

The Magazine of the Wiess School of Natural Sciences at Rice University ▶ Fall 2016

ENQUIRY

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

A LETTER FROM THE DEAN



PETER J. ROSSKY
Dean, Wiess School of Natural Sciences

“WHILE EACH OF THESE NARRATIVES RELATES THE PROBLEMS THAT EACH TEAM OF SCIENTISTS IS STRIVING TO SOLVE, WE HOPE THAT THE INTENSE CURIOSITY THAT DRIVES EACH INDIVIDUAL TO EXPLORE THE UNKNOWN IN EACH CASE IS EQUALLY EVIDENT. THE GOAL AT THE HEART OF THE SCHOOL OF NATURAL SCIENCES IS DISCOVERY.”

Dear Friends,

I am proud to have the privilege of introducing the inaugural issue of ENQUIRY, the magazine of the Wiess School of Natural Sciences at Rice University. In the pages that follow, we feature stories of the science and of the amazing scientists that make up this exceptional school. While each of these narratives relates the problems that each team of scientists is striving to solve, we hope that the intense curiosity that drives each individual to explore the unknown in each case is equally evident. The goal at the heart of the School of Natural Sciences is discovery.

These stories span a truly remarkable breadth of new knowledge — from the smallest subatomic particles being hunted by our physicists at the Large Hadron Collider at CERN to the unfathomable distances spanning the Carina Nebula being explored by our team of astronomers, from the rigorous theory of “nearly periodic” solid materials, being explicated by our mathematicians, to the tangible impact of synthetic nanomaterials on the health of cardiac patients being advanced by our chemists.

To appreciate the global recognition of our faculty, I can simply recommend that you peruse the summary of accolades they have received in the past year, and to fully appreciate the current and future impact of our remarkable students, I invite you to take note of their intimate role in all of our research. In fact, our Rice students have also written most of these stories — and you should not miss the opportunity to read about our contributors!

All of the faculty, staff and students in the Wiess School join me in welcoming you to these pages and wish you a pleasant sojourn through these highlights.

Best wishes,

A handwritten signature in black ink, appearing to read 'Peter J. Rossky', written in a cursive style.

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.

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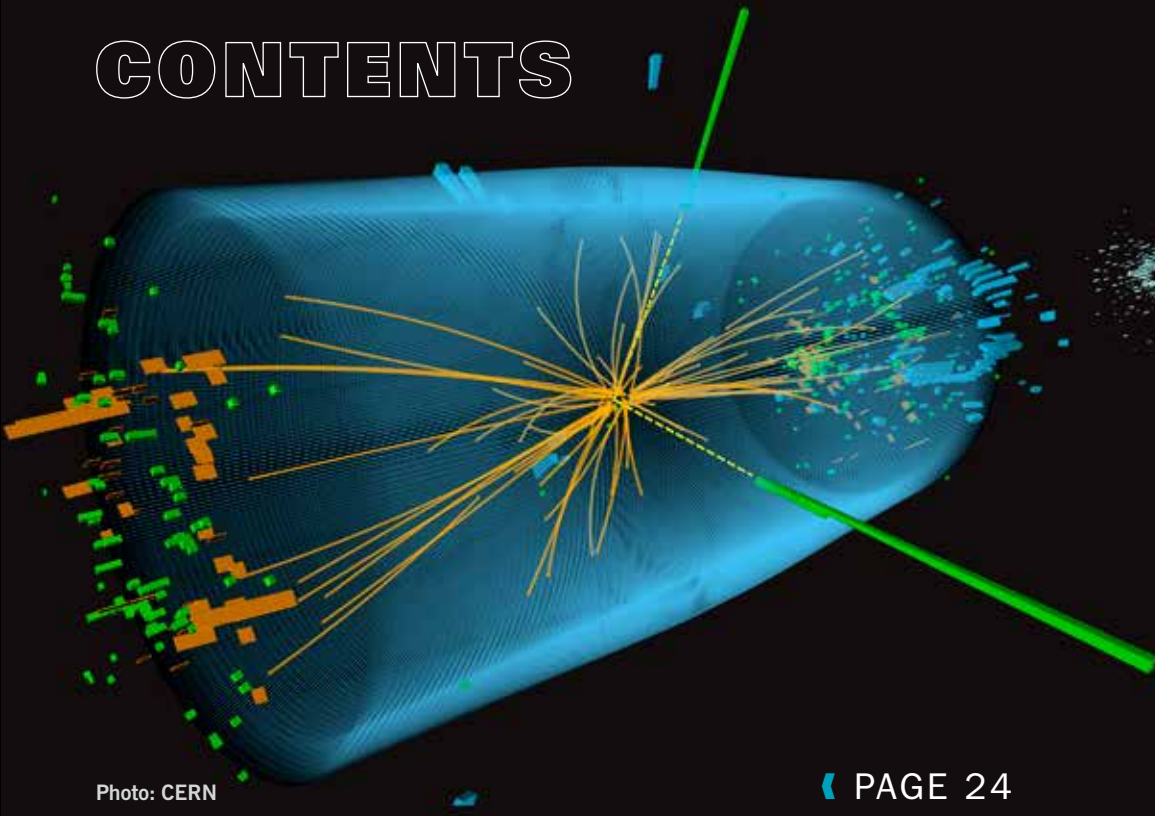


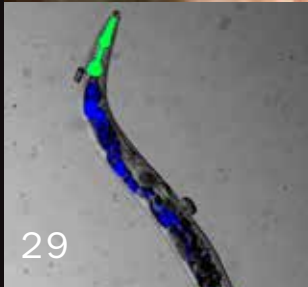
Photo: CERN

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Partnership Between Rice and Texas Children's Hospital Enables Exceptional Undergraduate Research ■ A Superposition of Outstanding Undergraduate Research and Excellent Teaching in Mathematics

On the cover: Super-resolution imaging of plasmonic structures is limited by the fact that plasmonic materials quench fluorescence when the dye is close to the particle's surface. To prevent quenching, gold nanowires are coated with a charged polymer layer. This false-colored image was originally obtained using a transmission electron microscope and captures one failure in the coating process. Here, the polyelectrolyte ignores the nanowire (black) and forms a nanowave instead (blue).

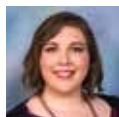
CONTRIBUTORS



NATALIE DANCKERS '17
("A High-Throughput, Low-Cost System for Testing Nanoparticle Toxicity") is a senior psychology and English double major with a business minor at Baker College. Science literacy is extremely important to Danckers, who believes that research should be accessible to everyone, regardless of their scientific background. She is an editor for Catalyst.



CHRISTOPHER HICKS '19
("The Rice Electron Microscopy Center Provides a New Perspective on Physical Science") is a sophomore at Baker College, majoring in biochemistry and cell biology. He is a writer for Catalyst and hopes to attend medical school. Hicks enjoys traveling and photography.



ANNELI HOGGARD is a fifth-year graduate student, pursuing a Ph.D. in chemistry under the supervision of Stephan Link. Hoggard's winning submission from Rice's inaugural Natural Sciences Image Contest is featured on the front cover of this issue. She enjoys creative ventures ranging from jewelry making to web design and communicating science via illustration. Hoggard also designed images for the feature, "Chemistry Duo Puts Nanoparticles Through Their Paces."



JAMES MCCREARY '16
("A Breakthrough Magnetic Material Made of Nonmagnetic Constituents") graduated this past May with a B.S. in chemical engineering. As an undergraduate, he was a writer for Catalyst. A lifelong athlete, McCreary was a member of the cross-country and track and field teams at Rice. A service-minded technology entrepreneur, he plans to design and deliver technologies that improve others' lives.



JANA OLSON '15
("A Superposition of Outstanding Undergraduate Research and Excellent Teaching in Mathematics") was the science writer for the Wiess School of Natural Sciences at Rice. She completed her Ph.D. in chemistry at Rice under the supervision of Stephan Link. Olson is passionate about accuracy, clarity and transparency in science communication.



TEJUS SATISH '18
("Carbon Nanotube Fibers Repair Hearts and Interface With Brains") is a junior at McMurry College, majoring in biochemistry and cell biology. He is an editor for Catalyst and recently won an award for his poster at the 2016 Rice Undergraduate Research Symposium. His hobbies include astronomy and astrophotography, and he plans to become a physician.



EVAN SHEGOG '18
("A Snapshot of One Rice Professor's Quest to Understand Our Universe") is a junior at Hanszen College, majoring in ecology and evolutionary biology. He is a writer for Catalyst, and his article on megafires is featured on the cover of the journal's current issue. Shegog also writes for the Rice Thresher, the official undergraduate newspaper at Rice, and is a member of Rice EMS.



ELAINE SHEN '18
("A Cautionary Tale: Protecting the World's Tropical Wildlife") is a junior, majoring in ecology and evolutionary biology at McMurry College. She is a writer for Catalyst, and her article on overfishing is featured on the cover of the journal's current issue. Shen is interested in marine biology, specifically fisheries management and the intersection of science and policy.



AJAY SUBRAMANIAN '18
is a junior 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
("Looking Deep Inside the Earth: Using Seismic Techniques to Map Subsurface Structures") is a senior cognitive sciences major at Lovett College. 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 is a writer for Catalyst.



TOM VANDENBOOM
("Almost-Periodicity and the Korteweg-de Vries Equation") is a graduate student, pursuing a Ph.D. in mathematics and anticipates graduating in May 2018. Outside of research, he enjoys music and plays the trombone in a local Houston jazz group.

*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



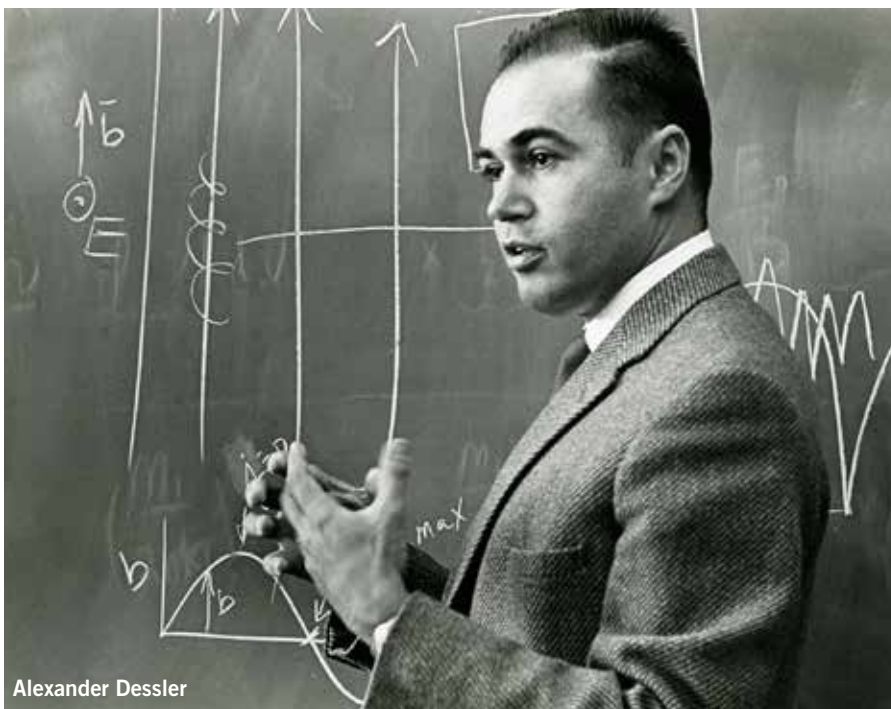
K.C. Nicolaou

WOLF PRIZE IN CHEMISTRY

K.C. Nicolaou, the Harry C. and Olga K. Wiess Chair of Chemistry, won the Wolf Prize in Chemistry in January. Nicolaou, who shares the prize with Harvard chemist Stuart Schreiber, was recognized “for advancing the field of chemical synthesis to the extremes of molecular complexity, linking structure and function and expanding our dominion over the interface of chemistry, biology and medicine.”

Nicolaou’s research specialty is total synthesis, an area of organic chemistry dedicated to the complete synthesis of nature’s most complex molecules. He is best known for publishing the first complete synthetic pathway to the natural substance taxol. Marketed as the chemotherapeutic drug paclitaxel, taxol is used to treat ovarian, breast, lung, pancreatic and other cancers and is on the World Health Organization’s List of Essential Medicines.

Since joining Rice’s faculty in 2013, Nicolaou and colleagues have achieved total syntheses of two complex antibiotics, viridicatumtoxin B and CJ-16,264, and several potential cancer-fighting agents, including shishijimicin A and trioxacarcins A, B and C. He also has developed a practical method for the synthesis of chemical building blocks that are widely used in drug discovery research and in the manufacture of drugs and dyes.



Alexander Dessler

NATIONAL ACADEMY OF SCIENCES ARCTOWSKI MEDAL

The National Academy of Sciences awarded the Arctowski Medal to **Alexander Dessler**, professor emeritus of space physics and astronomy, to honor his “notable imagination in framing many of space science’s most basic conceptions about the solar wind and interplanetary magnetic field and their interactions with the magnetospheres of Earth and other planets at the beginning of the Space Age.” During his tenure at Rice, Dessler founded the world’s first university department of space science and served as director of the Space Science Laboratory at NASA’s Marshall Space Flight Center for four years.

AMERICAN PHYSICAL SOCIETY DAVISSON-GERMER PRIZE



Randy Hulet

Randy Hulet, the Faye Sarofim Professor of Physics and Astronomy, was chosen to receive the Davison-Germer Prize in Atomic Physics by the American Physical Society. Hulet, a fellow of the American Physical Society, a fellow of the American Association for the Advancement of Science, and a member of the American Academy of

Arts and Sciences, was recognized for his “pioneering investigations of quantum degenerate gases and how they are affected by atomic interactions.”

WELCH FOUNDATION NORMAN HACKERMAN AWARD

The Welch Foundation presented **Stephan Link**, associate professor of chemistry and of electrical and computer engineering, its Norman Hackerman Award for his “groundbreaking contributions in plasmonic nanomaterials and recogniz[ing] his leadership, creativity and commitment to science as demonstrated through his research and teaching.” The Hackerman Award is named in honor of Norman Hackerman, Rice’s fourth president and a noted scientist and former longtime chairman of the Welch Foundation’s Scientific Advisory Board.



Stephan Link

SOCIETY OF EXPLORATION GEOPHYSICISTS MAURICE EWING MEDAL

The Society of Exploration Geophysicists (SEG) awarded **Manik Talwani** the Maurice Ewing Medal, the highest honor given by the SEG. Talwani, professor emeritus of advanced studies and research in earth science, received the award for developing 2- and 3-D gravity algorithms that are classics in the geophysical industry. Talwani earned his Ph.D. under the supervision of Maurice “Doc” Ewing himself, and this is his second medal awarded in honor of his mentor, having received the Maurice Ewing Medal from the American Geophysical Union in 1981.



Manik Talwani

AMERICAN SOCIETY FOR BIOCHEMISTRY AND MOLECULAR BIOLOGY

Kathleen Matthews, the Stewart Memorial Professor of Biochemistry and Cell Biology, received the American Society for Biochemistry and Molecular Biology’s William C. Rose Award.

NATIONAL SCIENCE FOUNDATION

The National Science Foundation named **Stephen Bradshaw**, the William J. Vietti Junior Chair of Physics and Astronomy, **László Kürti**, associate professor of chemistry, and **Aryeh Warmflash**, assistant professor of biosciences, as recipients of Early Career Awards.

John Calabrese, RTG Lovett instructor of mathematics, was awarded an NSF Mathematical Sciences Postdoctoral Fellowship.

HUMBOLDT FOUNDATION

The Alexander von Humboldt Foundation awarded **Gus Scuseria**, the Robert A. Welch Professor of Chemistry, professor of physics and astronomy, and professor of materials science and nanoengineering, a Humboldt Research Award in recognition of lifetime achievements in research. The foundation also awarded **Eugene Zubarev**, associate professor of chemistry and of materials science and nanoengineering, a Friedrich Wilhelm Bessel Research Award.

OPTICAL SOCIETY OF AMERICA

The Optical Society of America has awarded **Naomi Halas**, the Stanley C. Moore Professor of Electrical and Computer Engineering and professor of bioengineering, chemistry, physics and astronomy, and materials science and nanoengineering, and **Peter Nordlander**, professor of physics and astronomy, of electrical and computer engineering, and of materials science and nanoengineering, the R.W. Wood Prize for their groundbreaking work in nanophotonics.

KECK FOUNDATION

Rice University has received an award from the Keck Foundation, which funds projects that promise far-reaching benefits for humanity. The award supports the work of **Caroline Masiello**, professor of earth science, **Jonathan Silberg**, associate professor of biochemistry and cell biology and of bioengineering, **George Bennett**, the E. Dell

Butcher Professor of Biochemistry and Cell Biology, and **Matthew Bennett**, assistant professor of biochemistry and cell biology, in developing gas-releasing microbial sensors for the study of soil and marine life.

PRESIDENTIAL AWARD

Raymond Johnson '69, adjunct professor of mathematics, has been named as a recipient of the Presidential Award for Excellence in Science, Mathematics and Engineering Mentoring by President Barack Obama.

SCHOLARLY SOCIETIES

ACADEMY OF NUTRITION AND DIETETICS

Roberta Anding, lecturer of kinesiology, was elected a fellow of the Academy of Nutrition and Dietetics.

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

R. Bruce Weisman, professor of chemistry and of materials science and nanoengineering, has been named a fellow of the American Association for the Advancement of Science.

AMERICAN COLLEGE OF SPORTS MEDICINE

Alexis Ortiz, adjunct associate professor of kinesiology, was elected a fellow of the American College of Sports Medicine.

AMERICAN MATHEMATICAL SOCIETY

Robert Hardt, the W.L. Moody Professor of Mathematics, has been named a fellow of the American Mathematical Society.

AMERICAN PHYSICAL SOCIETY

Anatoly Kolomeisky, professor of chemistry and of chemical and biomolecular engineering, has been named a fellow of the American Physical Society.

NATIONAL ACADEMY OF INVENTORS

Naomi Halas, **Jim Tour**, the T.T. and W.F. Chao Professor of Chemistry and professor of computer science, and of materials science and nanoengineering, and **K.C. Nicolaou** have been named fellows of the National Academy of Inventors.

OPTICAL SOCIETY OF AMERICA

Jun Kono, professor of electrical and computer engineering, of physics and astronomy, and of materials science and nanoengineering, has been elected a fellow by the Optical Society of America.

FELLOWSHIPS

SLOAN FOUNDATION

Wei Li, assistant professor of physics and astronomy, was selected to receive a Sloan Research Fellowship from the Alfred P. Sloan Foundation.

STUDENT ACCOMPLISHMENTS

AMERICAN GEOPHYSICAL UNION

Matthew Weller, graduate student in earth science, received the 2015 Study of the Earth's Deep Interior Focus Group Graduate Research Award at the American Geophysical Union fall meeting.

BECKMAN FOUNDATION

Benjamin Toscano, postdoctoral fellow in biosciences, received an Arnold O. Beckman Postdoctoral Fellows Award.

FORD FOUNDATION

In a competition administered by the National Research Council of the National Academies, **Ernesto Calleros**, graduate student in mathematics, was awarded a Ford Foundation Predoctoral Fellowship.

FULBRIGHT SCHOLARSHIP

Christopher Chu '15 and **Lachezar Hristov '15** were awarded Fulbright grants to study, teach and/or conduct research in Brazil and Germany, respectively.

GOLDWATER SCHOLARSHIP

Peter Cabeceiras '16 and **Eric Sung '16** were named Goldwater Scholars for the 2015–2016 academic year.

NATIONAL INSTITUTES OF HEALTH

Kathryn Beabout, graduate student in biochemistry and cell biology, was awarded a National Research Service Award predoctoral training fellowship from the NIH.

NATIONAL SCIENCE FOUNDATION

David Cohen '15 was awarded an NSF Mathematical Sciences Postdoctoral Fellowship.

Andrea Drager, graduate student in ecology and evolutionary biology, **John Gomez**, graduate student in applied physics/chemistry, **Jaime Martinez '15**, **Rachel Marzen '15**, **Joey Olmos**, graduate student in biochemistry and cell biology, **Desmond Schipper**, graduate student in chemistry, **Kyle Smith**, graduate student in chemistry, **Dayne Swearer**, graduate student in chemistry, **Nicholas Zaibaq**, graduate student in chemistry, and **Julia Zhao '15** were selected for the 2015 National Science Foundation Graduate Research Fellowship Program.

RHODES SCHOLARSHIP

Tom Carroll '16 was chosen for a Rhodes Scholarship. While at Oxford, Carroll will study the p53 tumor suppressor protein.

SOROS FELLOWSHIP

Ismael Loera Fernandez, graduate student in chemistry, was awarded a Paul and Daisy Soros Fellowship for New Americans.

New Faculty



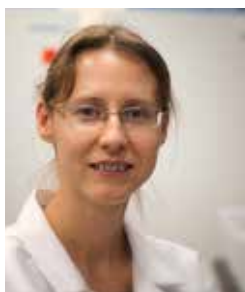
Mustafa Amin

MUSTAFA AMIN

Assistant Professor of Physics and Astronomy

Mustafa Amin is a theoretical cosmologist who studies the universe from the earliest times to its contemporary state. He often works at the intersection of astrophysics, cosmology and particle physics, and his recent work includes exploring the mathematical connection between particle production in cosmology and current conduction in wires. Amin also is passionate about teaching and outreach and has taught at the African Institute for Mathematical Sciences in South Africa and Senegal.

Before joining the Rice faculty, Amin earned his Ph.D. from Stanford University and then obtained postdoctoral training as a Pappalardo Fellow in Physics at MIT and as a senior Kavli Fellow at the University of Cambridge.



Natasha Kirienko

NATASHA KIRIENKO

Assistant Professor of Biosciences

Natasha Kirienko's research focuses on two related topics: identifying novel treatments for bacterial infections that exhibit resistance to antimicrobials and studying the importance of mitochondria in cancer. Kirienko uses the *C. elegans* worm as a model system and plans to leverage the high-throughput capabilities of the worm to help identify new ways to find targets for treatment-resistant cancers.

Kirienko received a Ph.D. in molecular biology from the University of Wyoming. She pursued postdoctoral training in genetics at Harvard Medical School and as an assistant in molecular biology at Massachusetts General Hospital. Kirienko comes to Rice as a Cancer Prevention and Research Institute of Texas scholar in cancer research.



László Kürti

LÁSZLÓ KÜRTI

Associate Professor of Chemistry

The main focus of László Kürti's research is the development of synthetic tools that help laboratories quickly build drug candidates without the need for the transition metals that are commonly used to catalyze chemical reactions. Kürti has co-authored three books on organic synthetic chemistry, including "Molecules and Medicine" with E.J. Corey and Barbara Czakó, which in 2008 was designated Best of Physical Sciences and Mathematics by the professional and scholarly division of the American Association of Publishers.

Kürti completed his Ph.D. at the University of Pennsylvania. He pursued postdoctoral training as a Damon Runyon Cancer Fellow under the direction of Nobel laureate E.J. Corey at Harvard University before beginning his independent career as an assistant professor in the Department of Biochemistry at UT Southwestern Medical Center in Dallas.

RONEN MUKAMEL

Assistant Professor of Mathematics

Ronen Mukamel is a mathematician whose research interests include Riemann surfaces, Teichmueller theory and dynamics on moduli spaces.

Mukamel was the recipient of a Herchel Smith Fellowship for study at Cambridge University, where he completed Part III of the Mathematical Tripos, a one-year taught master's course in mathematics. He was awarded an NSF Graduate Research Fellowship and received his Ph.D. from MIT. He received an NSF Mathematical Sciences Postdoctoral Research Fellowship and obtained postdoctoral training at Stanford University, where he also was a Szego Assistant Professor of Mathematics, and at the University of Chicago, where he also was a Dickinson Instructor.



Ronen Mukamel

Retirements

REGINALD DUFOUR

Physics and Astronomy



Reggie Dufour came to Rice in 1976 following graduate work at Wisconsin and a two-year appointment as a National Research Council Postdoctoral Associate at the NASA Johnson Space Center.

His research interests are in the areas of observational astrophysics related to gaseous nebulae and star-forming galaxies. His studies involve imagery and spectroscopy observations in the ultraviolet, optical and near-infrared spectral regions using a variety of ground-based and space-borne telescopes.

Beginning in 1980, Dufour was a guest observer with the International Ultraviolet Explorer satellite for 12 years. He was a general observer with the Hubble Space Telescope since 1990 and a guest investigator with the Far Ultraviolet Spectroscopic Explorer satellite since 2001. Dufour taught more than 38 courses and labs in astronomy during his 40 years at Rice. He served as the principal advisor to eight students earning the Ph.D. in astronomy and supervised four undergraduate winners of the department's Heaps Prize for excellence in research. He now is professor emeritus of physics and astronomy.

NEAL F. LANE

Physics and Astronomy



Neal F. Lane now is the Malcolm Gillis University Professor Emeritus and professor emeritus of physics and astronomy. He also is the senior fellow in science and technology policy at the Baker Institute.

Previously, Lane served in the federal government as assistant to the president for science and technology and director of the White House Office of Science and Technology Policy from August 1998 to January 2001. He served as director of the National Science Foundation (NSF) and as a member (ex officio) of the National Science Board from October 1993 to August 1998. Before his post with NSF, Lane was provost and professor of physics at Rice, a position he had held since 1986.

He first came to the university in 1966, when he joined the Department of Physics as an assistant professor. In 1972, he became professor of physics and space physics and astronomy. He left Rice from mid-1984 to 1986 to serve as chancellor of the University of Colorado at Colorado Springs. Additionally, from 1979 to 1980, while on leave from Rice, he worked at the NSF as director of the division of physics.

Lane has received the National Academy of Sciences Public Welfare Medal, the American Institute of Physics K.T. Compton Medal, the Association of Rice Alumni Gold Medal and the Distinguished Friend of Science Award from the Southeastern Universities Research Association. In 2013, the National Science Board presented Lane with the Vannevar Bush Award, which recognizes exceptional, lifelong leaders who have made substantial contributions to the nation through public service activities in science, technology and policy. He is a fellow of the American Academy of Arts and Sciences and other honorary and professional associations. Lane received his B.S., M.S. and Ph.D. in physics from the University of Oklahoma. ■

PAUL STEVENSON

Physics and Astronomy



Paul Stevenson was born in the U.K. and educated at Cambridge and Imperial College, London. He was a postdoctoral researcher at the University of Wisconsin at Madison and CERN before coming to Rice in 1984 as an assistant professor in the physics department's T. W. Bonner Laboratories. His research in theoretical particle physics includes such topics as jets in QCD (quantum chromodynamics); renormalization-scheme dependence and the "optimization" of renormalized perturbation theory; effective potentials in field theory; 'weak measurements' in quantum mechanics; and the Higgs vacuum considered as a medium.

Three of his four doctoral students won the department's H. A. Wilson Award for best Ph.D. thesis. He has taught courses ranging from introductory physics to quantum field theory, but is most associated with junior-level courses in classical and quantum mechanics. Despite being a notoriously demanding professor, he has won two George R. Brown Teaching Awards and several Distinguished and Outstanding Faculty Associate awards as an associate of Brown College.

Now professor emeritus of physics and astronomy, Stevenson intends to stay in Houston and continue with research, while spending more time in the U.K. and indulging his hobbies of musical composition and playing the piano.

Now professor emeritus of physics and astronomy, Stevenson intends to stay in Houston and continue with research, while spending more time in the U.K. and indulging his hobbies of musical composition and playing the piano.

In Memoriam



ESHEL BEN-JACOB

Senior Investigator, Center for Theoretical Biological Physics (CTBP)

Theoretical and experimental physicist Eshel Ben-Jacob, a pioneer of the study of bacterial intelligence and social behavior, died unexpectedly at his home in Israel June 5, 2015. He was 63. Ben-Jacob was one of the world's leading experts in bio-complexity, the theory of self-organization and pattern formation in open systems.

Ben-Jacob joined CTBP in 2005, shortly after the center was founded at the University of California at San Diego. The center moved to Rice's BioScience Research Collaborative in 2011. At Rice, Ben-Jacob joined his CTBP colleagues in focusing on ways to exploit the social behavior and decision-making process of cancer cells to develop new treatments that outsmart the disease.

Ben-Jacob was the Maguy-Glass Chair in Physics of Complex Systems, professor of physics and astronomy, and a member of the Sagol School of Neuroscience at Tel Aviv University.

His many honors and contributions to science included his election in 2014 to the American Philosophical Society, the 1986 Landau Research Prize, the 1996 Siegle Research Prize from the Israel Academy of Sciences and Humanities, and the 2013 Weizmann Prize in Exact Sciences. Ben-Jacob was a former president of the Israel Physical Society and a former chairman of the Israel Ministry of Education's Advisory Council of High School Physics Education.



TIM COCHRAN

Professor of Mathematics

Tim Cochran died Dec. 16, 2014, at the age of 59. Cochran, who joined Rice's faculty in 1990, was a beloved and highly successful researcher, teacher and mentor. "[Tim] was a driving force in our graduate program and helped shape it in many ways," David Damanik, the Robert L. Moody Sr. Chair in Mathematics, said. "He was also deeply involved in our undergraduate program and in mentoring numerous early career scientists, primarily through our G.C. Evans Instructor program.

In recognition of Cochran's demonstrated commitment to graduate education, he received the 2014 Rice Graduate Student Association's Faculty Teaching and Mentoring Award.

Cochran earned his bachelor's degree in mathematics from the Massachusetts Institute of Technology in 1977 and his doctorate from the University of California at Berkeley in 1982. He served on the faculty at both UC-Berkeley and Northwestern University before joining Rice as an associate professor. He was promoted to professor in 1998.

Cochran also was a noted researcher, whose interests included topology, knot theory, 3- and 4-D manifolds and group theory. He became a fellow of the American Mathematical Society in 2014 and was in the midst of a yearlong sabbatical supported by a prestigious Simons Foundation research fellowship at the time of his death.



JAMES KINSEY

D.R. Bullard-Welch Foundation Professor of Science Emeritus

James Kinsey died Dec. 20, 2014. He was 80. A native Texan, Kinsey earned his bachelor's degree at Rice in 1956. He also earned a doctorate in chemistry from Rice in 1959 as the first Ph.D. student of 1996 Nobel Prize winner Robert Curl '54. Kinsey traveled to Sweden on a fellowship from the National Science Foundation and in 1960 was named a Miller Research Fellow at the University of California at Berkeley.

In 1962, Kinsey joined the faculty of the Massachusetts Institute of Technology, where he served for 26 years, including five as chairman of the chemistry department. He returned to Rice in 1988 and served as dean of the Wiess School of Natural Sciences for 10 years, leading the school through many major accomplishments. In addition, he was interim provost from 1993 to 1994.

Kinsey was known for research in chemical dynamics, spectroscopy, lasers and highly excited molecular states. He also was much admired for providing leadership, while maintaining a low-key and unpretentious manner.

Kinsey served as chairman of the Scientific Advisory Board of the Robert A. Welch Foundation from 2006 to 2012. He was a member of the National Academy of Sciences and received the E.O. Lawrence Award from the Department of Energy and the Earle K. Plyler Prize from the American Physical Society. He was a fellow of the American Physical Society and of the American Academy of Arts and Sciences.



CURTIS MICHEL

Andrew Hays Buchanan Professor Emeritus of Space Physics and Astronomy

F. Curtis "Curt" Michel died Feb. 26, 2015, at the age of 80. Although he retired in 2000 after 37 years at Rice, Michel continued to keep an office on campus, where he pursued his studies of solar winds, radio pulsars and numerical methods.

As NASA ramped up the Apollo moon program, he was chosen as a part of the fourth class of astronauts. Michel was one of six scientist/astronauts in the class, the first on a roster that until that point had been largely limited to test pilots.

Though he never launched into space, Michel, who was an Air Force pilot in the 1950s, participated in the full astronaut training program while on leave from Rice. He left NASA in 1969 when it became apparent he would not be assigned to an Apollo mission.

Michel earned bachelor's and doctorate degrees at the California Institute of Technology, where he studied with Nobel laureates Richard Feynman and William Fowler. He was a research fellow there when Alexander Dessler, who founded Rice's first space science department in the nation, recruited him in 1963. He chaired Rice's space science department from 1974 to 1979.



JOHN J.W. ROGERS

Professor of Geology and Geology Department Chairman

John J.W. Rogers died Jan. 14, 2015. Rogers earned bachelor's and doctorate degrees at the California Institute of Technology and a master's degree from the University of Minnesota. He joined Rice's faculty in 1954, and together with Carey Croneis, former provost and Harry Wiess Professor of Geology, and John A.S. Adams, professor of geology and earth science and department chair from 1960 to 1971, established a program of courses in geology. Rogers served as chairman of the geology department from 1971 to 1974 and remained at Rice until 1975. In 1975, Rogers moved to the University of North Carolina at Chapel Hill. He retired from his position in 1997 as the W.R. Kenan Jr. Professor of Geology.

His paper charting the history of Earth's continents in the past three billion years was selected by Discover magazine as one of the top 100 science stories for 1996. Rogers continued to write after retirement, including "Women's College Education in the Past Two Centuries" and "Women, Rocks, and Professors: The Memories of a University Professor," which were inspired by his years as the master of Brown College, an all women's college at the time.



◀ A snapshot in time in the evolution of a large molecular cloud that is in the process of being destroyed by radiation from massive stars that have formed within it. The image was taken with the NEWFIRM camera attached to the 4-meter telescope atop Cerro Tololo in the Andes Mountains of northern Chile. Red shows molecular hydrogen, green shows where hydrogen has been ionized and blue traces high ionization gas near massive O-type stars.

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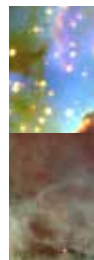
▼ A 50-light-year-wide view of the central region of the Carina Nebula composed from 48 frames taken with NASA's Hubble Space Telescope. Color information is added with data taken at the Cerro Tololo Inter-American Observatory in Chile. Red corresponds to sulfur, green to hydrogen and blue to oxygen emission.

CARINA NEBULA SURVEY REVEALS DETAILS OF STAR FORMATION

BY JADE BOYD



A RICE UNIVERSITY-LED SURVEY OF ONE OF THE MOST ACTIVE STAR-FORMING REGIONS IN THE GALACTIC NEIGHBORHOOD IS HELPING ASTRONOMERS BETTER UNDERSTAND THE PROCESSES THAT MAY HAVE CONTRIBUTED TO THE FORMATION OF THE SUN 4.5 BILLION YEARS AGO.



“Most stars form in giant molecular clouds, regions where the density of matter is sufficient for hydrogen atoms to pair up and form H₂ molecules,” said Patrick Hartigan, professor of physics and astronomy at Rice. “The Carina Nebula is an ideal place to observe how this happens because there are dozens of examples of forming stars at various stages of development.”

The Carina Nebula spans more than 100 light-years and is visible to the naked eye as a bright glowing patch in the Milky Way for observers in the Southern Hemisphere. In addition to thousands of stars similar in mass to the sun, Carina contains more than 70 O-type stars, each with a mass between 15 and 150 times that of the sun. O-stars burn hot and bright and die young, typically within 10 million years. These massive stars play a key role in how less-massive, solar-type stars in the same region evolve because O-stars evaporate and disperse dust and gas that might otherwise collect in a disk to form planets around the low-mass stars.

“Ultraviolet radiation from these hot, massive stars ionizes molecular hydrogen, and as the radiation evaporates the molecular cloud, O-stars carve beautiful pillars and clear the space around smaller stars that exist nearby,” Hartigan said.

A famous example of these pillars is found in the Eagle Nebula and was the subject of the Pillars of Creation, one of the most-recognized images from the Hubble Space Telescope.

Hartigan said the sculpting process that creates such pillars marks one stage of the destruction of a molecular cloud. In the first stage, the outer wall of the cloud appears largely unbroken. Fat pillars form first and are steadily eroded into skinny pillars that eventually become isolated globules that are disconnected from the receding wall. Often, a young star with a disk is present at the apex of a pillar or within a globule. The entire evaporation process takes about a million

years, and astronomers believe it is an essential aspect in the creation of solar systems like our own, Hartigan said.

The Carina star-formation region is about 7,500 light-years from Earth, about five times farther away than the Orion Nebula, which is visible in the northern hemisphere but is only about one-tenth the size of the Carina Nebula.

The new images of Carina show multiple examples of each of the different stages of cloud destruction.

“There is huge variety in Carina, in part because it is so large,” Hartigan said. “It spans more than a degree on a side, which means that it covers more of the sky than four full moons. In addition, Carina is young enough to have a great deal of ongoing star formation. But it is also old enough that the most massive stars have cleared away enough material to reveal a dizzying array of globules and pillars.”

In the new survey, Hartigan and colleagues Megan Reiter and Nathan Smith of the University of Arizona and John Bally of the University of Colorado used the National Optical Astronomy Observatory’s Extremely Wide-Field Infrared Imager and its Mosaic camera to photograph the entire Carina region from the four-meter Blanco telescope at Cerro Tololo in northern Chile. Both the optical and near-infrared imagers use large-format detectors to obtain high-resolution shots of wide swaths of the sky. Each of the images isolates a specific wavelength of infrared or optical light. By looking at these wavelengths separately and in composite, Hartigan and colleagues were able to penetrate Carina’s nebular dust and hone in the pillar-carving processes caused by O-type stars.

Hartigan said numerical simulations in recent decades have suggested that strong stellar winds from O-stars also induce star formation by compressing material in a molecular cloud to the point where it becomes gravitationally unstable, a process known as triggering. He said the new images reveal important constraints on this process.

“We observe two star clusters in which the pillars are being carved both from within, by young, newly formed stars inside the pillar, and from without by O-type stars,” Hartigan said. “It appears that the stars in the cluster already existed before the O-stars evaporated the cloud material, which implies that triggering did not create these clusters.”

While many of the pillars, globules and other structures that were detailed in the study were previously known to astronomers, Hartigan said the new images reveal details about the underlying physics of the region.

“Our images are sharper and deeper than previous ones,” he said, “and they provide the best snapshot so far of a massive star-formation region at one point in time.” ■

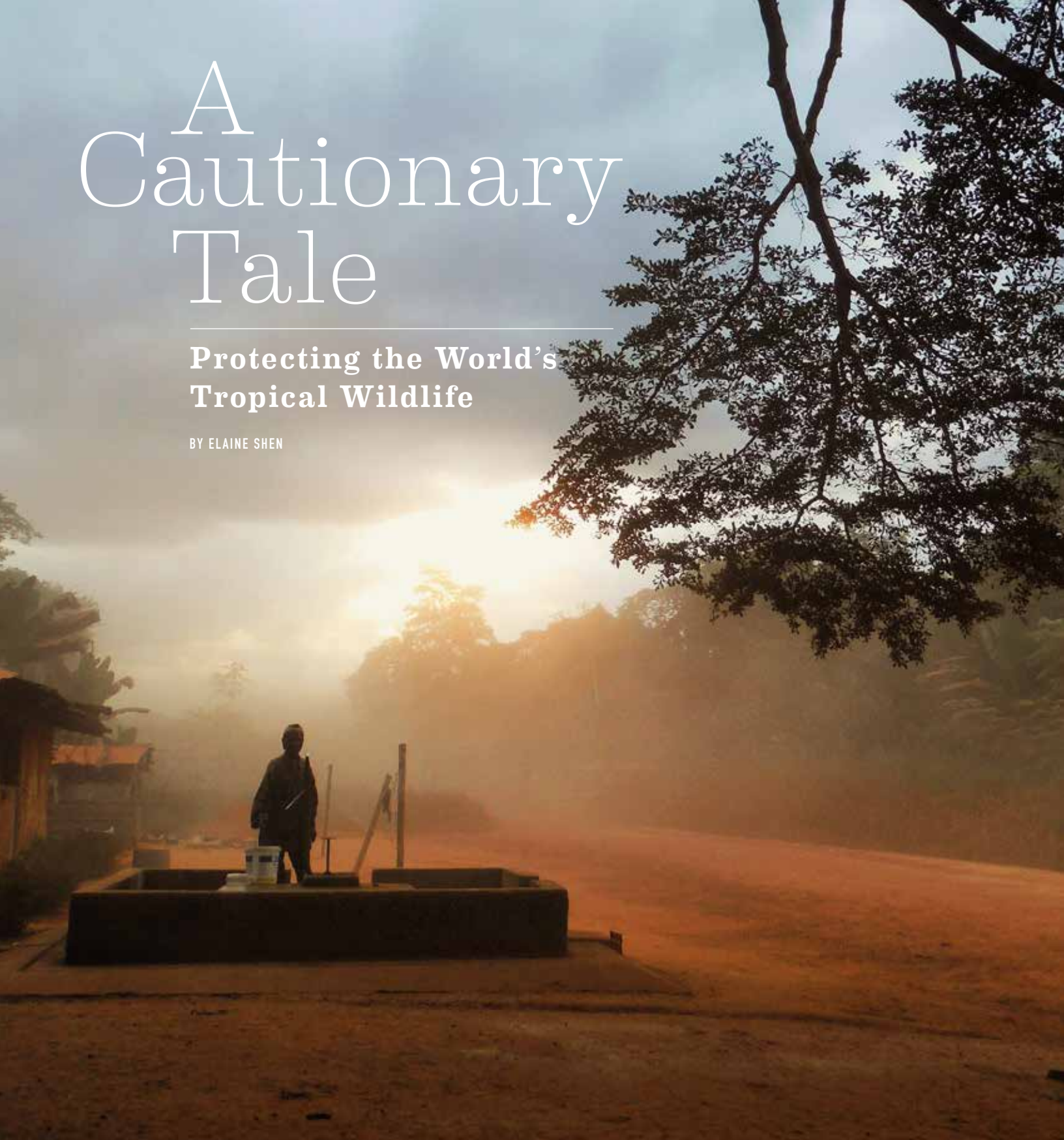


Image: NASA

A Cautionary Tale

Protecting the World's
Tropical Wildlife

BY ELAINE SHEN





“My Ph.D. advisor told me when I first visited Madagascar to be careful, because once you drink the water, you will be back,” Amy Dunham chuckled. “And she was right. It’s a naturalist’s paradise.”

For Dunham, assistant professor of ecology and evolutionary biology at Rice, the tropical rainforest is a home away from home. Her research sites, ranging from Madagascar and Gabon to the island of Guam, all boast highly diverse natural ecosystems as well as a rich culture celebrated by the native people who share their deep knowledge of the forest. Despite all of the scientific opportunities that such oases can offer, Dunham noted that there are few places left where such ecological treasures remain untouched by human development. With hunting, deforestation, habitat fragmentation, political instability and climate change threatening the abundant biodiversity in the world’s rainforests, Dunham’s research represents a last chance to understand the ecosystem shifts that are already underway. Through extensive collaboration with overseas research stations and intergovernmental organizations, Dunham is helping conserve these unique habitats using an approach that is not based on individual species, but is instead focused on preserving functional diversity. In other words, she is studying how the daily jobs of every species keep an ecosystem running smoothly.

One of the most important roles that animals play in tropical ecosystems is tree seed dispersal through various frugivores, or fruit-eating animals. Dunham explained that the extent of change that occurs from the absence of major frugivores is relatively unclear. The forests of Guam are interesting study sites for examining the role vertebrates play in the distribution of tree populations after its infamous ecological disaster in the 1940s. When a species of brown tree snake was accidentally introduced onto the island, it quickly became the top predator and eliminated 10 out of the 12 native bird species. The two remaining species are only maintained as a result of isolated and protected snake-free areas. Without the cacophony of birdcalls in the canopy, Guam soon became a silent forest, and the ecology of the area dramatically changed.



A man in Etakanyabe, Gabon, takes water from the sole village well. He and his family rely on bushmeat and timber collected from the forest to survive. Hunting and logging are causing devastating declines in the species responsible for sustaining and shaping the forest through seed dispersal.

Some of the small birds that originally inhabited the area were frugivores, eating and dispersing the seeds of a majority of the island's trees. They were especially important for pioneer trees, or the fast-growing trees that first populate open, sunlit areas in the forest and help stabilize the community after a natural disaster. If a seed of a pioneer tree does not reach a forest gap, it may never germinate or survive. Over the past three years, Dunham and a team of ecologists and students from Rice and the University of Guam have been working together to better understand the absence of such important seed dispersers. She and her colleagues are using observations, experiments and models to compare forests in Guam to the tree populations of nearby islands, whose bird populations remained intact after the introduction of the



The highly invasive brown treesnake was first transported to Guam as a stowaway from the South Pacific shortly after World War II. The native forest birds were not adapted to this stealthy predator, and 10 of the 12 small bird species were wiped out as the snakes migrated across the island. The loss of these birds may be thinning the island's forests as fewer seeds are spread into open gaps. Photo: Isaac Chellman

brown tree snake. So far, Dunham and her team have found that due to the absence of small birds in Guam, the tree gaps are increasing in size and pioneer trees are less successful in filling in the gaps. As a result, the entire composition of the rainforest is beginning to shift and change, demonstrating the domino effect in which one large-scale natural event can alter an entire ecosystem.

Another research site where the loss of critical seed dispersers is observed is in Madagascar, an island off the east coast of Africa, where Dunham is deeply involved in the study of lemurs, another group of frugivores. Lemurs are primates that are native only to Madagascar and resemble the earliest ancestors to monkeys and apes from tens of millions of years ago. Ever since her undergraduate college years, Dunham has been enraptured with the huge lemur species diversity present in this Texas-sized country.



"By understanding how behavior and life histories have evolved and the forces that affect them, we can even begin to understand our own evolution," Dunham explained. "After all, we are primates as well."

There are currently 103 species of lemurs that live in Madagascar, representing over 20 percent of the world's primate diversity. This group of primates exhibits female social dominance over males, an unusual characteristic for social mammals. In a groundbreaking study, Dunham found that female dominance in lemurs probably evolved over time in response to their unusual mating systems, resource competition, and the greater energetic demands faced by pregnant and lactating females. Lemurs also have very restricted breeding seasons, so small environmental variations can have a huge impact on future generations. Now, about 90 percent of lemur species are threatened with extinction. Dunham found that in addition to habitat loss and hunting, lemur populations are also sensitive to climate change. Increasing global sea temperatures causes wet seasons to get more extreme, resulting in a decrease in the fecundity, or reproductive capacity, of lemurs. Intense rainfall decreases the activity of lemurs, reduces forest fruit production, and has the potential to starve lemurs of the fruit they need to consume for lactating and caring for their offspring.

Similar to the small birds in Guam, Lemur populations are the main seed dispersers and are necessary to the functioning of the rainforests in Madagascar. In some cases, their generalist feeding behavior and consumption of the region's larger fruits and seeds make them the only animal that can distribute them. With former graduate student Onja Razafindratsima and a team of 10 local villagers with extensive knowledge of the forest, Dunham was able to track 24 groups of lemurs over the course of a year. Through mathematical modeling, observations and experiments, the team estimates that the seeds of a common canopy tree are 300 percent more likely to sprout and become a sapling if dispersed by a lemur versus simply falling to the ground. Thus, like the silent forests of Guam, the absence of lemurs could lead to large-scale shifts in Madagascar's unique flora.

Although her findings recommend an increase in rainforest conservation, Dunham recognized that it is not that simple. "The humanitarian and biodiversity crises in Madagascar are both so severe," Dunham said. "The people are dependent on the wildlife, and the wildlife are affected by the people, so the two issues are hard to reconcile."



Amy Dunham and the Madagascar seed dispersal team (center) study the relationship between fruit-eating lemurs and species of trees they help to survive by dispersing seeds from their research camp in the rainforest of Madagascar (bottom).

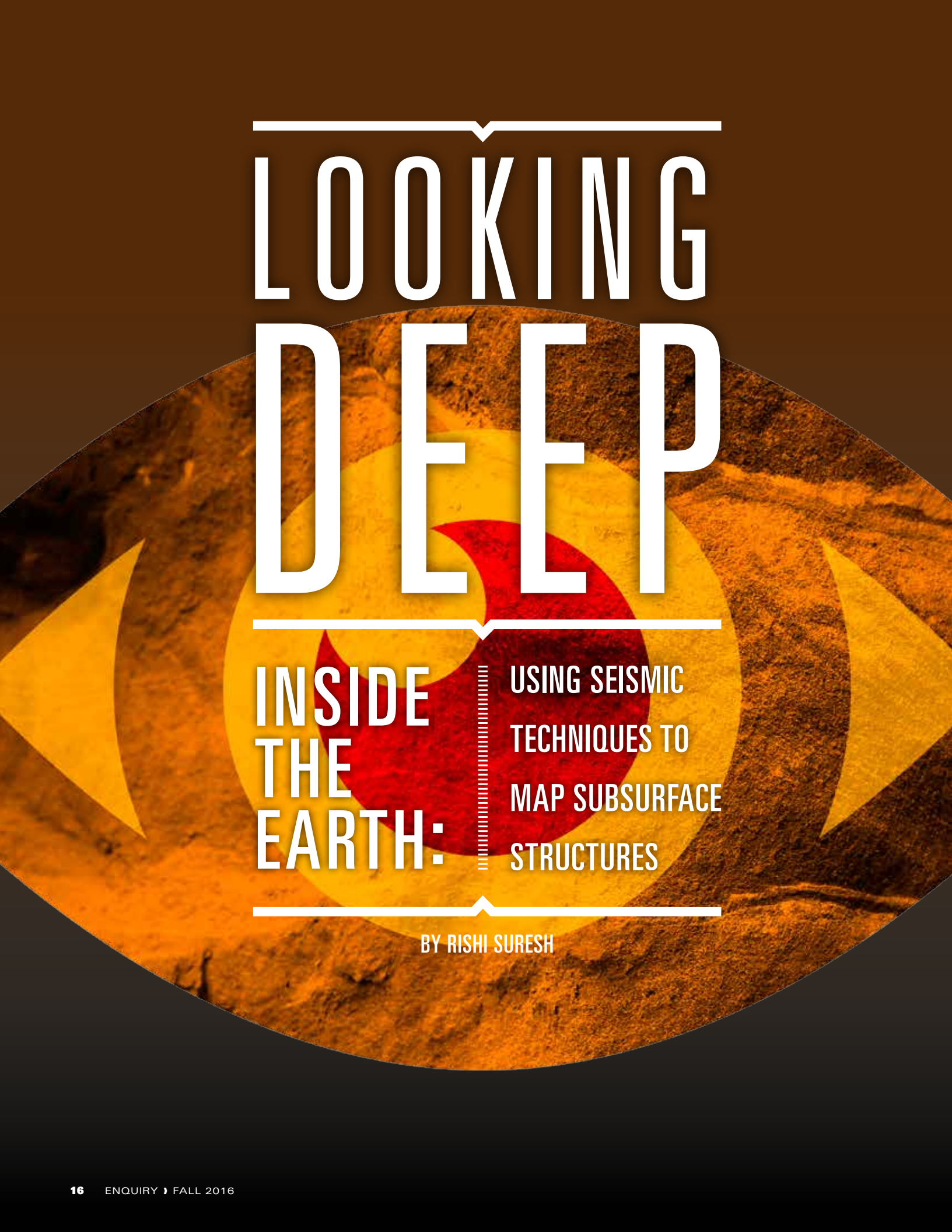


To better understand the social and political aspects of conservation issues in Africa, Dunham joined the Inter-governmental Platform on Biodiversity and Ecosystem Services, a three-year project run by the United Nations that connects ecologists, social scientists and policymakers to create a global assessment of biodiversity loss and change and how it relates to human livelihoods. As part of the African assessment, she contributes to this growing body of knowledge by providing a scientific perspective to African ecosystems. With this information, it is the hope that policymakers will be able to better prioritize and manage ecosystems and the services they provide to people. After joining last summer, Dunham is already discovering the challenges that African policymakers have struggled with for many years — an overall lack of infrastructure, communication difficulties and access to scientific information.

“My role is to translate science in an understandable and useful way to the world’s politicians,” Dunham said. “It is one of the most rewarding things I have done in a long time, because I am usually on the science side of things. This project allows me to collaborate with a diverse group of people, and it gives me a chance to use science to make a real impact.”

Both tropical ecosystems and conservation management are extremely complicated and inextricably intertwined. Dunham has been a part of the shift in ecosystem management and conservation biology that focuses more on the roles that animals play in the maintenance of biodiversity rather than individual species. Her research warns of community shifts as a result of anthropogenic and naturally induced stressors. The complicated networks and interactions between species mean that harming one species leads to detrimental changes in the whole ecosystem. In tandem to her research, Dunham’s involvement with interdisciplinary organizations shows her dedication to ensuring that advancements in ecological research leads to changes in conservation: without learning the ins and outs of policymaking, the prized regions that Dunham has spent so many years understanding will continue to deteriorate. Only through such diverse collaborations can large-scale changes productively preserve some of the world’s greatest biological treasures. ■





LOOKING DEEP

INSIDE
THE
EARTH:

USING SEISMIC
TECHNIQUES TO
MAP SUBSURFACE
STRUCTURES

BY RISHI SURESH

Since the early 2000s, the phrase “energy crisis” has become a ubiquitous buzzword in the news. Every few weeks, new predictions come out describing humanity’s overdependence on hydrocarbon resources to fuel everything from cars to streetlamps. In fact, an estimate from Stanford University suggests that the world’s hydrocarbon resources may be depleted in 41 years. The decreasing availability of hydrocarbon sources has forced some to turn to processes like hydraulic fracturing to squeeze out what little oil remains. However, fracking often has significant detrimental environmental impacts, ranging from creating fault lines that lead to earthquakes to contaminating drinking water sources. Fenglin Niu, a professor of earth science at Rice, has been developing seismic observational system and imaging techniques that can map subsurface structures using seismic waves. These maps can help in monitoring fracking efficiency and potential environmental damage fracking creates and help explore the Earth hidden deep beneath the surface.

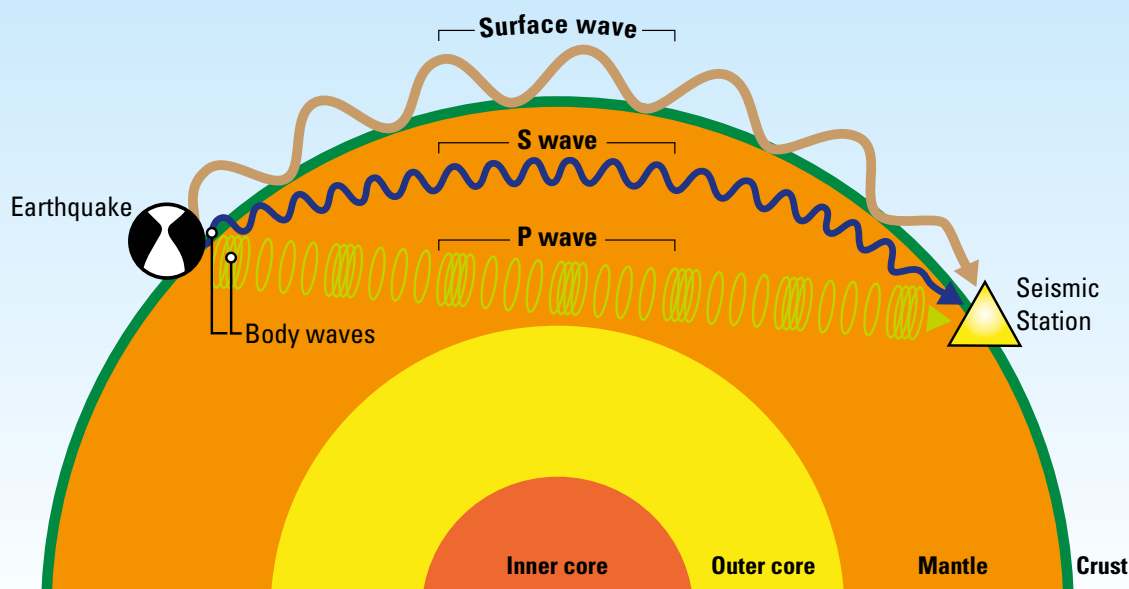
Seismic waves are large-amplitude waves that propagate throughout the Earth’s interior when large, subsurface rocks break. Both volcanoes and earthquakes create violent disruptions that can break surrounding rock, producing three types of seismic waves — P waves, S waves and surface waves. Both P and S waves are considered “body waves” because of their ability to penetrate deep inside the Earth. P waves are compressional or longitudinal waves that shake the ground in the direction that they propagate. S waves, on the other hand, are known as shear waves, and they shake the ground in a direction perpendicular to their direction of propagation. Studying

how these waves bend, reflect and change in velocity gives scientists, like Niu, the information to understand phenomena beneath the Earth’s surface. “Basically, seismic wavespeeds reflect the composition and physical state such as temperature of the rocks through which the wave moves,” said Niu. These wave speeds can then be compared to wave propagation data collected in a laboratory setting. Together, these two sets of data can be used to create clear images of the Earth’s subsurface, which can then be used to find hydrocarbon reservoirs as well as earthquake faults.

Over time, hydrocarbon resources tend to migrate upward through fractures from the source rock deep in the Earth and form reservoirs when they are trapped by low permeability rocks and other barriers. According to Niu, “With exploration seismology, we try to use seismic imaging to find these reservoirs.” Using vertical drilling, oil companies can tap these resources and access these hydrocarbons relatively easily. Drilling from these reservoirs is fairly inexpensive and can extract hydrocarbon resources for decades. However, as hydrocarbon resources become increasingly depleted, oil companies are frantically searching for new pools to tap.

“People now are turning to unconventional methods,” said Niu. Instead of waiting for oil to rise up to the top, companies are fracking: using high-pressure water streams that are blasted into the ground to form cracks in the underlying rock. This procedure forces oil through rock that has poor porosity and permeability by creating small fractures through which oil can flow. However, fracking is quite taxing on the environment. Niu argues that blasting high-pressure water into the ground

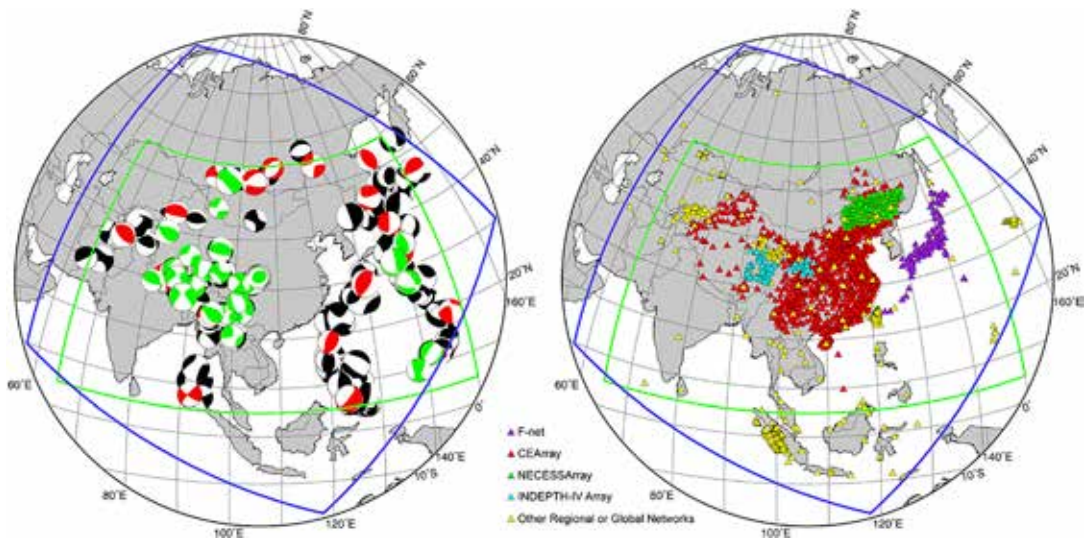
SEISMIC WAVES



Seismic waves are waves of energy that result from the sudden breaking of rock during an earthquake or volcanic eruption. There are two main types of seismic waves: body waves and surface waves. Surface waves travel only along the surface of the Earth’s crust while body waves travel through the Earth’s interior. P waves are compressional waves that move through rock much like sound waves move through the air. S waves are transverse waves where motion is perpendicular to the direction of propagation. The density and stiffness of the rock determines the speed of the wave.

A map of the earthquakes (beach balls) and seismic stations (triangles) used to model the crust and mantle beneath East Asia. Black and red beach balls indicate the 227 earthquakes used in the study, while the green beach balls indicate the 39 extra earthquakes used for model validation.

From Figure 2 in Chen, M., Niu, F., Liu, Q., Tromp, J., and Zheng, X. (2015) *Multiparameter adjoint tomography of the crust and upper mantle beneath East Asia: 1. Model construction and comparisons.* *Journal of Geophysical Research: Solid Earth* 120, 1762. Published with the permission of AGU/Wiley.

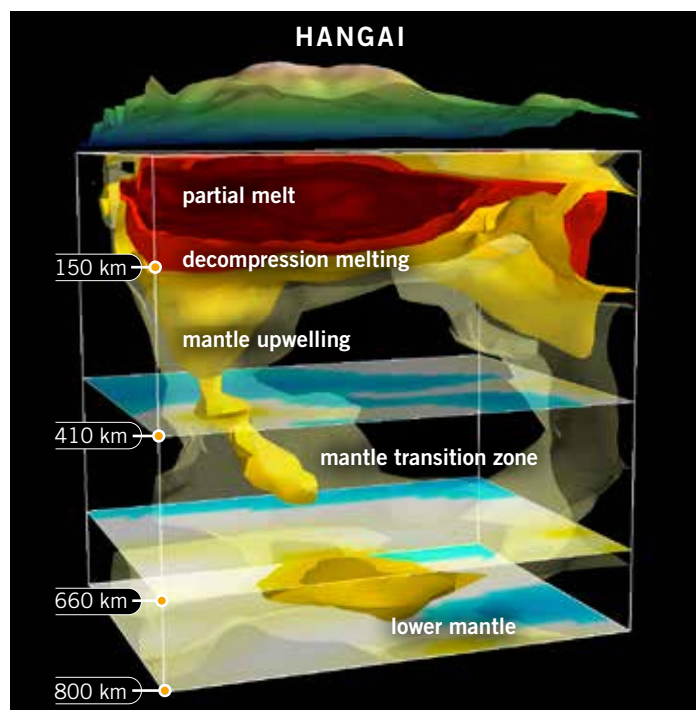


actually changes something known as the stress field, or the patterns of deformations and cracks in the rocks. Once stress accumulates to a critical point, a fault line is created that can eventually give rise to earthquakes.

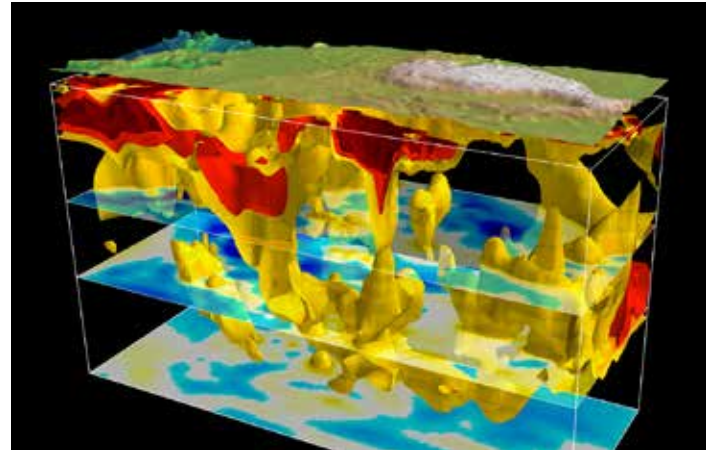
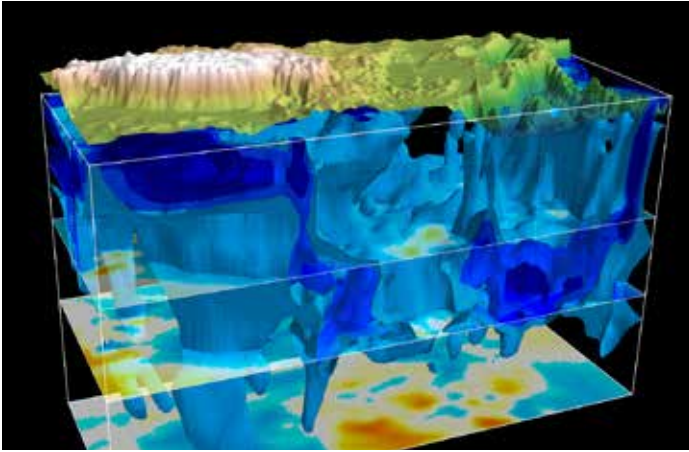
The techniques used by exploration geologists to identify hydrocarbon reservoirs are very similar to those Niu and his collaborators have used to create extremely detailed pictures of rock structures deep beneath East Asia. Using supercomputers, the researchers can set off a simulated earthquake. The time taken for the simulated P and S waves to reach the sensors can be compared to actual observations from 1,869 stations of 227 earthquakes that occurred in East Asia from 2007–2011. Differences between simulation and observation are then used to improve models of the Earth's interior. Although analyzing the disparity between observed and simulated wave speeds is relatively straightforward for a small number of waves, the problem becomes much more complex when considering hundreds of earthquakes and thousands of stations. In the end, the group used about eight million CPU hours on supercomputers, including Stampede and Lonestar at the University of Texas at Austin, through an allocation by XSEDE (the Extreme Science and Engineering Discovery Environment) to simulate enough earthquake data to generate 3-D, high-resolution images of the Earth subsurface beneath two huge geologic features.

Specifically, Niu's work has helped explain more about the initial formation of the Hangai dome, a highly elevated, low-relief structure in central Mongolia. Scientists generally agree that the dome is created by the buoyancy of lighter rock, which rises and creates the structure. However, the reason behind the buoyancy of this rock is a matter of much debate. Niu's high-resolution, 3-D images shed light on this puzzle. The maps revealed an anomalous region with strong, low velocity shear waves at a depth of less than 150 kilometers.

Low velocity waves indicate high temperatures and possibly a partial melting of the rock. This model of the Hangai dome formation suggests that as the warm rock rises from the deep mantle, it starts to melt at about 150 kilometers below the sur-



This 3-D image shows the Earth under the Hangai dome in central Mongolia. Warm rock (colored yellow) rises up from the deep mantle toward the Earth's surface. The pressure on the rock drops as it rises. When the rock reaches 150 km below the surface, it starts to melt and form magma, illustrated in red. Heat released by the magma modifies the rigid outer layer of the Earth that is now lighter and rises up creating the Hangai dome.



Rendered from 1.7 million measurements of earthquake recordings, these 3-D seismic images show (L): the cold part of the Earth beneath East Asia viewed from the south (colored blue) and (R): the hot part of the Earth beneath East Asia viewed from the northwest (colored yellow to red). Surface topography with vertical exaggeration is superimposed at the top, with the highest elevations in the left panel representing the Himalayas and the Tibetan Plateau. Three cut planes show shear wave speed maps at 410 km, 660 km and 1000 km.

face, creating magma. Once this magma hardens, the resultant rock is lighter and more buoyant, allowing it to rise up and form the Hangai dome.

Niu's clear images of the Earth's subsurface have also identified an enormous high velocity structure underneath the Tibetan Plateau, a structure with an elevation of 4.5 kilometers or nearly three miles. Home to the two tallest mountains in the world, the Tibetan Plateau has a complex tectonic history. About 50 million years ago, the Indian subcontinent collided with Eurasia, forming the Himalayan Mountains and the Tibetan Plateau. This region is a hotspot for earthquake activity, including intraplate earthquakes, which are earthquakes that happen away from plate boundaries. Most notably, in 2010 the earthquake in the Qinghai province in China that caused over 400 deaths was generated by intraplate activity in the Tibetan Plateau. Scientists have debated many details of the geology of the region, largely due to the limited seismic resolution of the subsurface structures. Niu's high-resolution seismic images are now providing a detailed picture of the large-scale rock structures that lie deep beneath the Tibetan Plateau. The new imaging techniques led to the discovery of a broad, high velocity structure beneath Tibet, extending from below 100 kilometers in depth to the bottom of the mantle transition zone at depths of 660 kilometers or about 400 miles. Furthermore, they find that sharp transitions from high velocity to low velocity regions clearly mark several tectonic boundaries, showing remarkable agreement between the 3-D maps and what is known about the tectonics of East Asia from surface observations.

Volcanic activity, another interest of Niu's, can also generate seismic waves that yield useful information. The majority of volcanic activity occurs at boundaries of tectonic plates either diverging or converging to create melting of the mantle that eventually reaches the surface. However, there is a less

common type of volcanism known as intraplate volcanism. In this type, volcanic activity occurs inside the plates, not on the boundaries. Studying how seismic waves propagate through various materials at different temperatures could help elucidate some of the mechanisms linked to volcanic activity.

As a part of a collaborative project started in 2009 that includes Rice University, the University of Texas at Austin, Beijing University and the University of Tokyo, Niu has been studying the mechanisms behind intraplate volcanic activity. This large-scale collaboration studies subsurface structures at incredible depths using seismographic sensors similar to Niu's earthquake studies. Previously, the different countries were not effectively sharing their data to collaboratively develop comprehensive models of subsurface structures. This new project led to placement of over 100 seismic sensors that can be used to construct novel, complex images of Earth underground. Placement of sensors in China is especially useful given that there is a significant amount of intraplate volcanic activity in the area. In the future, Niu hopes to further understand the controlling mechanisms behind intraplate seismic activity.

The Earth's continually active mantle is intimately related to plate tectonics, contributing to earthquakes, volcanic activity, the formation of mountains and even the motion of the continents. Despite more than five decades of trying to drill a hole that punches through the Earth's crust, scientists have not been able to directly access the mantle. The images generated by Niu and his team provide the clearest picture yet of this unseen region, aiding in the discovery of new features and ultimately leading to a better understanding of the processes occurring deep inside the Earth. ■

Chemistry Duo Puts Nanoparticles Through Their Paces

BY LAUREN KAPCHA

Putting together a great tennis doubles team isn't easy. The best pairings should have complementary strengths and a commitment to achieving common goals.

"The Woodies" are a perfect example of the winning combination that can result from a yin and yang pair. Mark Woodforde was a left-handed baseliner with a steady temperament. Todd Woodbridge was right handed with quick reflexes at the net and a fiery personality. Together they formed one of the greatest doubles pairings of all time. Like the Woodies, Christy Landes and Stephan Link, both associate professors of chemistry and of electrical and computer engineering at Rice, also form an exceptionally strong partnership. In addition to competing at tennis, they are joining forces to figure out how metallic nanoparticles interact with each other and their environment.

Landes and Link met as grad students at Georgia Tech. She was outgoing and talkative, a lifelong risk taker. He was reserved and serious, dedicated to careful progress. No one who knew them at the time predicted that they would become friends, let alone partners, but as they got to know each other while working in the lab that is exactly what happened. The two are now tennis partners as well as life partners and frequent collaborators. They may not be quite as formidable on the tennis court as the Woodies, but when they team up in the lab they are unstoppable.

Single nanoparticle measurements

Landes' group uses single molecule spectroscopy to understand how biological molecules work and so that synthetic materials might be designed that mimic these structure-function relationships. She is particularly interested in understanding how heterogeneity drives function, both in materials and in biology. Her group studies the conformational dynamics of proteins as they interact with natural and man-made targets, using single molecule spectroscopy to see protein transitions between different structural states. They also use single molecule spectroscopy to study the effects of local structural features on reactivity, adsorption, and diffusion of molecules on biological and synthetic surfaces.

Link's specialty is in plasmonics, studying how nanoparticles interact with light. When light interacts with a metallic nanoparticle, its electric field causes the electrons in the conduction band to oscillate in phase with the frequency of the light, a phenomenon known as a surface plasmon. Plasmonic materials have unique optical properties that make them ideal candidates for use as building blocks when designing new devices and materials. Link's research aims to understand not only the plasmons of a single nanoparticle, but also what happens when you have many plasmonic

nanoparticles interacting with each other.

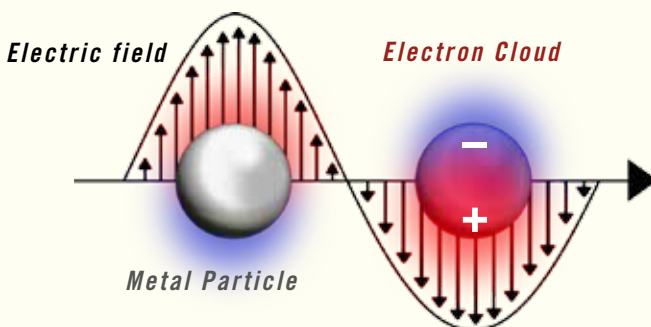
Landes and Link combine their expertise in surface dynamics and plasmonics to learn more about the physical properties of plasmonic nanoparticles and to decipher the impact of nanoparticle subpopulations on the ensemble behavior. Some of their most exciting discoveries happen when they are working together.

Link was born and raised in Germany, so it is fitting that he begins an explanation of single molecule spectroscopy with an obvious "fact": Germans make the best beer.

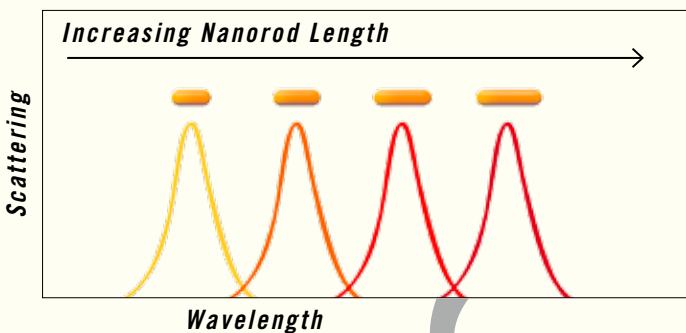
How can you prove this to the rest of the world? Using a traditional chemistry approach, you might mix Avogadro's number of different German beers together in an enormous vat. Then, you could have 100 researchers sample and rate that mixture. It's easy to see what the problem is here. When you sample the mixture in the vat, you get an average of all the individual components, but you can't appreciate the exceptional beers included or identify the below-average beers.

Similarly, measurements of ensembles of nanoparticles only provide information about the average behavior, not the contributions of individual particles or subpopulations.

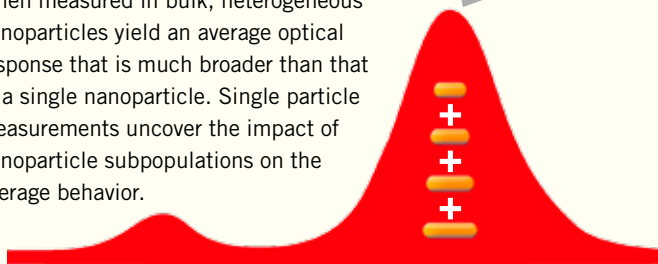
When light waves interact with nanoparticles, the conduction band electrons in the metal particle oscillate in response to the light's electric field. This movement of the electron's cloud is known as a surface plasmon.



The plasmon resonance scatters a narrow range of wavelengths – the color of which depends on both nanoparticle size and shape.



When measured in bulk, heterogeneous nanoparticles yield an average optical response that is much broader than that of a single nanoparticle. Single particle measurements uncover the impact of nanoparticle subpopulations on the average behavior.



Bridging the Gap

Silver ions in solution are deposited onto gold nanoparticle cores. This process provides precise control over interparticle gap width.



Gold nanoparticles coated with insulating silver chloride act as capacitors (left). Applying a negative voltage causes a conductive silver drawbridge to form between particles (right).

Au cores/AgCl shells

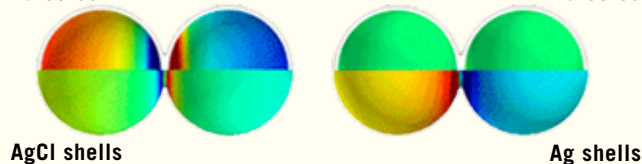
Au cores/Ag shells



Markedly different colors of light are scattered thanks to plasmonic shifts that occur when no metal bridges are present (left) and when they are (right).

Au cores

Au cores



AgCl shells

Ag shells

The properties of nanoparticle systems are affected not only by the size and shape of individual particles, but also by interparticle interactions and the local environment of the nanoparticle — parameters that can be different for each nanoparticle in a system. Landes and Link use single particle and single molecule spectroscopy to understand the contribution of each individual component to the system as a whole.

We think of nanotechnology as a relatively new field, but nanoparticle use dates back more than 1,000 years. Medieval artisans mixed gold chloride into molten glass to produce the deep red glass they used in stained-glass windows. They didn't know it, but this vibrant color resulted from the incorporation of gold nanoparticles in the glass. These medieval artisans served as a source of inspiration to Link and Landes. "Wouldn't it be interesting if we could create stained-glass windows that changed colors at the flip of a switch?" said Landes. A material like this would also prove useful to engineers hoping to make a full-color display from optically active nanoparticles. To make a device like this possible, the nanoparticles need to produce huge color changes rapidly and reversibly. Other researchers have produced either irreversible, dramatic color changes or reversible, small shifts in color. Until Link and Landes' recent

work, no one had been able to achieve both reversible and dramatic color shifts.

Their breakthrough demonstration started with the simple idea that the optical properties of a single nanoparticle can be significantly altered by changing the charge density — adding or removing electrons. They wanted to be able to do this reversibly, simply by turning a voltage on or off. While the experiments worked, the color change produced was very small. "It wasn't going to get anyone excited about any sort of switchable display applications," said Landes.

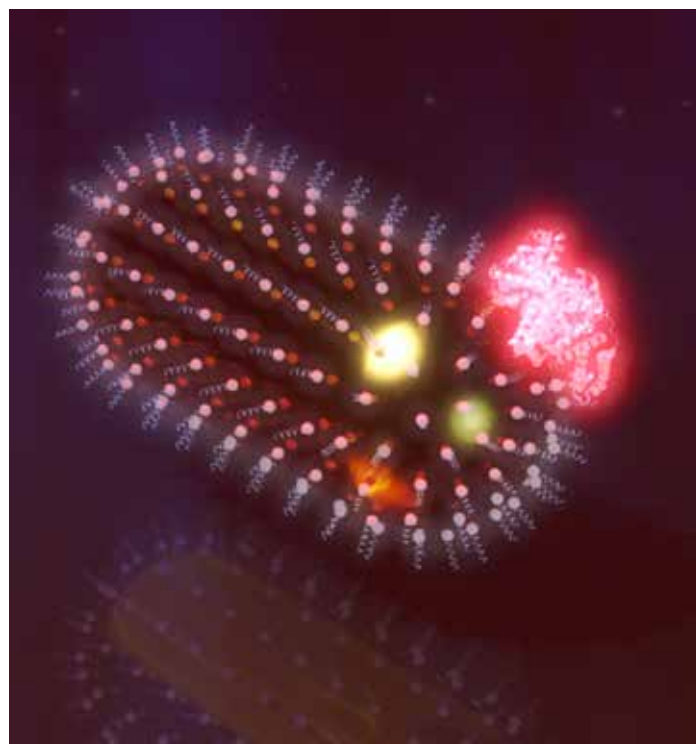
Although they were disappointed in the size of the initial color changes, the team found it interesting that their experimental results differed from theoretical predictions. They assumed an inert counter electrode, but their experiments used a silver counter electrode that was able to oxidize to form a layer of silver chloride on the nanoparticles. Rather than discarding these "contaminated" results, they decided to use the silver to their advantage in their follow-up experiments on gold nanoparticle dimers. Along the way, their new system had grown to encompass chemistry and physics that was outside their expertise. So they recruited Rice plasmonics experts Naomi Halas, the Stanley C. Moore Professor of Electrical and Com-

puter Engineering; Peter Nordlander, professor of physics and astronomy; and Emilie Ringe, assistant professor of materials science and nanoengineering; along with renowned Australian chemist Paul Mulvaney to join their efforts.

Since the optical properties of nanoparticle dimers depend strongly on the interparticle distance, Link and Landes, along with the new team, worked to actively tune the effective gap width between gold dimers by depositing a thin silver shell on the gold cores. Shell thickness can be directly controlled by salt concentration, and standard redox chemistry can be used to reversibly switch the shell between insulating silver chloride and highly conductive metallic silver. When a negative voltage is applied, silver chloride is reduced to silver and a conductive “drawbridge” forms between the gold cores. Applying a positive voltage switches the shell back to silver chloride and breaks the conductive coupling, withdrawing the drawbridge. This ability to introduce and remove conductive coupling between nanoparticles is the key to producing extreme, but reversible, changes in the color of light scattered by the nanoparticles.

This precise control over interparticle gaps is important for the development of plasmonic devices such as switches and modulators. However, plasmonic nanoparticles are also being studied for biomedical applications, which require a thorough understanding of how nanoparticles act in the human body. “We are interested in the interaction between nanoparticles and proteins,” said Link. “We want to understand what happens in the protein corona and investigate biosafety and environmental safety issues and methods of drug delivery.” Landes and Link are using gold nanoparticles and bovine serum albumin (BSA) to study the ways that the physical properties of plasmonic nanoparticles affect protein nanoparticle interactions.

Serum albumin, the most abundant protein in blood, binds to things that aren’t water soluble and makes them soluble. Al-



A single bovine serum albumin protein molecule binds to a gold nanoparticle surface and begins to unfold.

“If we only look in our own immediate fields, we discount the entire world of possible ways to look at systems and solve problems.”

— Christy Landes

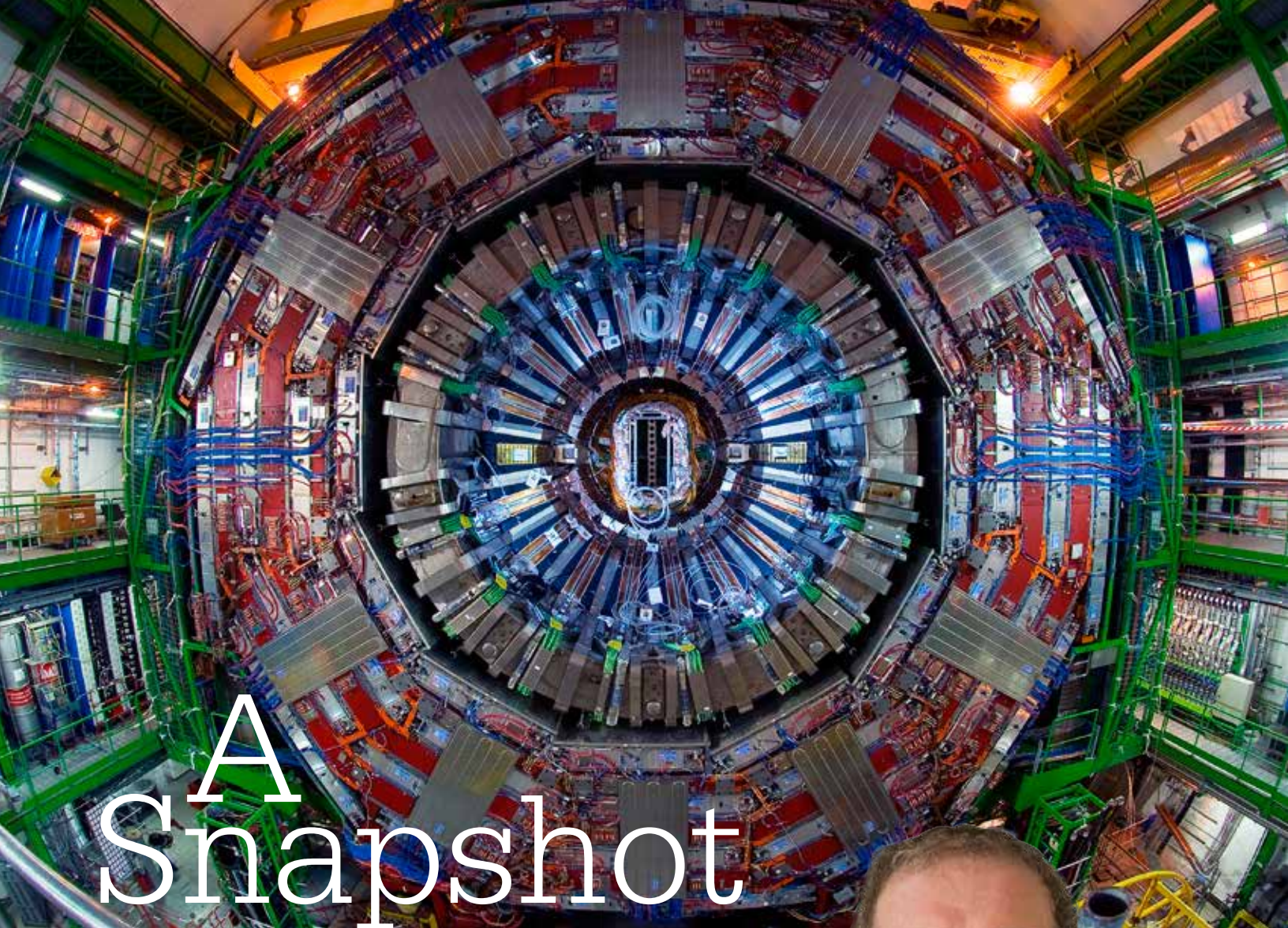
bumin would likely play a key role in transporting metallic nanoparticles in the circulatory system. Depending on their surface chemistry, metallic nanoparticles tend to aggregate in solutions with high salt concentrations. When you put them in a salty solution, like blood plasma, they clump together

because of strong attractive forces. Nanoparticle aggregation in the body could lead to toxicity issues and also affect the nanoparticle’s physical properties. This is a problem because the ability of gold nanoparticles to absorb and redirect light is at the heart of sensing and detection, diagnostics and therapeutic applications. “The only way that nanoparticles exhibit their really nice optical properties in very specific optical frequencies is if they’re separated,” Landes said.

Landes and Link found that at high concentration, BSA prevents gold nanoparticles from clumping in solution, a behavior that has also been observed for other nanoparticles. Each gold nanoparticle is surrounded by a biological coating termed the “corona.” This corona keeps the gold nanoparticles well separated and prevents aggregation. However, at low BSA concentrations, Landes and Link observed a one-to-one binding of nanoparticle to protein rather than the formation of a protein monolayer. “We think the protein is attaching first and unfolding, and that prevents other proteins from coming in,” Link explained. “But it also facilitates aggregation.” The bound BSA unfolds in the presence of the gold nanoparticle, spreading out and leaving no room for other proteins to bind. Unfolded proteins expose hydrophobic surfaces that are typically buried when the protein is in its native fold. These hydrophobic surfaces bind to other exposed hydrophobic surfaces, leading here to the aggregation of nanoparticle-protein pairs.

This suggests that researchers should proceed with caution when studying the interactions of nanoparticles with proteins. Consideration of not just the nanoparticle itself, but also of the environment that it will experience in vivo will aid in the rational design of nanoparticles for biomedical applications. Exposure of a nanoparticle to even a small amount of protein can cause changes to the protein’s secondary structure that lead to aggregation, which is correlated with many diseases including Alzheimer’s and Parkinson’s disease. “People really need to pay attention to the ratio between the protein — in this case, BSA — and nanoparticles because different things can happen,” Link said.

Landes and Link continually push one another to higher levels. On the tennis court, you will find them doing calisthenics and grueling exercises to improve their match play. In the lab, they encourage each other to learn more about the subjects they know a bit less about and to take the lead on projects outside their comfort zone as they continue to tackle difficult problems. “The only way to get better,” said Landes, “is to force yourself to do something that you aren’t already good at doing.” ■



A Snapshot

of One Rice Professor's
Quest to Understand
Our Universe

BY EVAN SHEGOG | Collider Image courtesy of CERN



“Anybody doing particle physics is really a reductionist,” Paul Padley explained. “What we are trying to do is break nature down to its most fundamental basic element.”

I nod my head and lean closer toward him, closing the distance that separates us in his cramped office. “That’s what drives us intellectually,” he continued with a slight smile. “To understand nature at its most basic form, to try and understand what our universe is made out of. It’s really, really infuriating how little we know and I want, before I die, to figure out all that stuff.”

Padley, a professor of physics and astronomy at Rice, was born in the United Kingdom, completed his studies in Canada and moved to Texas to continue his work in particle physics. As this was going on, across an ocean, in Geneva, Switzerland, the Large Hadron Collider (LHC) was being built. Upon its completion, the LHC became the largest and most powerful particle accelerator. The mission: to discover fundamental, unobserved particles that pervade the universe by simulating conditions that existed in the first billionth of a second after the Big Bang. These simulations most commonly include colliding two beams of protons together at near light speed. When this occurs, some of the energy of the collision turns into mass and elemental particles that live for a fraction of a second. “Imagine if you threw two strawberries together and a bowl of fruit came out,” said Padley. “Using the equation $E=mc^2$ (which states that you can turn energy into matter) you can take two strawberries and create heavier fruits.

“Even though the media portrays the LHC as a European project, it is a worldwide project,” Padley said, “and Rice plays a major role.” One specific part of the LHC that Rice researchers are spearheading is the Compact Muon Solenoid (CMS), one of two major experiments collecting data at the LHC. The CMS detector is comprised of 100 million individual detector elements, each designed to look for the traces of particular kinds of subatomic particles. These particle detectors are nested like Russian dolls, and they allow for the identification and precise measurement of the energies and momenta of all particles produced in collisions.

The CMS detector was built above ground in pieces, then lowered below ground to be fully assembled, all by particle physicists. “When NASA builds a rocket they hire contractors to build the rocket,” Padley said, “but, with particle physics experiments, when the work is appropriate, the actual building is done by students, postdocs and faculty at hundreds of collaborative institutions.” The CMS detector they built is massive, requiring more steel than the Eiffel Tower. The superconducting solenoid at its center generates a magnetic field of four Tesla, about 100,000 times that of the Earth. The CMS experiment currently supports research conducted by more than 4,000 scientists from 182 institutions in 42 countries, and Padley is in

charge of all the United States’ contributions to the detector’s operation.

“The U.S. has contributed various parts of the detector and played a multitude of roles in designing and building it,” Padley said. “All of that has to get funded and managed and it is my responsibility to make sure that the work is going well and that people are getting the appropriate funding.” Each year, Washington allocates approximately \$30 million to support U.S. contributions to the CMS experiment, of which about \$7 million is for the detector’s operation.

“Our current knowledge about the constituents of the universe is bewilderingly limited,” said Padley. It has been shown that undetectable dark matter and dark energy make up about 95 percent of the universe. “When you look at the Milky Way Galaxy, you can’t understand how this galaxy rotates without invoking this dark matter,” said Padley.

Although dark matter and energy constitute the majority of what surrounds us, we know very little about the phenomena. What we do know thus far is that dark matter affects gravity; however, this interaction is so weak that it cannot be directly

detected. When looking for dark matter directly, no specific signal has yet been observed “since we really don’t know what to look for,” said Padley. The current study of dark matter is very exploratory, and it is uncertain what, if anything will be found. There are hundreds, if not thousands, of hypotheses that are being tested, and it’s just a guess as to what all this research will reveal.

When experiments are being conducted at the LHC, collisions are happening 40 million times per second. This translates to 100 terabytes of data being generated per second by the CMS.

In order to analyze the results of these trials, the data needs to be sifted through to determine what yields relevant information.

Work is being done at Rice University to figure out how to cope with the huge amounts of data being generated and how to pick out specific signals in the data that are statistically significant. The data can be assessed in a multitude of ways depending on the hypotheses being studied. For example, the same data can be analyzed and modeled in different ways to support theories for supersymmetry, grand unification or extra dimensions.

At this time, particles are being fired at the highest energies ever at the LHC. Many scientists believe that the data being collected now will yield the exciting new results that the particle physics world has been waiting for. Padley and Rice University will help analyze the data that will be collected in order to uncover the secrets of the universe.

For now, the global scientific community, along with Padley, is eagerly hoping for that integral piece of data that will shed some much-needed light on our mostly dark universe. According to Padley, “There is something really deep and basic missing from our understanding of nature, and when we discover that, we can do new things.” ■

“Our current knowledge about the constituents of the universe is bewilderingly limited.”

Almost Periodicity and the Korteweg-de Vries Equation

If mathematics is the language of the universe, then differential equations must certainly be the words. It is no wonder, then, that David Damanik, Rice's Robert L. Moody Sr. Chair in Mathematics, turns to differential equations to learn more about the world at an atomic level. The Schrödinger equation, for example, models the propagation of a quantum wave-particle through potential energy barriers over time. Certain energy barriers, or "potentials," are extremely well understood, such as the periodic potentials arising in crystalline structures. In the 1980s, however, physicists discovered an exotic variety of material, dubbed quasicrystals, that demonstrate properties of both structured and random materials. So-called "almost

periodic" potentials similarly share certain aspects of periodic and random potentials, and they are Damanik's primary area of research.

The Korteweg-de Vries (KdV) equation was proposed over 150 years ago as a non-linear partial differential equation, modeling long waves in shallow water. Since then, it also has been shown to be an accurate model of a number of different physical phenomena, including the propagation of acoustic waves on a crystal lattice. What makes the KdV equation mathematically remarkable is that it describes a completely integrable system, that is, a system with infinitely many conservation laws, such as total energy and center of mass. In search of these laws, it was found that when

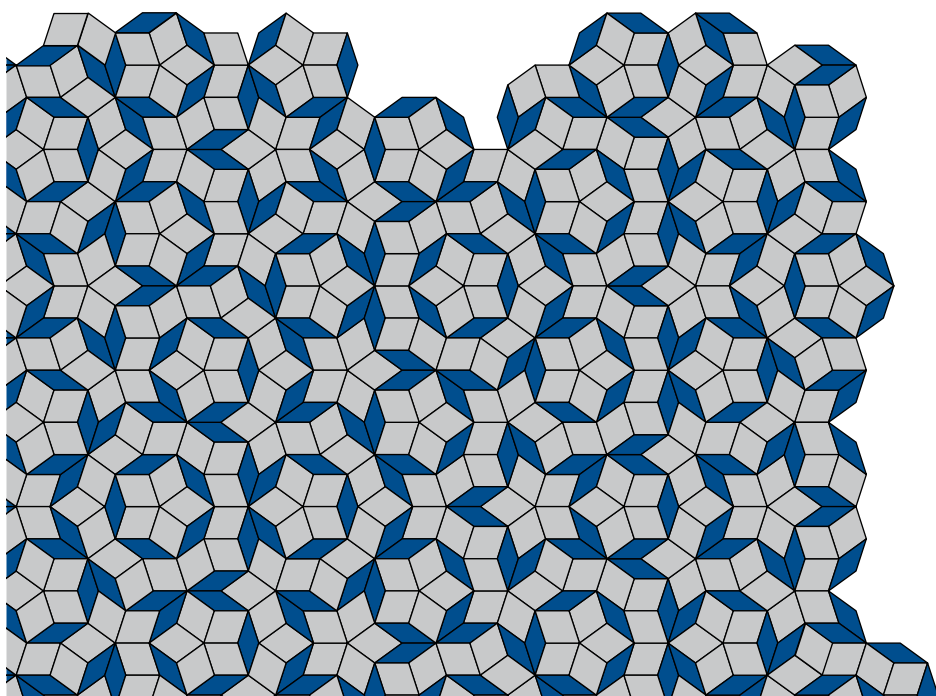
solutions to the KdV equation are viewed as potentials in the Schrödinger equation they preserve certain spectral properties. For example, if a crystalline material was to experience the effects of a KdV flow, the frequencies of light it reflects wouldn't change over time.

A major test of the practicality of a differential equation as a physical model is the question of existence and uniqueness of solutions: Can a given material change according to the KdV equation, and if so, will it always change the same way? In mathematics, this is known as an initial value problem. Existence and uniqueness are known for the KdV initial value problem for crystalline, periodic initial data. The question Damanik and his collaborators asked was whether existence and uniqueness also hold for almost periodic initial conditions.

Using mathematical rigor and logic, Damanik and his collaborators were able to show existence and uniqueness to the KdV initial value problem for almost periodic potential energy barriers that were sufficiently small. They did this by approximating the almost periodic potentials with nearby potentials, which share many important properties of periodic potentials. By taking increasingly fine approximations, they were able to show that their potential was indeed a solution of the KdV equation. Even better, the group showed that this solution must itself be almost periodic.

Physically speaking, this result isn't exactly a revelation as physicists and applied mathematicians have shown experimentally and numerically that the KdV equation is an effective model for this and many situations. But experiments, both numerical and physical, can't preclude the possibility that there is a more accurate and effective model for these phenomena. Damanik's work offers further evidence that these phenomena are indeed governed by the KdV equation, suggesting that perhaps we have managed to decipher a little of the universe's language after all. ■

"It is the competition between order and disorder that makes quasicrystals fascinating. The realization that long-range order is possible in the absence of periodicity led to a paradigm shift in materials science."



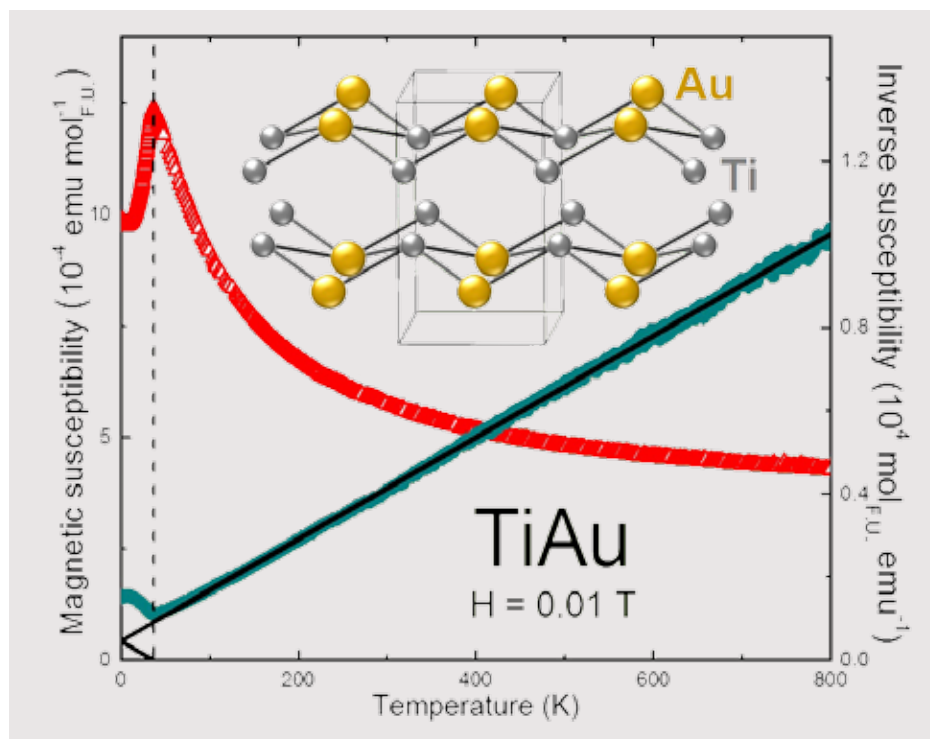
— TOM VANDENBOOM

A Breakthrough Magnetic Material Made of Nonmagnetic Constituents

Magnets are typically associated with magnetic elements, like iron, nickel, cobalt and more. However, a research team led by Emilia Morosan, a Rice professor of physics and astronomy, of chemistry, and of materials science and nanoengineering, has discovered novel magnetic properties in a material made entirely out of nonmagnetic constituents: titanium and gold.

The team discovered that TiAu is an “itinerant” magnetic material. In a metal crystal, the structure consists of a crystal lattice of atoms whose conduction electrons make up an electron sea surrounding the lattice. In TiAu, the magnetic properties arise from local imbalances in the up and down spins of conduction electrons in the material that occur because unpaired conduction electrons are not bound to the lattice. “Local moment” magnetic materials, on the other hand, have long-range order in the atomic magnetic moments because the unpaired electrons are lattice bound. The team’s recent discovery identified TiAu as only the third-known magnetic material made from nonmagnetic constituents, with the other two being $ZrZn_2$ and Sc_3In that were discovered in the 1960s.

“When we started looking, we found out why 50 years had passed without any additional discoveries,” Morosan said. “Most other possible candidates were problematic in one way or another. They were hard to make, chemically unstable, toxic or required a high temperature that was not accessible in the lab.” Electronic structure calculations showed that a one-to-one ratio of Ti and Au might have the properties they were looking for, but previous reports of TiAu described three different crystal structures. Due to the difficulty of separating the crystal phases or preparing them individually, researchers could not probe the magnetic properties that inherently depend on the crystal structure. Morosan’s real breakthrough was the production of a sample containing only one crystal structure. Once they had accomplished this, they could probe the temperature-dependent magnetic prop-



Measurements show that a crystalline form of titanium and gold – TiAu – becomes magnetic (red peak) at 36K. This material is the first known example of an itinerant antiferromagnet.

erties of TiAu by cooling the crystal to -237 degrees Celsius, just 36 degrees above absolute zero.

Magnetic properties rely on unpaired electrons that allow for the average electron spin in the material to be unbalanced, where more electrons are in either a spin up or spin down state. This produces a magnetic moment for the material. Magnetic properties are frequently correlated with temperature, and that is certainly the case for TiAu.

At room temperature, an itinerant magnet like TiAu possesses conduction electrons that have enough thermal energy to move within the metal lattice and fluctuate between their spin states often. This results in a net zero magnetic moment, and so the material is nonmagnetic. As TiAu is cooled below a transition temperature, called the Néel temperature, the electron spins align antiparallel to one another in an ordered pattern, creating what is called an antiferromagnet. This

is the opposite from more well-known ferromagnets, which have most or all of the unpaired electrons spin aligned with one another. TiAu is the first itinerant antiferromagnetic material with no magnetic elements to have been discovered, and its discovery will help provide a deeper understanding of magnetism.

The Rice team is excited for further investigations, which will aim to understand the strength and role of the TiAu electron spin fluctuation contributions to its magnetic behavior. “Theoretically we understand local-moment magnetism quite well, and we have some understanding of the itinerant moment, but most true systems really live in between,” said Morosan. “We have to understand the extremes in order to figure out the physics of what’s going on in between.” ■

– JAMES MCCREARY

Carbon Nanotube Fibers Repair Hearts and Interface With Brains

Carbon nanotube fibers are extraordinary materials. They are small and flexible, but possess immense strength. They can be excellent conductors of electricity, but are lighter and more flexible than metallic wires. Researchers in the lab of Matteo Pasquali, the A. J. Hartsook Professor of Chemical and Biomolecular Engineering and professor of chemistry and of materials science and nanoengineering, are exploiting these incredible qualities of carbon nanotube fibers to both repair hearts and interface with brains.

Pasquali, who also serves as the chair of Rice's Department of Chemistry, aims to harness the unique attributes of nanotube fibers to create cardiac patches that can not only repair damaged heart tissue, but also mimic normal heart activity. "The unique combination of strength, conductivity and softness makes [nanotube fibers] ideal for interfacing with the electrical function of the human body," Pasquali said.

Some cardiac illnesses arise from structural issues within the heart and can only be repaired with an implanted

patch. Normal cardiac patches have some problems — for example, they can cause delays in electrical signaling that lead to heart arrhythmias. Pasquali and his team used electrically conductive nanotube fibers to get around this issue. They created novel hydrogels by dispersing the fibers into gelatin and chitosan, two polymers commonly used in tissue engineering. The team then grew rat cardiac cells on the hydrogels to test their ability to support cell growth. While high concentrations of nanotubes in the gels decreased the viability of the growing cells, concentrations lower than 69 parts per million (ppm) did not noticeably inhibit growth.

When the team further examined the growing cells, they found that those grown on gels with a nanotube concentration greater than 33 ppm contracted at over 300 beats per minute, a speed close to that of a normal rat heart. They also transmitted electrical signals roughly three times faster than cells grown on gels without nanotubes. According to the researchers, heart patches built based on this technol-

"The unique combination of strength, conductivity and softness makes [nanotube fibers] ideal for interfacing with the electrical function of the human body."

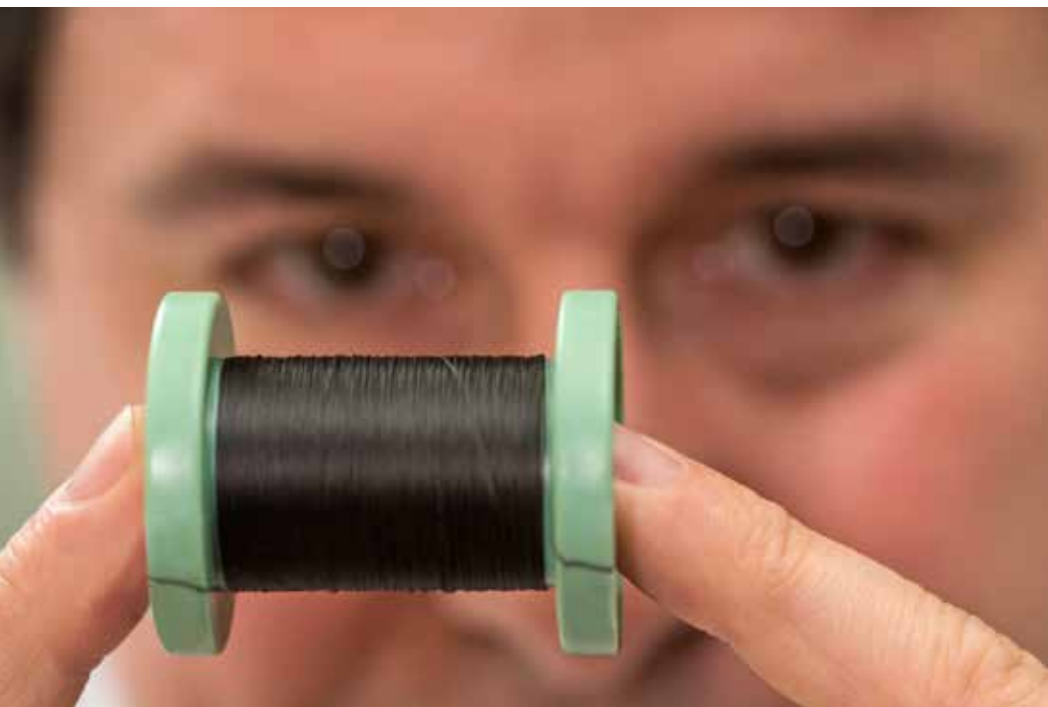
ogy could provide a superior solution to physical heart defects.

Electrically conductive nanotube fibers aren't just useful in fixing heart defects — they can also provide a better way to interface with neurons. Doctors excite neurons in a variety of situations, including during deep brain stimulation (DBS), a technique used to treat neurological disorders like Parkinson's. Typically, DBS is performed using metal electrodes implanted into the brain, but these hard, large metal implants can cause scarring, further harming sensitive brain tissue. Carbon nanotube fibers have lower electrical impedance and are softer than typical metal wires, allowing them to serve as more effective, less invasive electrodes.

When Pasquali's team implanted nanotube fiber electrodes into rats with Parkinson's and subjected the rats to DBS, they found that the nanotube fibers were able to attenuate the Parkinson's symptoms while inducing less scarring than metal implants. In addition to stimulating neurons, the implanted fibers were able to precisely monitor neural activity for up to three weeks, raising the possibility of closed-loop systems that might detect neural issues and administer appropriate treatment automatically.

Pasquali said he is gratified to see a new way in which nanotechnology can help save lives. "We're determined to find ways to treat rather than manage disease." ■

— TEJUS SATISH



Matteo Pasquali holds a spool of fiber made of pure carbon nanotubes. The fibers are being studied to bridge gaps in the conductivity in damaged heart tissues and to stimulate neurons in the brain.

A High-Throughput, Low-Cost System for Testing Nanoparticle Toxicity

Nanoparticle technology is becoming an increasingly prominent feature in our daily lives. From electronics to health technology to antimicrobial food packaging, nanoparticles are integrated into the products that surround us. With the regular presence of these particles comes the question of whether they are safe. Weiwei Zhong, assistant professor of biochemistry and cell biology at Rice, is part of a team of researchers that has created a way address this issue.

Zhong, along with a team of engineers and biologists, designed a way to test the toxicity of nanoparticles that provides a more thorough understanding of systemic toxicity than previous processes. Traditional animal tests of toxicity (e.g., tests on mice) are costly. Other scientists have designed toxicity-testing processes that involve either individual cells or chemical based models, both of which are cost effective but don't reflect the complexity of cell interactions on the scale of an entire organism. Zhong and her associates have overcome these obstacles while still being able to test entire organisms in a high-throughput and low-cost manner. Their system uses a 1-millimeter-long worm, *C. elegans*, as the subject. In addition to low cost and minimal care requirements, *C. elegans* has the benefit of being available in large quantities given that one worm can produce over 300 offspring during its three-day life cycle.

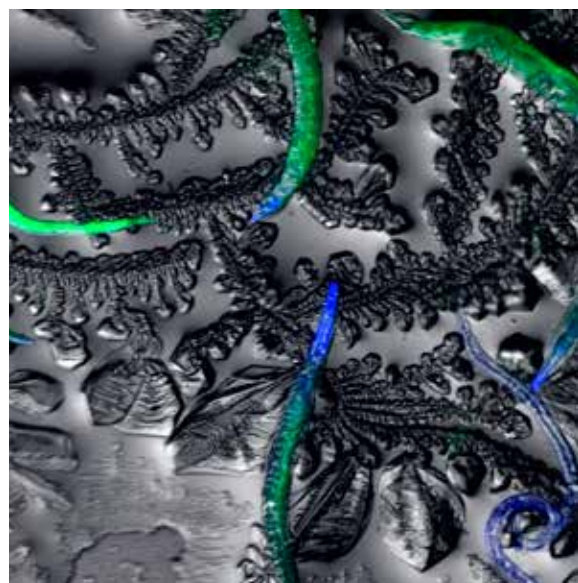
The use of these worms does present some challenges. "The biggest challenge is that they're so tiny; how do you test whether they're sick or not?" Zhong explained. "You want to have quantitative assays, not just whether they survive.

Our challenge was designing a system to score the worms on whether they were growing, eating enough and moving." By measuring food consumption, body length, lifespan and speed of the organism using their QuantWorm system, in which the worms were tested in both aqueous and solid mediums, Zhong and her colleagues were able to create quantitative measurements of nanoparticle toxicity. This quantitative data paired with high-throughput capabilities — large populations of the worm mean that dozens of nanoparticles can be efficiently tested — is what Zhong described as the most revolutionary aspect of the system.

The team's study revealed that only five of the 20 nanoparticles tested were minimally toxic, while the majority demonstrated dose-dependent toxicity. Titanium dioxide nanoparticles were found to be the least toxic (highest fitness, body length, lifespan and speed) while multiwalled and single-walled carbon nanotubes were highly toxic even at low doses.

The study also revealed that factors such as shape and surface chemistry of the nanoparticles can affect their toxicity. For example, amine-functionalized multiwalled nanotubes (MWNT) were significantly more toxic than hydroxylated MWNTs. When asked about the implications of these results Zhong said, "We shouldn't stop using nanoparticle technology but we need to do more research to fully understand them and make them safer. It's time to start studying the effects of nanoparticles."

Zhong and her fellow researchers have made their data and a specific description



C. elegans worms stained blue and green are embedded in a salt crystal. These round-worms are favorite models of biological systems for their relative simplicity, their transparency and the ease with which scientists can manipulate their genetic sequences.

of the QuantWorm system publically accessible to allow other researchers to build on their work. As for their current data, Zhong expressed her hopes that engineers could use the study's findings to build quantitative structure-activity relationship models. These models, if they integrate enough data, could eventually link certain features or functional groups of the nanoparticles to toxicity. With this information, dangerous features of nanoparticles could be redesigned. For these models to create accurate predictions, they would require more information about the toxicity of various nanoparticles.

Zhong envisions this possibility becoming a reality: "You can imagine a huge database. Right now we only have 100, but if you collect more data, you can build a more accurate model. And this will allow the design of safe nanoparticles and safer materials." ■

— NATALIE DANCKERS

"We shouldn't stop using nanoparticle technology but we need to do more research to fully understand them and make them safer. It's time to start studying the effects of nanoparticles."

The Rice Electron Microscopy Center Provides a New Perspective on Physical Science

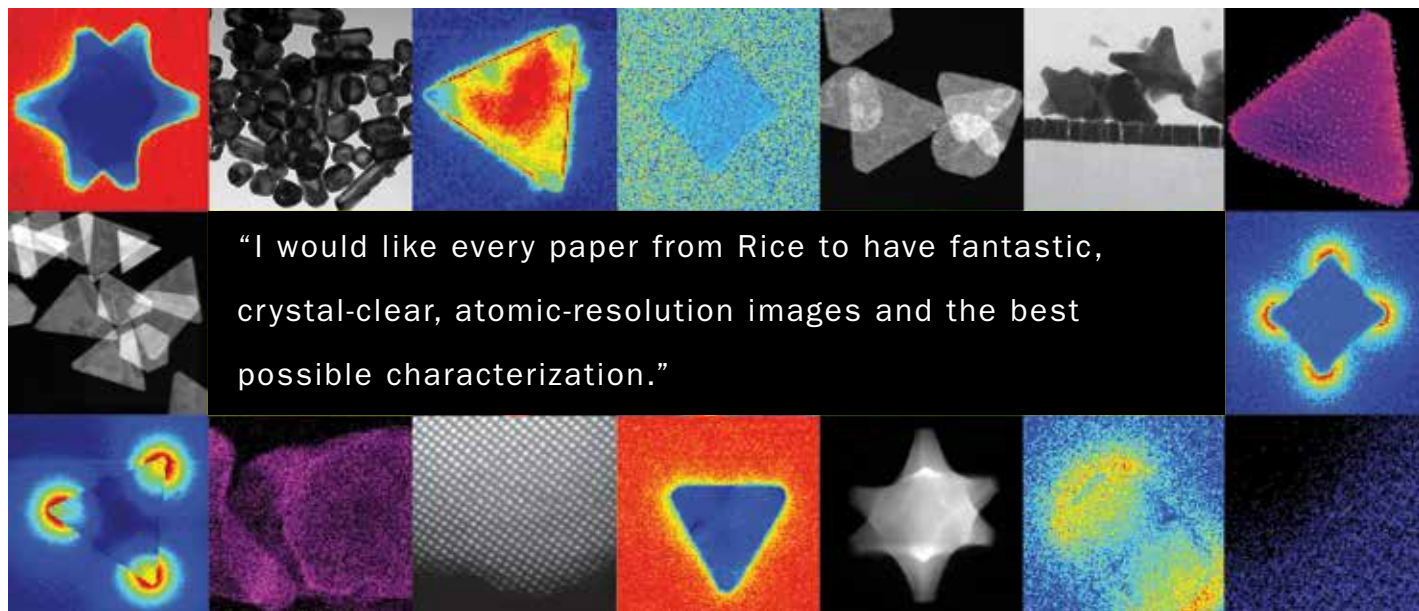
With the ability to analyze materials at subnanoscale resolution, the Titan Themis scanning transmission electron microscope (STEM) at Rice is providing scientists and researchers a new look at the physical world. A far cry from the tabletop light microscopes populating high school biology classrooms, the Titan utilizes a beam of high-energy electrons to capture high-resolution images of nanoscale materials, some as small as a single hydrogen atom. Recently installed in the Rice Electron Microscopy Center, it is the newest and most powerful model to

scopes is determined by the diffraction limit, which is the wavelength divided by two, or roughly 200 nm for visible light. Electron microscopes like the Titan, however, work by firing a beam of electrons at their target. Because electrons have wavelengths up to 100,000 times shorter than those of visible light photons, the Titan can capture highly detailed images of materials at the angstrom scale (one-tenth of a nanometer), the size of single atoms.

Such a system far outclasses light microscopes, and the Titan itself is, accord-

and composition of atoms. These images also can be used to create 3-D reconstructions of the samples, providing researchers with a deeper understanding of their materials.

The Titan's impact on materials science research at Rice will undoubtedly be massive. "We have people from basically every department using this instrument," noted Ringe. "The main impact here is that the Titan will give [researchers] the key to understanding their material's properties, [and] when you work with a material, you need to understand its



be assembled in the United States and is now open to Rice students and faculty as well as external academic and industrial researchers.

The microscope was selected and purchased for the university by Emilie Ringe, an assistant professor of materials science and nanoengineering and of chemistry, who is currently using it in her research on the plasmonic and catalytic properties of bimetallic nanoparticles. As Ringe described, the main advantages of the Titan are the quality of its detectors and the clarity of its images, providing researchers with much more reliable data on extremely small samples — down to single atoms. The resolution of micro-

ing to Ringe, much more efficient than other electron microscopes. "It's about 10 times better, would be my estimate, compared to the other microscopes at Rice, the standard run-of-the-mill electron microscopes." The resolution of electron microscopes is limited not by diffraction, but by intrinsic imperfections in the electron lenses that distort the image, and as Ringe explained, "the Titan is aberration corrected, so it can correct those imperfections, leading to this amazing resolution." The Titan captures images with a variety of detectors, including X-ray, visible light and several electron detectors, capable of providing simultaneous information about position, bonding

properties." The excitement surrounding the purchase of the Titan extends to graduate and undergraduate students as well. "We've started an electron microscopy class at Rice where [students] can actually [learn to] use this microscope in a lab setting. And it's really fun!"

Ringe's enthusiasm is contagious, and she looks forward to sharing her passion with this next generation of scientists. "I really hope that by having the Titan here we will bring more students interested in nanotechnology and materials engineering to Rice." ■

— CHRISTOPHER HICKS

UNDERGRADUATE RESEARCH

Partnership Between Rice and Texas Children's Hospital Enables Exceptional Undergraduate Research

Lindsay Pang '16, was eager to get started in undergraduate research when she first came to Rice in fall 2012. Fortunately, Texas Children's Hospital Center for Human Immunology was launching a competitive and comprehensive undergraduate research experience that same year, accepting its first cohort of Rice undergraduate students into the Developing Investigative Scholar's Program (DISP). DISP aims to train the next generation of scientists through the thorough development of a long-term biomedical research project during the undergraduate years. Pang was excited to take advantage of this opportunity and spent the next four years conducting translational research as one of the first Rice students accepted into DISP.

Like most freshmen, Pang had little lab experience when she was paired with Texas Children's Hospital and Baylor College of Medicine doctors Jordan S. Orange and Pinaki Banerjee as her research and bench mentors. She quickly began learning the basics of cell culture and immunology and soon realized that she could also reach out to other trainees and scientists in the center for help learning new techniques or deciding on the next experiment. "[The PIs] are dedicated to teaching us and showing us how to conduct research and learn about the scientific method," Pang said. "They were so excited to bring in students and teach them and that translated into my own excitement. I couldn't wait to hit the ground running with my project."

Under Orange and Banerjee's guidance, Pang began investigating the role of natural killer cells (NK cells) in the onset of multiple sclerosis (MS). MS is a chronic disease where the immune system attacks myelin, the protective sheath covering nerve fibers. MS often occurs as a relapsing-remitting disease. Patients can experience months of remission from the disease only to develop new symptoms over a few days or weeks. The role of NK cells may be equally two-faced as the disease itself, as some studies have associated NK cells with MS remission, while other studies have associated NK cells with progression.

A key feature of NK cells is their ability



Lindsay Pang '16

to distinguish stressed cells, such as tumor cells or virally infected cells, from normal cells. A dynamic balance of activating and inhibitory cell surface receptors determines whether or not NK cells kill target cells. Inhibitory receptors dampen NK cell activity upon interaction with their corresponding ligands, stopping NK cells from targeting healthy cells. These inhibitory receptors include KIRs (killer cell immunoglobulin-like receptors), which recognize HLA (human leukocyte antigen) molecules.

There is a great deal of variety in the expression of these genes, and certain HLA haplotypes have been linked with the susceptibility to autoimmune diseases such as MS. An HLA haplotype is a group of closely linked HLA genes on one chromosome that are inherited as a unit. Typically, when inhibitory KIRs bind with matching HLAs, NK cells do not kill those target cells. However, certain HLA haplotypes may lead to a mismatch between the HLA and receptor. This HLA mismatch lowers the KIR-HLA binding affinity, thereby reducing NK cell inhibition and leading to the destruction of healthy cells.

Previously, in Orange's laboratory, Banerjee had established that activated NK cells have greater demyelinating activity than resting NK cells, but had not tested whether this activity is restricted to HLA haplotype mismatch. Pang set out to understand the mechanism of demyelinating activity by NK cells and to elucidate the role of HLA haplotype in demyelination. After showing that activated NK cells form more conjugates with target cells and

perform more demyelinating activity than resting NK cells, Pang reached a pivotal moment for her research project when she was faced with the task of creating a new cell line.

DISP students are encouraged to take full ownership of their research projects from the beginning, and Pang emphasizes that creative problem-solving and critical thinking were stressed throughout her four years. "It was an entire summer's worth of work filled with failures over and over again as I learned new techniques for cloning and genetic tagging," Pang said. "But each failure was a lesson in and of itself. Although it hurt, by the end of the summer [we had] cell lines, which did not exist before." These two new cell lines were essential for moving the research forward, eventually allowing Pang to show that the observed demyelinating activity of NK cells does not depend on HLA haplotypes, which are being expressed on neuronal cells.

Conducting research in the Texas Medical Center allowed Pang to gain an appreciation for the connection between basic science research and the clinical treatment of disease. She believes that it is crucial to keep this link between medicine and research in mind as she now pursues a medical degree. "There are so many resources right next to Rice University that are so easily accessible for students. That's why I came to Rice. It was an opportunity that I didn't want to give up." ■

— LAUREN KAPCHA

A Superposition of Outstanding Undergraduate Research and Excellent Teaching in Mathematics

A group of students stands around a chalkboard, where they are writing and erasing, discussing the merits of one approach or another to solve a problem. This is a stereotypical description of research in popular media, but is often an uncommon sight in graduate and undergraduate research these days. In David Damanik's group, however, this scene is common place. "I think it's kind of an experiential thing," said Jon Erickson, one of the students who worked with Damanik, the Robert L. Moody Sr. Chair in Mathemat-

equations. They were led by Ph.D. graduate Jake Fillman '14, who served as both a mentor and a fellow researcher. "We would get away from the group setting, explore on our own and try to figure out the way we think would work best," recalled Vu. "Then we'd come back together and say 'this worked for me.'"

A key concept in the work is a quantum walk, though the basics of a "walk" are most easily explained beginning with the classical 1-D random walk. For each discrete step in time, the walker may de-

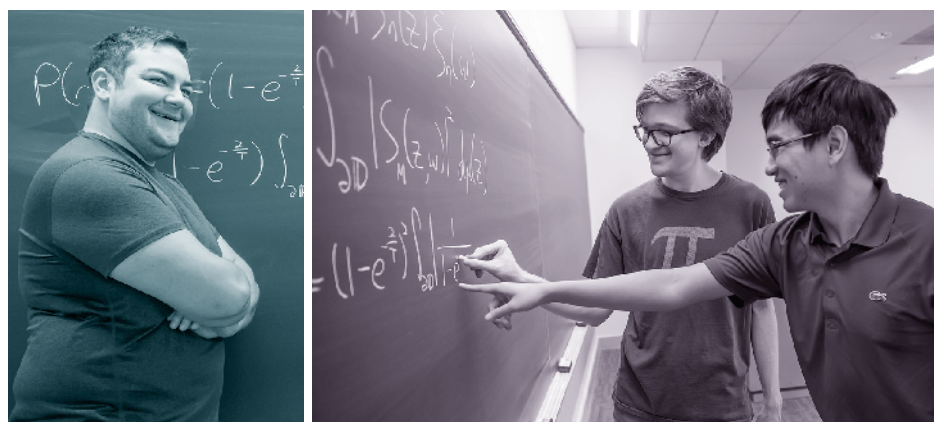
the normal distribution, as in the classical case. Instead, an interference pattern is observed. The distribution is described by a combination of Hermite and Airy functions, oscillating throughout the region on the number line.

Both classical and quantum walks can be utilized in computational algorithms, and quantum walks often arrive at a difficult solution faster than classical algorithms. In fact, quantum computers are already being developed with quantum walks in mind. Classical and quantum walks can be used to model the behavior of systems that transition through or exist in multiple states from the diffusion of molecules and small particles to how a photon's energy travels from state to state along a plant's chlorophyll complex.

All three students worked as if they were graduate students, earning an in-depth, inside look at what top-level research is all about. Hinkle is now pursuing a graduate degree in mathematics and Vu is pursuing a medical degree. Like Hinkle, Erickson also plans to go to graduate school, but he intends to teach at the high school level for a few years first. "It was something I've always kind of wanted to do," Erickson said, "because the teachers I've had were really instrumental in shaping my appreciation for mathematics."

Erickson recalled a previous discussion with Damanik. "He was asking us about our experiences with math professors," said Erickson. "He really wanted to work with people who not only had the research background, but also the teaching ability, because he felt that was really crucial to the mission of the math department." ■

— JANA OLSON



Jon Erickson '16, Gerhardt Hinkle '16 and Alan Vu '16

ics, for the summer. "There's something that's just really nice about writing on a blackboard."

Using this blackboard, Jon Erickson '16, Gerhardt Hinkle '16 and Alan Vu '16 worked to describe a quantum walk on the half line. "Our goal was to take this paper, which is a continuous model of a quantum particle on the half line with these barriers, and turn it into a quantum walk model where instead of moving continuously, you have discrete steps," said Erickson. "Quantum coins, as they're called, represent how the particle transitions [between states]."

The threesome spent their daily working hours reading and discussing research articles, determining which new approaches could be utilized in their own research and working out complicated

decide whether to move to the left or to the right on the number line, like flipping a coin and recording the results. Constraints on the walker's motion and the amount of time over which the experiment occurs control the shape of the probability distribution resulting from multiple walks. The typical distribution for a random walk is a normal distribution that broadens as time increases and may be skewed in some direction by the constraints.

"But then, in the quantum case, you have this additional piece of data which is the spin of the particle. Like say the possible states are not just each position, but also whether it's spin up or spin down," said Hinkle. In this way, the position of the subject and its spin are coupled and constrain one another at each time point. This complicated coin does not follow

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delving into a new kind of science

Is the world really as complicated as you think?

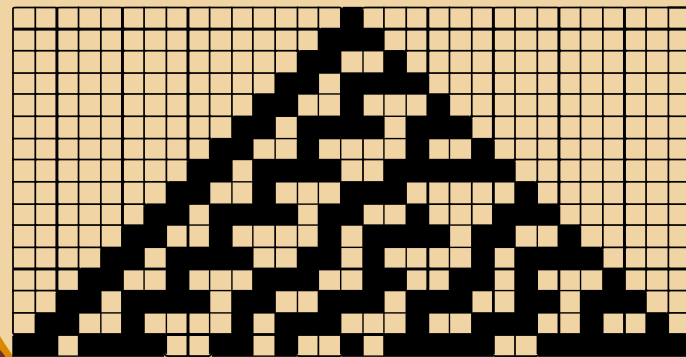
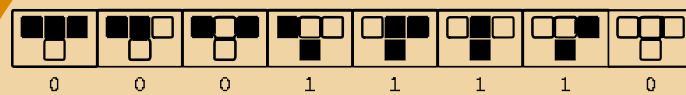


Figure 1: The Rule 30 Automaton, from Wolfram Mathworld.¹

By Seokin Yeh

Since ancient times, humans have attempted to create models to explain the world. These explanations were stories, mythologies, religions, philosophies, metaphysics, and various scientific theories. Then, about three centuries ago, scientists revolutionized our understanding with a simple but powerful idea: applying mathematical models to make sense of our world. Ever since, mathematical models have come to dominate our approach to knowledge, and scientists have utilized complex equations as viable explanations of reality.

Stephen Wolfram's *A New Kind of Science* (NKS) suggests a new way of modelling worldly phenomena. Wolfram postulates that elaborate mathematical models aren't the only representations of the mechanisms governing the universe; simple patterns may be behind some of the most complex phenomena. In order to illustrate this, he began with cellular automata.

A cellular automaton is a set of colored blocks in a grid that is created stage by stage. The color of each block is determined by a set of simple rules that considers the colors of blocks in a preceding stage.¹ Based on just this, cellular automata seem to be fairly simple, but Wolfram illustrated their complexity in

rule 30. This cellular automaton, although it follows the simple rule illustrated in Figure 1, produces a pattern that too irregular and complex for even the most sophisticated mathematical and statistical analysis. However, by applying NKS fundamentals, simple rules and permutations of the building blocks pictured can be developed to produce these extremely complex structures or models.²

By studying several cellular automata systems, Wolfram presents two important ideas: complexity can result from simple rules and complex rules do not always produce complex patterns.²

The first point is illustrated by a computer; relying on Boolean logic, the manipulation of combinations of "truths" (1's) and "falses" (0's), computers can perform complex computations. And with proper extensions, they can display images, play music, or even simulate entire worlds in video games. The resulting intuition, that complexity results from complexity, is not necessarily true. Wolfram shows again and again that simple rules produce immense randomness and complexity.

There are other natural phenomena that support this theory. The patterns on mollusk shells reflect the patterns generated by cellular automata, suggesting

that the shells follow similar simple rules during pattern creation.² Perhaps other biological complexities are also results of simple rules. Efforts are being made to understand the fundamental theory of physics based on ideas presented in the NKS and Wolfram's idea might even apply to philosophy. If simple rules can create seemingly irregular complexity, the simple neuronal impulses in the brain might also cause irregular complexities, and this is what we perceive as free will.²

The most brilliant aspect of NKS lies in its underlying premises: a model for reality is not reality itself but only a model, so there can be several different, accurate representations. Our current approach to reality -- using mathematical models to explain the world -- does not have to be the only one. Math can explain the world, but NKS shows that simple rules can also do so. There may be methods and theories that have been overlooked or remain undiscovered that can model our world in better ways.

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DESIGN BY Lucy Guo, Vidya Giri



Rice University
Wiess School of Natural Sciences—MS 102
P.O. Box 1892
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HIGHLIGHT

Rice Geologists Study Half-Billion Year Old ‘Time Capsules’

Outcrops like these cliffs on Eagle Ridge Ranch in Central Texas were under the ocean on a wide, shallow continental shelf during the Upper Cambrian era. This is what attracted marine geologist André Droxler, a professor of earth science at Rice, to a land-based expedition. Droxler and his team of researchers have drilled more than 150 core samples across the area and created a virtual image of the cliffs with inch resolution using a sophisticated drone. Like modern corals, microbes and bacteria built these 10–15 meter high reefs that entombed the first forms of life on Earth. These core samples may provide clues to the kind of early life that might be discovered on other planets like Mars. ■

— JANA OLSON