions involving a

GMO product could prove devastating for the environment.

While the dangers of genetic modification are being considered, genetic engineering has proven to have benefits to human health and the farming industry. Genetically modified foods maintain a longer shelf life, which allows for the safe transport of surplus foodstuffs to people in countries without access to nutrition-rich foods. Genetic engineering has supplemented staple crops with vital minerals and nutrients, helping fight worldwide malnutrition. For example, Golden rice is a genetically-modified variant of rice that biosynthesizes beta-carotene, a precursor of vitamin A.<sup>3</sup> This type of rice is intended to be produced and consumed in areas with a shortage of dietary vitamin A, which is a deficiency that kills 670,000 children each year. Despite the controversial risks, genetic engineering of crops promises to continually increase the availability and durability of food.

### WORKS CITED

- [1] Learn.Genetics. <http://learn.genetics.utah.edu/content/science/gmfoods/> (accessed Sep 20, 2016)
- [2] Fernandez-Cornejo, Jorge, and Seth James Wechsler. USDA ERS – Adoption of Genetically Engineered Crops in the U.S.: Recent Trends in GE Adoption. USDA ERS – Adoption of Genetically Engineered Crops in the U.S.: Recent Trends in GE Adoption. <https://www.ers.usda.gov/data-products/adoption-of-genetically-engineered-crops-in-the-us/recent-trends-in-ge-adoption.aspx> (accessed Sep 30, 2016)
- [3] Dan Charles. In A Grain Of Golden Rice, A World Of Controversy Over GMO Foods. <http://www.npr.org/sections/thesalt/2013/03/07/173611461/in-a-grain-of-golden-rice-a-world-of-controversy-over-gmo-foods> (accessed Sep 24, 2016)

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## HIGHLIGHT

### Big Thicket BioBlitz Tracks Biodiversity

The Io moth caterpillar is well-known for its stinging spines that release venom with the slightest touch. This caterpillar is one of the 856 species identified during a two daylong BioBlitz held at nearby Big Thicket National Preserve to identify as many species of plants, animals and other organisms as possible. The event was organized by the National Park Services to celebrate their centennial. More than 3,600 observations were identified and catalogued with the help of 26 trained taxonomists and 118 field hands, including several Rice biologists. The Big Thicket, often called the biological crossroads of North America, is home to an amazing diversity of life with more than 1,000 species of flowering plants and ferns — including 24 species of orchids and four species of carnivorous plants, 38 species of ants, 300 species of migratory and nesting birds, 13 species of crayfish and all four groups of North American venomous snakes. ■

— LAUREN KAPCHA