

The Magazine of the Wiess School of Natural Sciences at Rice University ▶ Winter 2019

ENQUIRY



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

A LETTER FROM THE DEAN



PETER J. ROSSKY
Dean, Wiess School of Natural Sciences

“AS YOU READ THROUGH THE STORIES, I HOPE THAT EACH OF YOU CAN SENSE THE CURIOSITY THAT FUELS THE EFFORTS OF OUR FACULTY AND STUDENTS AT ALL LEVELS TO UNDERSTAND THE MOST BASIC ELEMENTS OF NATURE.”

Dear Friends of the Wiess School,

I am delighted to welcome you to this issue of ENQUIRY, the magazine of the Wiess School of Natural Sciences at Rice University. Within the pages of this issue, you will find exciting stories of discovery — examples of the scientific explorations and the frontier work of the scientists that make up our exceptional school. As you read through the stories, I hope that each of you can sense the curiosity that fuels the efforts of our faculty and students at all levels to understand the most basic elements of nature.

The spectrum of investigations in Rice’s natural sciences is extraordinary and ranges from the origin of Earth’s atmosphere to the synthesis of biomedical materials, and covers a breadth of scales from the subatomic regime of fundamental particle physics, to the life form of a virus, to the diverse ecosystems that support biodiversity.

I also am delighted to have this opportunity to share with you the national and international recognitions received by our faculty and students during the past year. I am particularly proud to draw your attention to the primary authors of the magazine’s content — our amazing Rice students from across the university. I hope you will take a moment to read about these accomplished contributors.

All of the faculty, staff and students in the Wiess School join me in welcoming you to this issue, and we wish you an inspiring journey 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
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For information about supporting the natural sciences at Rice, please contact Ryan Kenney at 713-348-4268 or ryan.p.kenney@rice.edu.

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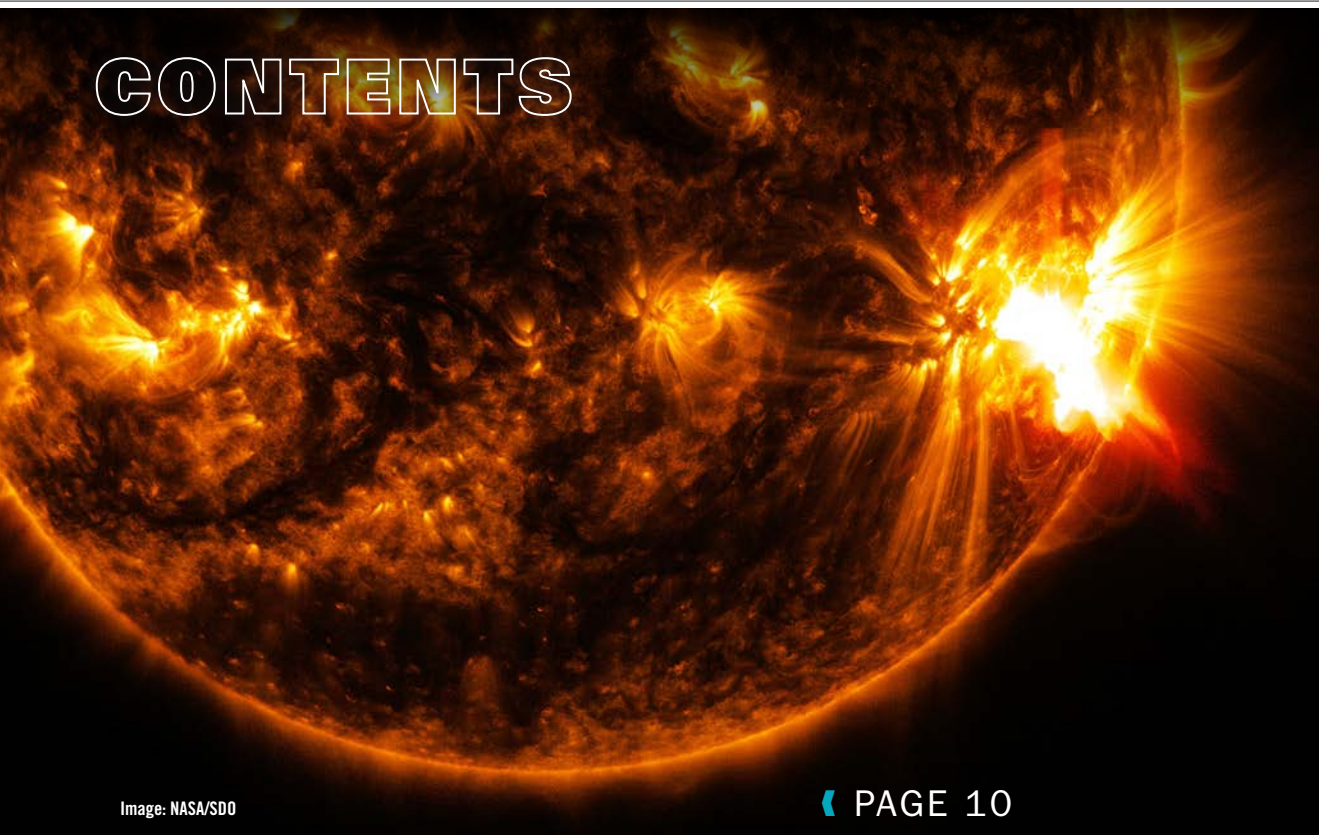
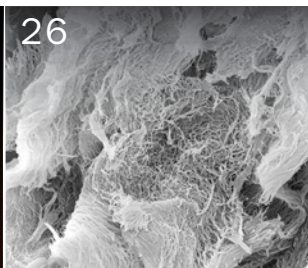


Image: NASA/SDO

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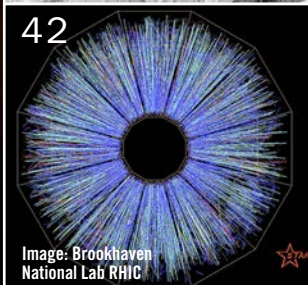


Image: Brookhaven National Lab RHIC

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Image: NASA

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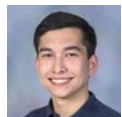
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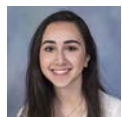
On the cover: Plant stigma are seen under a light microscope with their tentacle-like arms extended to capture pollen landing on the stigma. In an effort to understand pollen transfer between rare trees, Rice researchers are developing a community pollen network that identifies which rare tree species receive pollen from other tree species. Analyzing pollen morphology through microscopy techniques is tedious work, but is critical to understanding these pollen networks. Image: Laura Nicholson.

CONTRIBUTORS



THOMAS ETHERIDGE '19

(“Heavy Ion Collisions Produce Speediest Vortex” and “Protein Spies: A New Proteomics Tool”) is a senior cognitive science major and biochemistry and cell biology minor at Lovett College. Etheridge spends his free time performing community service at local hospitals and playing music in several ensembles. He is a writer for Catalyst and hopes to attend medical school.



RUCHI GUPTA '20

(“More Efficient Catalysts for Water Splitting”) is a junior at Sid Richardson College, majoring in chemistry and minoring in biochemistry and cell biology. She is an editor for Catalyst and hopes to attend an M.D./Ph.D. program. In her free time, Gupta enjoys reading, writing and running.



DORA HUANG '21

(“The Environmental Impacts of Hurricane Harvey”) is a sophomore bioengineering major at Duncan College. Huang is involved with Engineers Without Borders, is passionate about painting and dancing, and is a huge music buff. She is a writer for Catalyst.



MAHESH KRISHNA '20

(“Engendering an Early Earth Environment”) is a junior at McMurtry College double majoring in biochemistry and cell biology and policy studies. He is a writer and editor for Catalyst and the head mentor for Catalyst Eureka outreach. Krishna conducts research with Richard Kellermayer at Baylor College of Medicine studying the origins of inflammatory bowel disease and primary sclerosing cholangitis, two diseases that have impacted him personally. He hopes to pursue an M.D./Ph.D. to continue his study of gastroenterology and immunology.



SANKET MEHTA '19 is a senior computational and applied mathematics major at Will Rice College. He is

co-president of Catalyst and served as Catalyst’s liaison for this issue of ENQUIRY.



GRESHMA NAIR

(“Uncovering the Mysteries of the Sun”) was a postdoctoral research scientist in electrical

and computer engineering working with Gururaj Naik. Prior to her work in the Naik lab, she received her Ph.D. from the Indian Institute of Science. Nair enjoys reading fiction and is a trained Indian classical dancer.



SRIPARNA SAHA

(“A Chemist’s Quest to Mimic Nature”) is a fifth-year graduate student, pursuing a Ph.D.

in earth science under the supervision of Rajdeep Dasgupta. Saha is passionate about science communication and outreach and wants to teach young students about science and encourage them to pursue STEM fields. She is an avid bookworm and blogger, a part-time poet and crafter, and the author of the novel “Remember.”



ELAINE SHEN '18

(“Crypt-Keeper Wasp Manipulates the Behavior of Its Parasite Host”) graduated

this past May with a major in ecology and evolutionary biology and a minor in environmental studies. Shen is interested in marine biology, specifically fisheries ecology and seafood systems, and is continuing her education in the Ph.D. program at the University of Rhode Island. She enjoys dancing, finding new music and spending time outside. Shen was a writer for Catalyst.



JULIANA SPECTOR

(“Unexpected Enrichment of Heavy Nitrogen in Earth’s Atmosphere”) is a second-year

graduate student, pursuing a Ph.D. in earth science under the supervision of Mark Torres. Spector enjoys rock climbing and singing with the Houston Cecilia Chamber Choir. She also writes for the Rice Thresher, the official student newspaper at Rice.



SOPHIA STREETER '18

(“A Superior Dietary Assessment for Cancer Patients” and “Assessing the Pollination

Success of Rare Trees”) graduated this past May with a major in ecology and evolutionary biology. She enjoys horseback riding, traveling and spending time in the great outdoors.



OLIVER ZHOU '21

(“Toward Long-Lasting Influenza Immunity”) is a

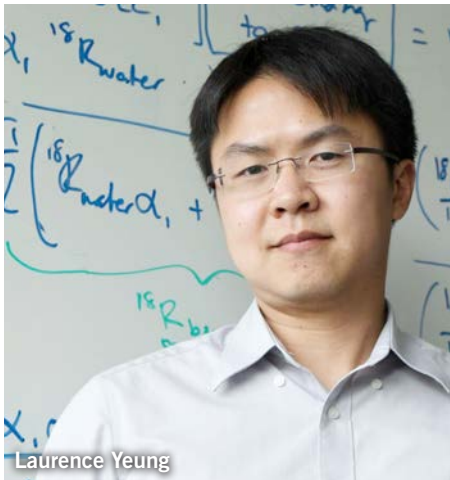
sophomore at Martel College majoring in biochemistry and cell biology and minoring in neuroscience. Zhou enjoys tennis, soccer, playing the piano, drumming and video games. He is a member of Rice EMS, is interested in molecular biology and scientific journalism and hopes to attend medical school. Zhou is a writer for Catalyst.

*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

PACKARD FELLOWSHIP FOR SCIENCE AND ENGINEERING

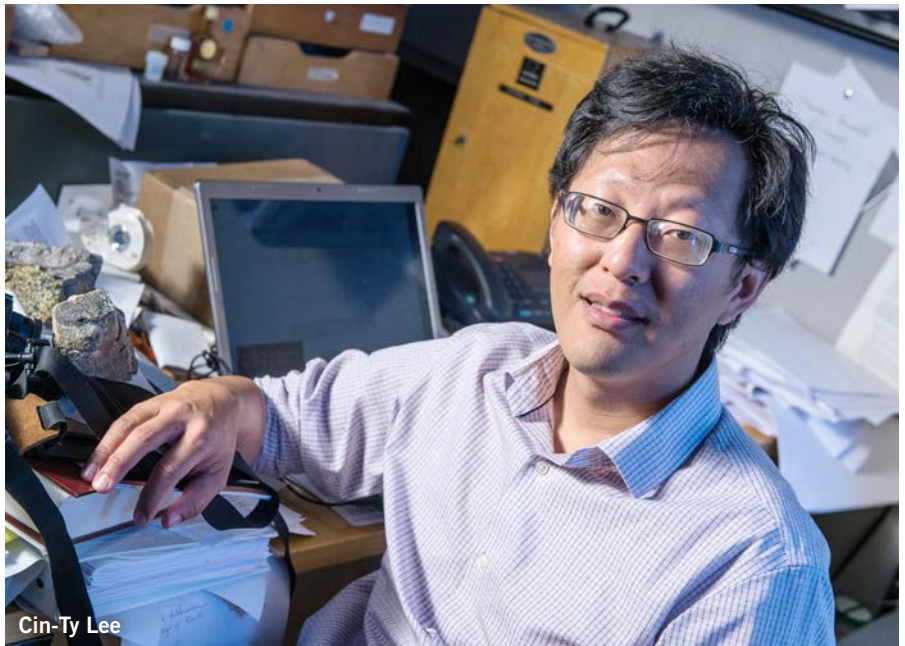
The David and Lucile Packard Foundation awarded **Laurence Yeung**, assistant professor of earth, environmental and planetary sciences, a 2017 Packard Fellowship for Science and Engineering. Yeung's research is a mix of physical chemistry, photochemical experimentation, quantum-mechanical theory, atmospheric modeling and more, all aimed at understanding how the atmosphere broadcasts the state of the Earth system in its chemical composition. His core approach typically revolves around counting exact numbers of "clumped isotopes," extraordinarily rare molecules that contain two or more rare isotopes.



Laurence Yeung

GUGGENHEIM FELLOWSHIP

Cin-Ty Lee, chair of the Department of Earth, Environmental and Planetary Sciences and professor of earth, environmental and planetary sciences, is one of 173 scholars, artists and scientists — and the only Earth scientist — chosen as 2017 Guggenheim Fellows by the John Simon Guggenheim Memorial Foundation. He studies the composition of rocks to reconstruct how Earth's interior, surface, atmosphere and life have evolved over time. In addition to researching the emergence and impact of continents, Lee will use the Guggenheim funding to explore crystal growth and kinetics in magmatic and hydrothermal conditions.



Cin-Ty Lee



Aryeh Warmflash

SIMONS INVESTIGATOR AWARD

Aryeh Warmflash, assistant professor of biosciences and bioengineering, was named a 2017 Simons Investigator in the Mathematical Modeling of Living Systems. Presented by the Simons Foundation, the award supports outstanding scientists and enables them to undertake long-term study of fundamental questions. Warmflash was recognized for his development of systems to mimic embryonic development in vitro using human embryonic stem cells and his ongoing work developing dynamical system models of cell fate patterning and morphogenesis that can be rigorously compared with quantitative data on in vitro development.

HERBERT WALTHER AWARD

Randall Hulet, the Fayez Sarofim Professor of Physics and Astronomy, won the prestigious 2017 Herbert Walther Award from the German Physical Society and the Optical Society of America. This annual award recognizes distinguished contributions in quantum optics and atomic physics as well as leadership in the international scientific community. The society cited Hulet for pioneering achievements in the field of ultracold atomic gases, including the achievement of Bose-Einstein condensation with attractive interactions and groundbreaking studies of atomic fermions.



Randall Hulet

S F BOYS—A RAHMAN AWARD

Gustavo Scuseria, the Robert A. Welch Professor of Chemistry and professor of physics and astronomy and of materials science and nanoengineering, was awarded the 2017 Royal Society of Chemistry S F Boys—A Rahman Award. This biennial award from the London-based international organization for chemical scientists recognizes outstanding innovative research in the area of computational chemistry, including both quantum chemistry and molecular simulations. Scuseria focuses on work that straddles the interface of quantum chemistry, condensed matter physics and materials science and, ultimately, the development of important materials for energy and the environment.



Gustavo Scuseria

MINNIE STEVENS PIPER FOUNDATION PIPER PROFESSOR

Michael Gustin, professor of biochemistry and cell biology, was selected as a Piper Professor for 2017 for superior teaching by the Minnie Stevens Piper Foundation. Established in 1958, the roster of Piper Professors includes outstanding college and university professors. The Piper Award adds to Gustin's many teaching honors at Rice. In 2016, he was the 11th faculty member to receive Rice's George R. Brown Certificate of Highest Merit, which honors outstanding performance in the classroom.



Michael Gustin

FACULTY HONORS

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCES

Janet Braam, the Wiess Professor of Biosciences and chair of the Department of Biosciences, and **José Onuchic**, the Harry C. and Olga K. Wiess Chair of Physics and professor of physics and astronomy, of chemistry and of biochemistry and cell biology and co-director of Rice's Center for Theoretical Biological Physics, have been named fellows of the American Association for the Advancement of Science.

AMERICAN ASTRONAUTICAL SOCIETY

David Alexander, professor of physics and astronomy and director of the Rice Space Institute, was elected to the board of directors of the American Astronautical Society.

AMERICAN GEOPHYSICAL UNION

Gerald Dickens, professor of earth, environmental and planetary sciences, was elected a fellow of the American Geophysical Union.

CHINESE ACADEMY OF SCIENCES

The Chinese Academy of Sciences has awarded **Randall Hulet**, the Faye Sarofim Professor of Physics and Astronomy, a Distinguished Scientist Award.

CLARIVATE HIGHLY CITED RESEARCHERS

Pulickel Ajayan, the Benjamin M. and Mary Greenwood Anderson Professor in Engineering, professor and chair of the Department of Materials Science and NanoEngineering and professor of chemistry and of chemical and biomolecular engineering; **Pedro Alvarez**, the George R. Brown Professor of Materials Science and NanoEngineering; **Bonnie Bartel**, the Ralph and Dorothy Looney Professor of Biochemistry and Cell Biology; **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; **Peter Nordlander**, professor of physics and astronomy, of electrical and

computer engineering, and of materials science and nanoengineering; and **Gustavo Scuseria**, the Robert A. Welch Professor of Chemistry and professor of physics and astronomy, and of materials science and nanoengineering, have been named to the Clarivate Highly Cited Researchers list for 2017.

GEOLOGICAL SOCIETY OF AMERICA

Caroline Masiello, professor of earth, environmental and planetary sciences, has been named a fellow of the Geological Society of America.

GLOBAL SCOT

David Alexander, professor of physics and astronomy and director of the Rice Space Institute, has been designated a Global Scot by the Scottish government.

ITALIAN SCIENTISTS AND SCHOLARS OF NORTH AMERICA FOUNDATION

The Italian Scientists and Scholars of North America Foundation has awarded **Andrea Isella**, assistant professor of physics and astronomy, the Young Investigators Award in Environmental Sciences, Astrophysics and Chemistry.

NATIONAL ACADEMIES

Beth Beason-Abmayr, teaching professor of biosciences, and **Jamie Catanese**, assistant teaching professor of biosciences, have been named as National Academies Education Mentors in the Life Sciences for 2017–2018.

OPTICAL SOCIETY OF AMERICA

Randall Hulet, the Faye Sarofim Professor of Physics and Astronomy, has been elected a fellow of the Optical Society of America.

SCIENCE BOOKS AND FILMS

Science Books and Films, a division of the American Association for the Advancement of Science, has named "Future Humans," by **Scott Solomon**, associate teaching professor of biosciences, as a Best Book of 2017.

THIEME CHEMISTRY AWARD

Zachary Ball, associate professor of chemistry, has been selected to receive a

2017 Thieme Chemistry Journals Award, presented to young individuals working in chemical synthesis and catalysis or closely related areas of organic chemistry.

UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION

David Alexander, professor of physics and astronomy and director of the Rice Space Institute, has been appointed to the United Nations Educational, Scientific and Cultural Organization–Encyclopedia of Life Support Systems subcommittee on the Science of Space.

STUDENT ACCOMPLISHMENTS

FULBRIGHT GRANTS

Rachel Buissereth '17 was awarded a 2017 Fulbright grant to conduct research with James Cook University and the Commonwealth Scientific and Industrial Research Organization in Cairns and northwest Australia. **Cyrus Ghaznavi '17** was also offered a Fulbright grant but declined the offer because he was named a 2017–2018 Luce Scholar.

LUCE SCHOLARSHIP

Cyrus Ghaznavi '17 was one of 18 Luce Scholars for 2017–18.

NATIONAL SCIENCE FOUNDATION

Morgan Abernathy '17; **Megan McCurry '17**; graduate students in chemistry **Taylor Hernandez**, **David Leach**, **Kaitlyn Lovato** and **Nicholas Moringo**; **Fernando Alvarez '16**; **Rebecca Maher '16**; **Margaret McDonnell '15** and **Raymundo Moya '16** were selected for the 2017 National Science Foundation Graduate Research Fellowship Program.

WATSON FELLOWSHIP

Allison Yu '17 was awarded a 2017 Thomas J. Watson Fellowship for travel to South Africa, Norway, Australia and Japan to explore how people value their hearing loss in various daily circumstances under cultural influences.

New Faculty



Gregory Chambers

GREGORY CHAMBERS

Assistant Professor of Mathematics

Gregory Chambers is a mathematician whose research interests include metric geometry, geometric analysis, and discrete and combinatorial geometry.

Chambers was the recipient of a Natural Sciences and Engineering Research Council of Canada (NSERC) Canadian Graham Bell Postgraduate Award at both the master's level and the doctoral level. He received a M.Sc. and a Ph.D. in mathematics from the University of Toronto. He was awarded a NSERC postdoctoral fellowship and obtained postdoctoral training at the University of Chicago, where he was an L.E. Dickson Instructor.

JAMES CHAPPELL

Assistant Professor of Biosciences

James Chappell's main research focus is synthetic biology, a field seeking to rationally design biological systems and create biological solutions for global challenges. He studies how RNA can be used to create new genetic tools for engineering cells — allowing for the manipulation of natural cellular processes to elicit deeper biological understanding and for the engineering of new synthetic cellular functions.

Prior to joining the Rice faculty, Chappell received his Ph.D. from Imperial College London and then was a postdoctoral researcher at Cornell University and Northwestern University.

ADRIENNE M.S. CORREA

Assistant Professor of Biosciences

Adrienne Correa applies interdisciplinary approaches to quantify how microorganisms influence hosts and ecosystem-level processes, particularly under environmental stress. Her primary research interests include the diversity and evolutionary histories of marine microorganisms, the context-dependent roles of microbes in host health and disease, and the influence of microbes on ecosystem function and persistence.

Correa received a Ph.D. in ecology and evolution from Columbia University and pursued postdoctoral training at Florida International University and Oregon State University. She was a lecturer and laboratory coordinator in the department of biosciences at Rice before joining the tenure track.

MATTHEW JONES

Norman and Gene Hackerman Assistant Professor in Chemistry

Matt Jones takes a systems approach to nanoparticle assembly, understanding materials as a function of their constituent parts and also considering the influence of collective properties and higher-order effects. His research interests include frustrated nanoparticle crystallization, single-particle dynamics and nanoparticle-based structures that assemble under nonequilibrium conditions.

Prior to joining the Rice faculty, Jones was awarded an NSF Graduate Research Fellowship and received his Ph.D. in materials science and engineering from Northwestern University. He obtained postdoctoral training at the University of California, Berkeley as an Arnold O. Beckman Fellow.



James Chappell



Adrienne M.S. Correa



Matthew Jones

ALAN REID

**Edgar Odell Lovett Professor of Mathematics,
Department Chair of Mathematics**

Alan Reid is a mathematician whose research interests include hyperbolic manifolds, geometric group theory and low-dimensional topology.

Reid completed a B.Sc., M.Sc. and Ph.D. at the University of Aberdeen. He was an instructor at the Ohio State University, a postdoctoral fellow at the Mathematical Sciences Research Institute, a Royal Society University Research Fellow at the University of Cambridge and a fellow of Emmanuel College Cambridge before joining the University of Texas at Austin faculty as an assistant professor of mathematics in 1996. He was promoted to full professor in 2002 and was appointed the Pennzoil Company Regents Professor in 2005. He joined the Rice faculty in 2017 and began his term as department chair in 2018.

Reid is an elected fellow of the American Mathematical Society and is a former Alfred P. Sloan Foundation Fellow and recipient of the Edinburgh Mathematical Society Sir Edmund Whittaker Prize. He also was invited to give a 45-minute address at the 2018 International Congress of Mathematicians, which is among the highest honors in mathematics.

MARK TORRES

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

Mark Torres studies the biological, chemical and geological processes that distribute elements across our planet's surface and interior. He is particularly interested in the set of elements and compounds that regulate Earth's habitability, focusing on the cycling of water, carbon and oxygen across a range of surface environments.

Torres received his Ph.D. in geochemistry from the University of Southern California, and he was the recipient of a Center for Dark Energy Biosphere Investigations graduate student fellowship. He obtained postdoctoral training at the California Institute of Technology as a Texaco Postdoctoral Fellow.

ROSA URIBE

Assistant Professor of Biosciences

Rosa Uribe studies how specialized cells form during embryonic development using the freshwater zebrafish as a model organism. In particular, she studies how a certain type of stem cell, called neural crest cells, responds to microenvironmental signals that exist in the embryo in order to become the appropriate type of specialized cell in the right place at the right time.

Uribe completed her Ph.D. in cellular and developmental biology at the University of Texas at Austin and was a National Institutes of Health and Burroughs Wellcome Fund Postdoctoral Fellow at the California Institute of Technology.

HAN XIAO

**Norman Hackerman-Welch Young Investigator
and Assistant Professor of Chemistry**

Han Xiao's research focuses on understanding the interface between cancer and immunity and synthesizing biomolecules to manipulate this interface. His work has a strong translational focus that seeks to initiate new clinical opportunities and will contribute to advances in chemical biology, glycobiology and cancer immunology.

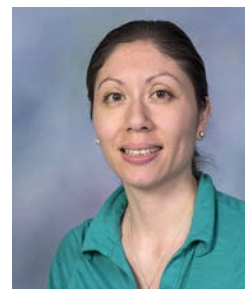
Xiao received his Ph.D. in chemical biology from the Scripps Research Institute and completed his postdoctoral training as a Good Ventures Postdoctoral Fellow of the Life Science Research Foundation at Stanford University. Xiao comes to Rice as a Cancer Prevention and Research Institute of Texas scholar in cancer research.



Alan Reid



Mark Torres



Rosa Uribe



Han Xiao

Faculty Retirements



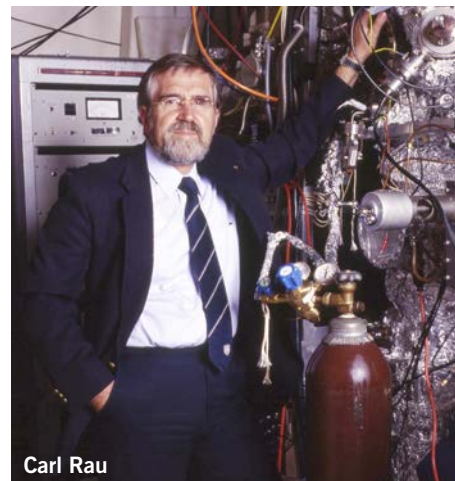
Bruce Etnyre

BRUCE ETNYRE
Kinesiology

Bruce Etnyre’s professional career began as a teacher and coach at a small high school in Indiana. He served as a head football coach while obtaining his first master’s degree from Purdue University. He later received a Master of Physical Therapy degree from Texas Woman’s University and his doctoral degree from the University of Texas at Austin. After completing his doctoral work, he joined the Rice faculty in 1984. He served as chairman of the kinesiology department from 2001–2006.

His primary research interests have included the study of flexibility and the study of movement when rising from sitting, especially for those who suffer from back pain. He has also conducted research involving motor control and biomechanical analysis of anterior cruciate ligament (ACL) surgical repair in athletic women and studies of distractions while driving.

Etnyre is now professor emeritus of kinesiology.



Carl Rau

CARL RAU
Physics

Carl Rau was born in Germany and received his B.S., M.S. and Ph.D. from the Technische Universität München. He received his habilitation in physics at the Ludwigs-Maximilians Universität (LMU). Rau was directive head of the surface physics group at LMU before visiting Bell Laboratories. He joined the Rice faculty as an associate professor in the department of physics in 1983 and was promoted to full professor the following year.

Rau’s research expertise was in surface physics, magnetism and nanoscience. His research focused on the electronic, magnetic and structural properties of novel magnetic materials to be used in future ultrafast nanoscale memory cells and logic devices. He pioneered several spin-sensitive surface spectroscopies, including electron capture, spin-polarized electron emission and scanning ion microscopy with polarization analysis for spin mapping of features such as magnetic vortices.

Rau is now professor emeritus of physics.

In Memoriam



SANDRA BISHNOI
Lecturer of Natural Sciences

Sandra Bishnoi, a lecturer in natural sciences and coordinator of Rice University's Sustaining Excellence in Research (SER) Scholars Program, died July 26, 2018, after a long battle with cancer. She was 44.

Bishnoi taught the hands-on Introduction to Scientific Research Challenges course for freshmen to give them the opportunity to do research on practical projects.

Bishnoi earned a Bachelor of Science in 1997 and a Ph.D. in 2001 in chemistry at the University of Texas at Austin. She was a Rice postdoctoral researcher in chemistry and electrical engineering from 2003 to 2005 and became an assistant professor of chemistry at the Illinois Institute of Technology in Chicago.

She returned to Rice as a visiting scholar and then a lecturer and lab coordinator in 2012 and assisted with cancer nanotechnology projects as a research scientist in the Laboratory for Nanophotonics through 2014. She was also a faculty associate at McMurry College.

She was well-known in Houston's cancer community as an advocate for patients, working as a volunteer with the MD Anderson Cancer Center, the Metastatic Breast Cancer Network and the Inflammatory Breast Cancer Network, even while she was in treatment over the past seven years.



JOHN FREEMAN
Professor Emeritus and Research Professor of Physics and Astronomy

John Freeman, Rice professor emeritus and research professor of physics and astronomy, died July 15, 2017. He was 92.

Freeman joined Rice's then-named Department of Space Science in 1964 after a year as a staff scientist at NASA headquarters in Washington, D.C.

Freeman's primary research focused on space weather. He followed in the footsteps of space science pioneer James Van Allen, his mentor at the University of Iowa, where Freeman earned his master's degree and a Ph.D. in 1963. He worked on early models of Earth's magnetosphere for space weather analysis and prediction and was instrumental in developing the Magnetospheric Specification and Forecast Model funded and deployed by the Air Force.

In the late '60s and early '70s, Freeman was principal investigator of the Suprathermal Ion Detection Experiment (SIDE), part of the Apollo Lunar Surface Experiment Package (ALSEP). Set up on the moon during the Apollo 12, 14 and 15 missions, the nuclear-powered ALSEP was an octopus-like set of experiments that measured characteristics of the thin atmosphere found near the moon's surface.

His work on Apollo earned Freeman the NASA Medal for Exceptional Scientific Achievement, the Apollo Achievement Award and a Distinguished Service Citation from his undergraduate alma mater, Beloit College.

He became the first director of the Master of Liberal Studies degree program at the Glasscock School in 2005, serving in that position until August 2016. He also served as a master of Lovett College.



GEORGE TRAMMELL
Professor Emeritus of Physics

George Trammell '44, professor emeritus of physics, died July 29, 2017. He was 94.

Trammell, who earned a B.A. in physics from Rice and a Ph.D. from Cornell University, served on the Rice faculty from 1961 through 1993. He received tenure as a professor of physics in 1964.

Trammell worked with students on fundamental research on neutron scattering, rare earth magnetism, coherent gamma-ray optics, gamma-ray superradiance, resonant magnetic X-ray scattering, X-ray holography and electron holography. He also collaborated with colleagues on papers about gravitationally induced electric fields in conductors.

"I found working with George a real joy, partly because George was so smart and so open in sharing what he knew," said Jim Hannon '62, also a professor emeritus of physics. "But also because he was just a lot of fun to be around. He genuinely liked people and saw a lot of humor in life, and he could tell very funny stories about himself as well."

A large, glowing orange sun with a stylized face cutout and solar flares. The sun is the central focus, with a bright orange and yellow glow. A stylized face is cut out of the sun, showing a red and black pattern. The background is dark with solar flares and rays of light.

Uncovering the Mysteries of the Sun

BY GRESHMA NAIR AND LAUREN KAPCHA

Throughout human history, the sun has held a place of supreme importance. Ancient Egyptians worshiped the sun god Ra, while Druids built the prehistoric monument Stonehenge to align with the summer and winter solstices. Renaissance scientists Copernicus, Galileo and Kepler advanced our understanding of the heavens, placing the sun at the center of our solar system and describing how planets orbit around it. Much more recently, 88 percent of American adults viewed the Aug. 21, 2017, solar eclipse — more than twice the number who watched the Super Bowl. Given our fascination with the sun, it may be surprising to realize how much we don't know about it.



Solar physicist Stephen Bradshaw, associate professor of physics and astronomy at Rice, is trying to understand why the outer atmosphere, or corona, of the sun is much hotter than the surface. “If you think about moving away from a source of heat like the sun, it should get colder,” he said. “And that happens in the interior, from the core to the surface: The temperature drops as you’d expect. But once you get to the surface of the sun and start going up into the atmosphere, the temperature suddenly rises again. And it’s not just a little bit: It goes from 6,000 to 2–3 million degrees kelvin.” Why is there a sudden increase in the temperature of the gas as you move away from the sun and how does it acquire the vast amounts of energy required to make this happen?

The sun generates its energy by the nuclear fusion of hydrogen into helium in its core, which can reach temperatures of millions of degrees. At such a high temperature, electrons can be stripped from atoms, creating a fluid of electrons and ions called a plasma. The corona is also a plasma and it interacts with the sun’s magnetic field, which creates a magnetic bubble around the solar system.

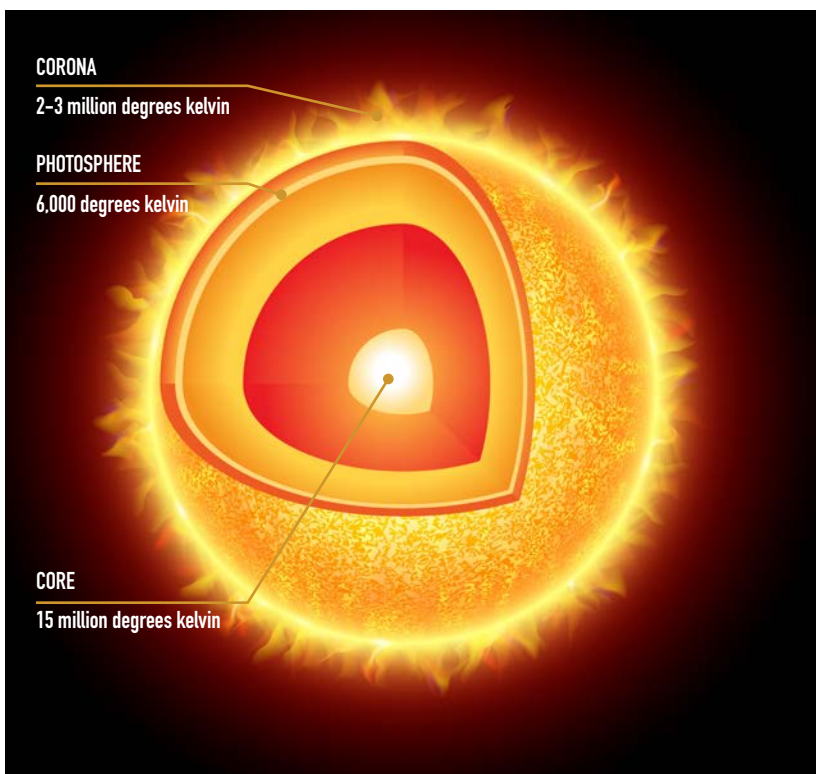
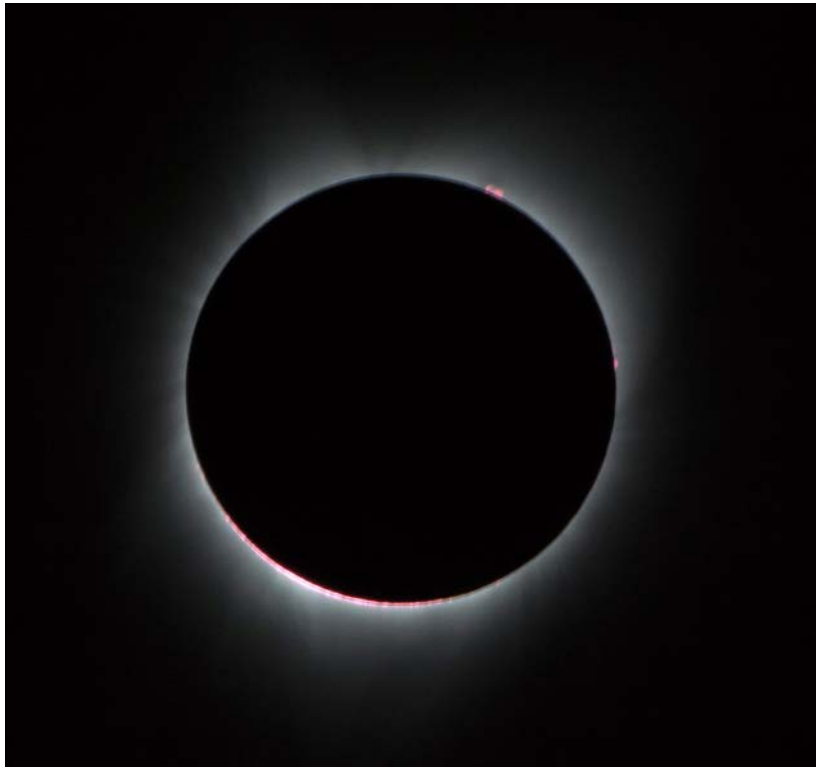
Solar physicists agree that the sun’s magnetic field is what carries such an enormous amount of energy from the surface to the corona. “There’s energy stored in the magnetic field that’s available to be released into the plasma, and when released this energy can increase the plasma’s thermal energy, raising its temperature,” said Bradshaw. “The key is figuring out what the mechanism is that removes energy from the magnetic field and dissipates it into the plasma.”

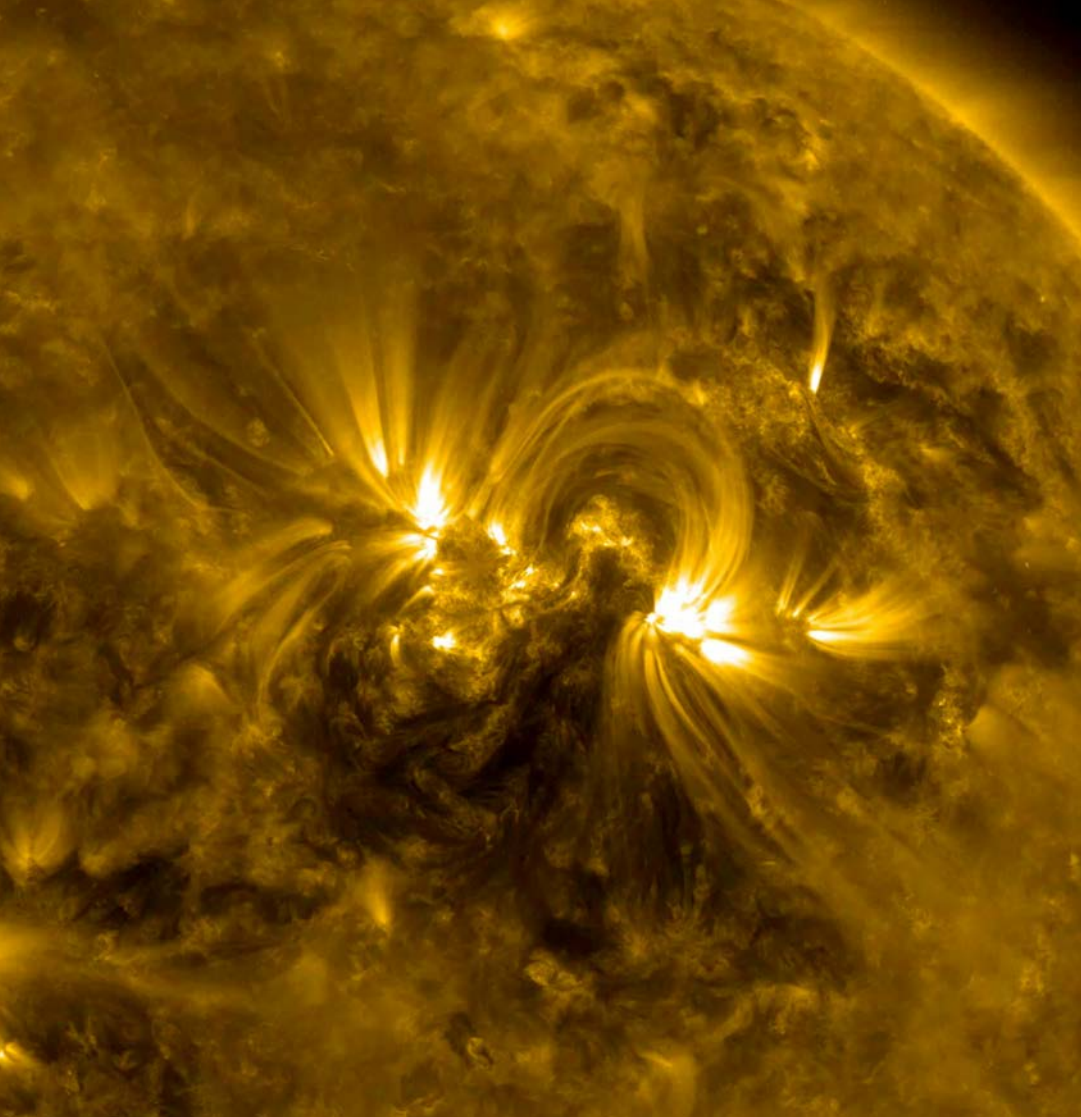
Normally, magnetic field lines don’t break or intersect other field lines. However, in the sun’s turbulent plasma, adjacent magnetic field lines can get twisted and braided. When the field lines become sufficiently stressed they can “break” and “reconnect” with one another. This mechanism drives the explosion of energy released during powerful solar flares. Bradshaw believes that a much smaller version of solar flares, called

Right: The sun’s visible-light corona, the inner part of which is only visible during a total solar eclipse, is seen here during the Great American Eclipse Aug. 21, 2017.

Image credit: NASA/Carla Thomas

Below: The fusion reactions in the sun’s core generate an enormous amount of energy, heating the core to 15 million degrees kelvin. Energy from the core moves slowly outward, taking more than 100,000 years to reach the surface. The temperature drops from the core to the surface, cooling down to 6,000 degrees kelvin at the photosphere, the visible surface of the sun that we know so well. As you move away from the surface into the atmosphere, however, there is a sudden increase in temperature with the corona, or outer atmosphere, reaching temperatures of 2–3 million degrees kelvin. This coronal heating problem is one of the biggest unsolved problems in physics.





Below: A visualization from Bradshaw's group of a solar active region near the center of the sun during the Great American Eclipse of Aug. 21, 2017. An active region is an area of intense magnetic activity on the sun where plasma in the outermost layer of the sun's atmosphere can reach temperatures of 2–3 million degrees kelvin. Red (negative) and blue (positive) patches show the observed magnetic field strength, and the faint white lines represent an approximation of the 3D magnetic field. The overlaid golden, blue and green show simulated intensity from coronal plasma heated by many small bursts of magnetic energy, called nanoflares. Image credit: Will Barnes.

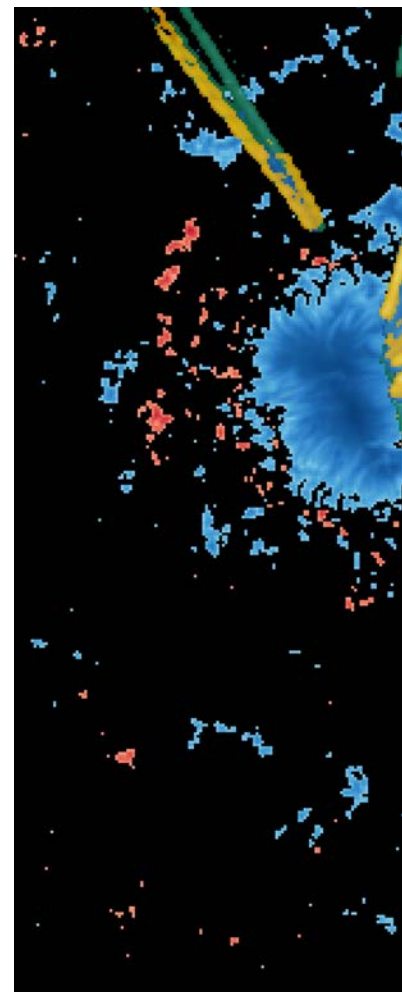
nanoflares, is what heats the corona.

Though small compared to full-size solar flares, nanoflares pack a great deal of energy into each explosion and tens of thousands of them may be occurring each second across the sun. Models have predicted that repeated nanoflares could bring the temperature of the corona up to 10 million degrees kelvin, but there is no direct observational evidence to support the theory yet. "Nanoflares have been so difficult to spot because the plasma they heat has a low initial density," said Bradshaw. "It doesn't emit much radiation for us to detect and cools very quickly, so the signatures from super-hot plasma, that would be the smoking gun of nanoflares, don't last long."

Heating the ions in the plasma causes them to emit radiation as X-rays when the plasma reaches sufficiently high temperatures. Detecting these waves is a difficult task. The Earth's atmosphere is very good at absorbing high-energy radiation, so detectors must be launched into space. Even in space, collecting useful data is a challenge. The emission signal is very faint because the ion populations are so small and the nanoflares so fast. Furthermore, high-energy X-rays pass through lenses, mirrors and most other components of conventional detectors making it hard to produce sharp images.

Advances in instrumentation have only recently made it possible to collect data that may contain the signature of a super-hot plasma. This data also provides information about how fast the plasma is moving toward or away from the detector and how hot the ions are compared to how hot the electrons are. Observing evidence of

Above: The magnetic field lines between a pair of active regions form a beautiful set of swaying arches rising up above them, with the connection between opposing poles visible in exquisite detail. This image shows charged particles spinning along the magnetic field lines, which are traced as they reach out in other directions as well. Image credit: Solar Dynamics Observatory, NASA.



“There’s an awful lot of work and very difficult physics to tackle in the sun’s atmosphere, and once you put a magnetic field into anything, it complicates the treatment enormously.”

really hot plasma in the corona would lend a great deal of support to the idea of nanoflares as the mechanism for converting magnetic energy into heat.

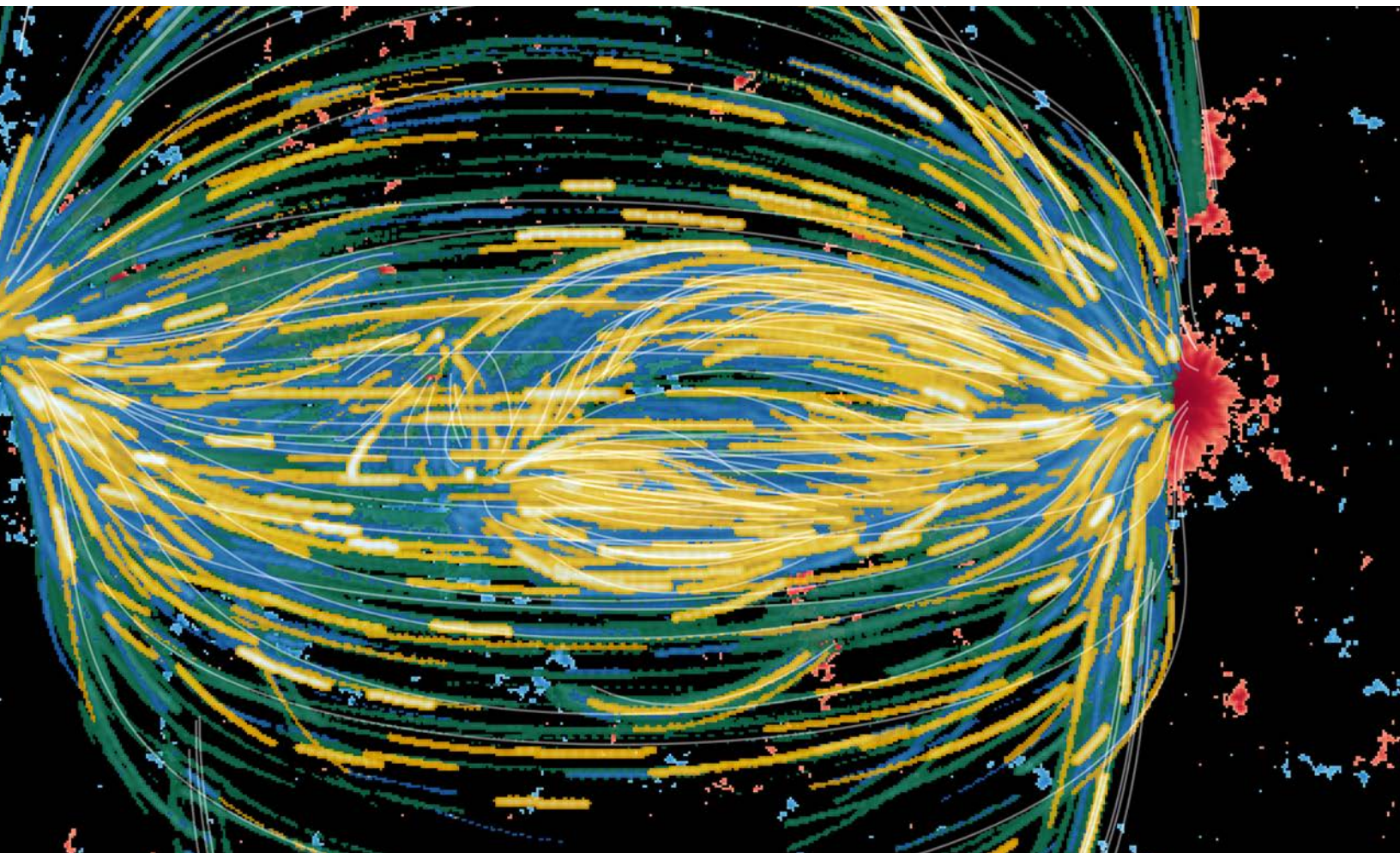
Bradshaw — who once spent an internship year during his undergraduate degree working on sport simulation games as a video game programmer — creates computational models that describe how energy is transported through the sun’s atmosphere and uses the actual data from detectors to validate his models. He and his research group use their code to calculate properties of the coronal plasma, such as temperature and density, and generate spectra that they can compare to what is actually observed by the instrumentation. “You know pretty quickly if you are right or wrong,” he said.

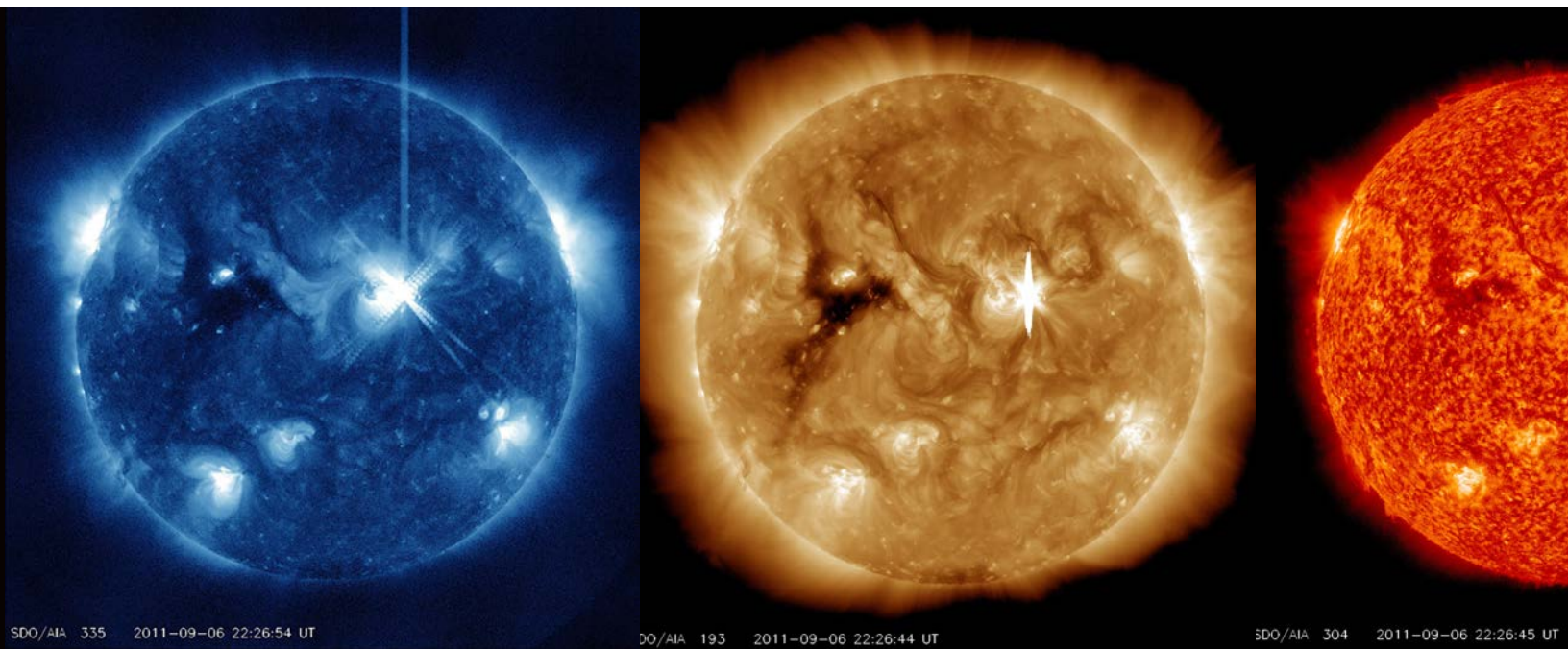
It’s no surprise to hear that it is challenging to accurately describe all of the processes occurring in the corona. “There’s an awful lot of work and very difficult physics to tackle in the sun’s atmosphere,” said Bradshaw, “and once you put a magnetic field into anything, it complicates the treatment enormously.” In order to make calculations more feasible, many models ignore important information about the plasma — how the ionization state of the plasma is changing over time. Bradshaw has developed a model that describes the evolution of the ionization state, and, more importantly, his

model is able to complete these calculations on readily accessible computer systems with modest processing power and in a reasonable amount of time.

Using these models, Bradshaw is able to focus in on some of the characteristics nanoflares must have to allow them to build up so much energy before bursting. “Our models tell us the properties the heating mechanism must have in order to reproduce what we are actually seeing,” he said. He and his team have learned a few things about how magnetic energy is dissipated into the corona as heat. First, the process of energy conversion must happen on timescales of a minute or less. The processes must also be localized to a region of just a few hundred kilometers or so — quite a small distance when you consider that the circumference of the sun is 4.4 million kilometers. Finally, the process of energy release into the plasma occurs in cycles, with strong heating followed by cooling, and wait times of 30 minutes or so between repeated heating events.

In addition to predicting some of the required characteristics of nanoflares, using models that allow the ionization state of the plasma to change over time can also help direct the design of instruments looking for the signatures of extremely hot plasma that are consistent with nanoflare-like heating.



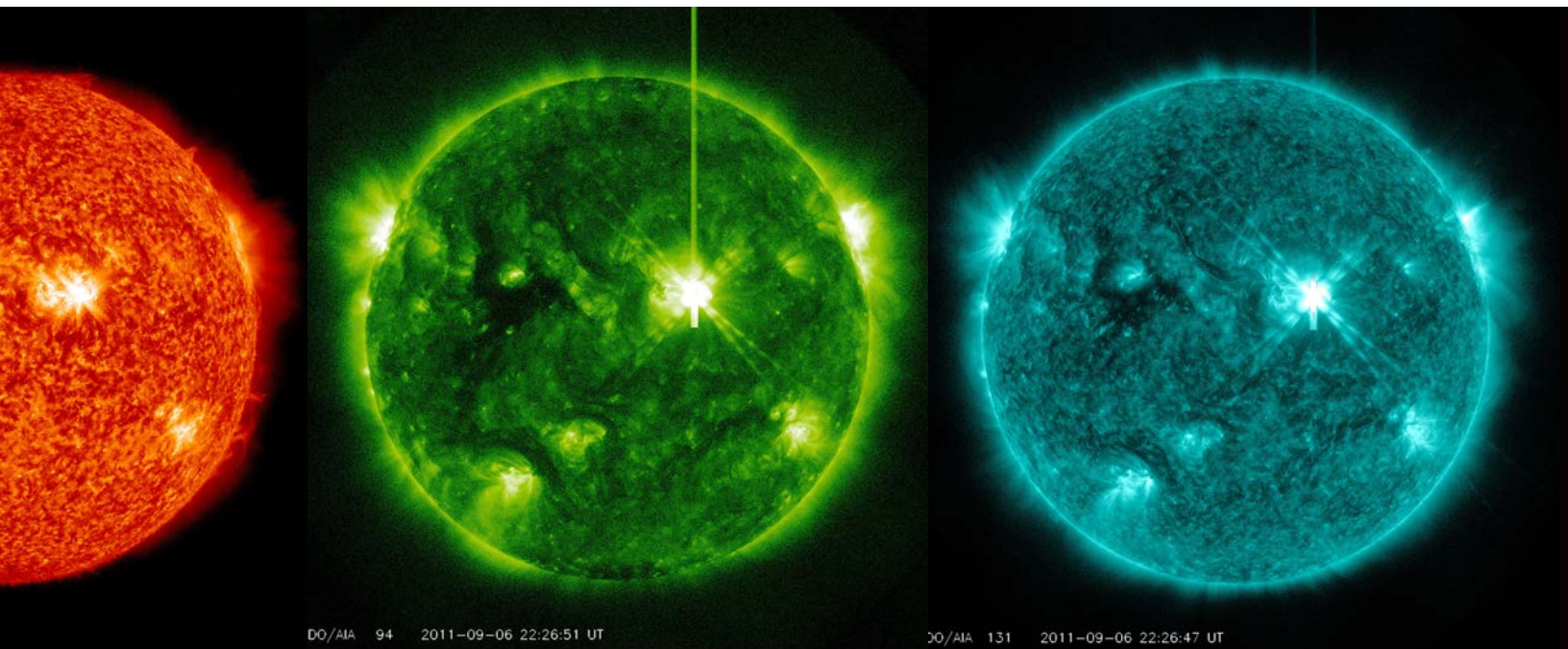


Instruments that produce conventional images of the sun focus light around a few different wavelengths. Each wavelength is chosen based on the signature of a single ion to highlight particular parts of the sun's atmosphere, including hot, magnetically active regions in the corona. These images of a large solar flare were taken at the same time using various wavelengths. The brightness of the flare causes saturation near the flare region of the detector and extended diffraction patterns in all of the images. Image credit: Solar Dynamics Observatory, NASA.

The ionization state of an atom tells you how many electrons have been removed. An atom can be partially ionized — it loses some of its electrons — or completely ionized — it loses all of its electrons. A hydrogen atom, which has only one electron, can only be completely ionized. Helium, which has two electrons, can be partially ionized or completely ionized. Elements with a larger number of electrons, like iron with 26 electrons, have a large number of possible partial ionization states, each with their own signature in the X-ray data.

Nanoflares dump energy into the corona causing the temperature to rise very rapidly, but changes in the ionization state lag behind the change in temperature. In order to detect the signatures of hot plasmas, instruments must be tuned to look for the signal from the right ionization state of the right atom or they could miss these heating events altogether. Bradshaw's models are able to predict the relative amounts of the different ionization states of iron, for example, that you would expect to find for different heating scenarios. This information can then be used to make sure that instruments are optimally designed to detect radiation from the most abundant ionization states.

Because the technology to detect coronal X-rays, with enough sensitivity to identify signatures of nanoflares, is still quite new, it hasn't yet been launched on a large dedicated solar observing mission. Solar physicists are only able to collect data when less-ideal instruments tasked with looking at other objects of astrophysical interest occasionally point towards the sun or when older solar observing instruments are pushed to their limits. These telescopes have, however, started to detect the hot signatures of nanoflare-like heating in the corona. "We're starting to see some evidence of really, really high temperature emission in particular parts of the sun's atmosphere, called active regions. These active regions sit above sun spots and they're where all the fun stuff like solar storms and solar flares happen," Bradshaw said. "What we've seen from some



“We’re starting to see some evidence of really, really high temperature emission in particular parts of the sun’s atmosphere, called active regions. These active regions sit above sun spots and they’re where all the fun stuff like solar storms and solar flares happen.”

of our instruments are hints of plasma that gets up to a temperature of 10 million degrees or so.”

So far, instruments that have been designed for the sun have been sent up on rocket flights where they are able to collect data for a mere six minutes. Bradshaw has been involved with the development of one of these instruments specifically designed to collect X-ray spectra from the corona to provide signatures of hot plasma and perhaps the most compelling evidence yet for nanoflares as the coronal heating mechanism. This instrument will be launched next year and will hopefully serve as a stepping stone to a larger observing mission. “Once this instrumentation has been fully developed and proven that it works, then instead of observing for six minutes, we can have a space mission that will be up for years. Hopefully then we’ll crack the coronal heating problem open,” said Bradshaw.

These future missions will certainly answer some of the outstanding questions we have about the sun, and they will likely bring up new questions that activate our curiosity and focus our attention yet again on the quest to understand our nearest star. After all, Bradshaw’s solar research has taught him one thing for certain. “What’s become clear to me over the time I have been working on this problem,” he said, “is that the sun’s atmosphere in its entirety is a much, much more complicated place than we had anticipated.” ■



A large puzzle of Earth images against a fiery background. The puzzle pieces are arranged in a semi-circle on the left side, showing various views of Earth from space. The background is a vibrant, fiery orange and red, suggesting a hot, early Earth environment. The puzzle pieces are interlocking, symbolizing the interconnectedness of the environment and the development of life.

Engendering an Early Earth Environment

BY MAHESH KRISHNA

The oxygen you breathe, the water you drink and the carbon in your body are all important aspects of human life. Have you ever wondered about the specific conditions that enabled life on Earth to develop?

When asked, Rajdeep Dasgupta, professor of earth, environmental and planetary sciences at Rice University, answered with questions of his own. “How did our planet get the right conditions that allowed the life-essential chemical species to build up and sustain over time?” he queried. “Maybe for our planet, the initial conditions were alright, but how were these conditions maintained? Mars used to have water on its surface and conditions perhaps favorable for

elements like carbon, hydrogen, nitrogen, oxygen, phosphorus and sulfur made life possible. The overarching theme in Dasgupta’s research is understanding how volatile elements — those that prefer to be gasses, not solids — shape our planet’s evolution. How do these life-essential elements move around and what processes make them available in the environment?

“When studying planetary processes and habitability, it is important to look at

the surface leading to the emergence of life. Exploring the delivery mechanism of these elements and learning how they were separated into different states will improve our understanding of the evolutionary origins of our planet.

Petrologists like Dasgupta study the origin, composition and structure of rocks and how they form. In field-based petrology, researchers travel to different sites to find rock samples and analyze their composition.



Raj Dasgupta uses powerful hydraulic presses to crush rock samples in pressures that simulate those found deep inside the Earth.

life, but eventually it lost its liquid water and atmosphere. Why did the same thing not happen to our planet?” Dasgupta and his research group attempt to answer these questions by simulating the high pressure and high temperature environment found deep inside the Earth.

Our planet is unique in that it is a solid rocky planet with oxygen in its atmosphere and liquid water on its surface, and it also has life. A particular combination of specific

the whole planet, which means addressing questions like: How did the core form? How did the mantle form? What was the fate of each of the life-essential elements when these processes occurred? And, what combination of processes helped in retaining the elements?” said Dasgupta. To develop conditions suitable for life, it is not sufficient just to get all the life-essential elements. Many planets can get all the elements, but this does not mean they will be retained on

Dasgupta, however, is an experimental petrologist who works in the lab to simulate the conditions under which rocks form and observe what happens to these rocks under a variety of conditions. His experimental petrology lab can simulate the high pressure and high temperature conditions equivalent to a depth of 400 kilometers beneath the surface of the planet, allowing them to discover what happens to materials in extreme conditions.



An artist's impression of the early Earth. During the earliest geological eon, the Hadean Eon, the newly formed Earth frequently collided with meteorites, asteroids and failed planets. The planet was largely molten and likely covered by a magma ocean. Image credit: Tim Bertelink.

When Earth was first forming, it collided with a lot of nearby objects. It was very hot and likely covered by a magma ocean, a molten mixture of all of the elements that made up the early Earth. Over time, temperatures dropped, and the heavier metals, like iron, concentrated in the center of the planet to create the core, which was surrounded by a less dense outer layer. Eventually, this outer layer differentiated into the mantle and crust that we have today. The mantle, crust and atmosphere are constant-

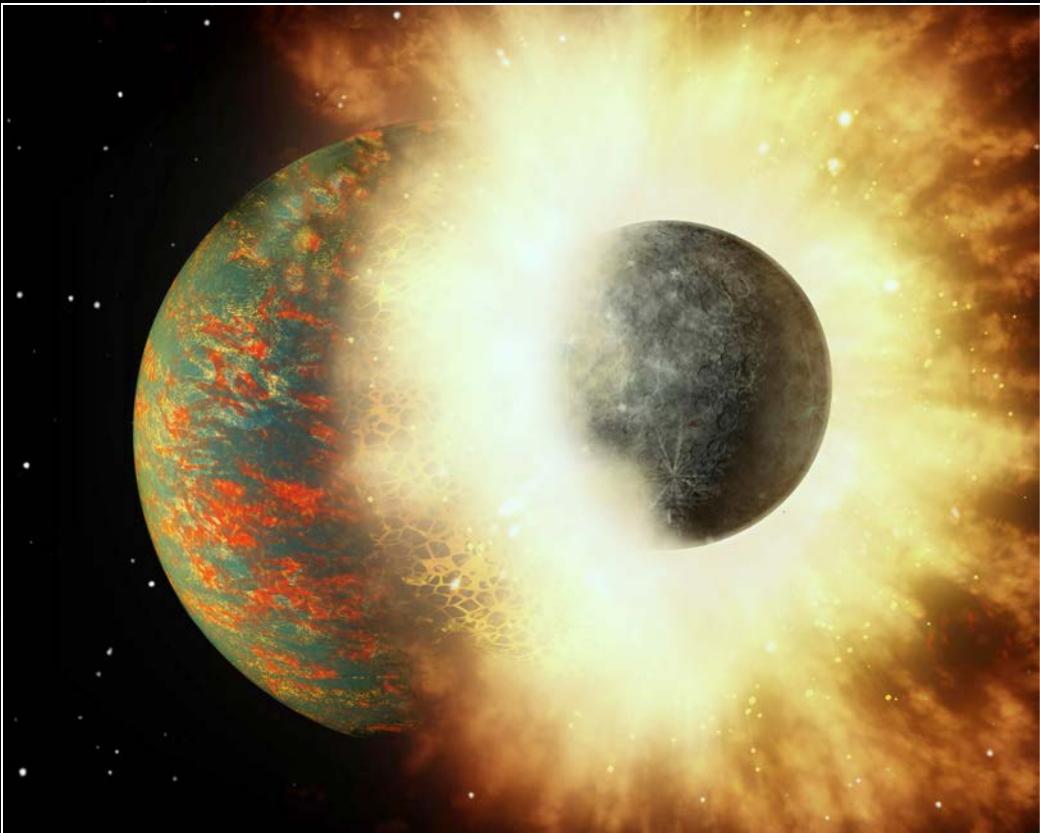
ly exchanging those elements that did not get separated into the core through geologic processes like volcanism and plate tectonics, or the movement and deformation of the outer layers of the Earth.

An important question is how did life-essential elements like carbon end up outside of the core? In other words, how was carbon present at the surface to create carbon-based life on Earth? "Even if carbon did not vaporize into space when the planet was largely molten, it would end up in the metallic core of our planet, because the iron-rich alloys there have a strong affinity for carbon," Dasgupta said. One possible explanation for this phenomenon is that the volatile elements, including carbon, were added to Earth after the formation of the iron-based core through collisions with meteorites or asteroids. While this would account for the presence of these volatiles, the problem with this theory is that there are no known meteorites with the ratio of life-essential elements similar to what we find on Earth.

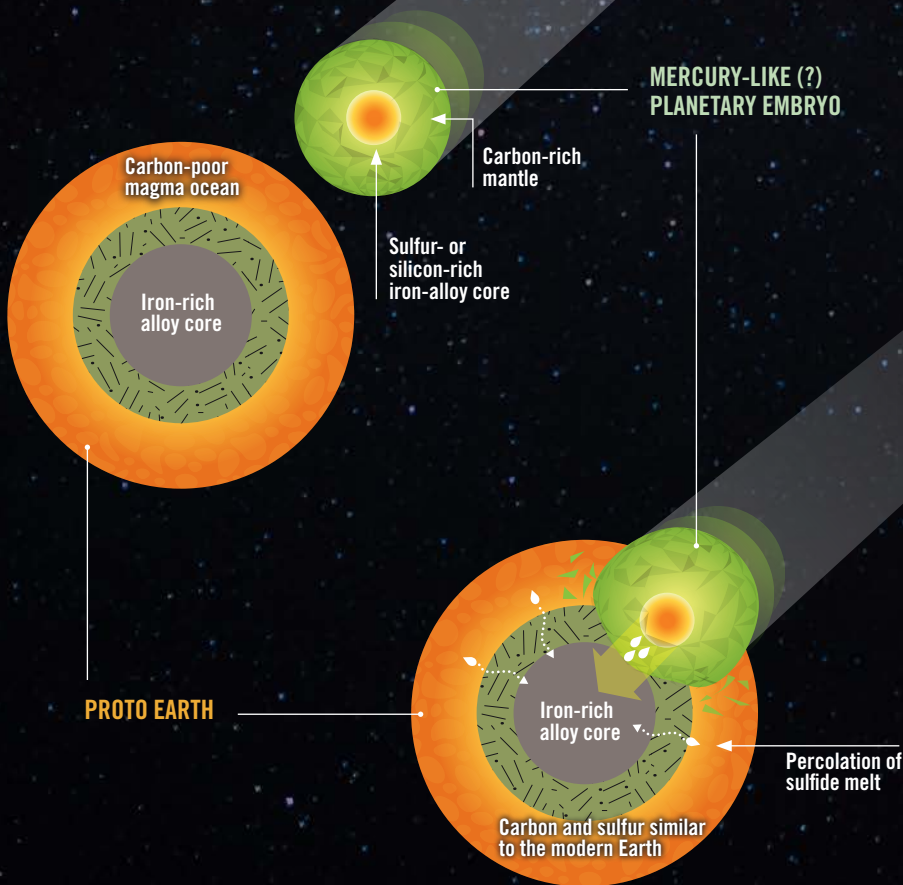
Dasgupta's team looked to our planetary neighbors for inspiration to address this problem. "We thought we definitely needed to break away from the conventional core composition of just iron and nickel and carbon," he said. "So we began exploring very sulfur-rich and silicon-rich alloys, in

part because the core of Mars is thought to be sulfur-rich and the core of Mercury is thought to be relatively silicon rich."

The team performed experiments to determine the portioning of carbon between the core and mantle at different temperatures, pressures and sulfur or silicon content. They found that carbon could be excluded from the core — and remain in the mantle — if the core was rich in either silicon or sulfur. "One scenario that explains the carbon-to-sulfur ratio and carbon abundance is that an embryonic planet like Mercury, which had already formed a silicon-rich core, collided with and was absorbed by the Earth," said Dasgupta. "Because it's a massive body, the dynamics could work in a way that the core of the planet would go directly to the core of our planet, and the carbon-rich mantle would mix with Earth's mantle."



The ratio of volatile elements in Earth's mantle suggests that virtually all of the planet's life-giving carbon came from a collision with an embryonic planet approximately 100 million years after Earth formed.



A schematic depiction of the young proto Earth's merger with a Mercury-like planetary embryo. Magma ocean processes could lead planetary embryos to develop silicon- or sulfur-rich metallic cores and carbon-rich outer layers. If Earth merged with such a planet early in its history, it could explain how Earth acquired its carbon and sulfur.



Earth's atmosphere, as seen in 2003 from the International Space Station, hasn't always contained large amounts of oxygen. Petrologists from Rice University and the Carnegie Institution recreated hot, high-pressure conditions from 60 miles below Earth's surface in search of new clues about

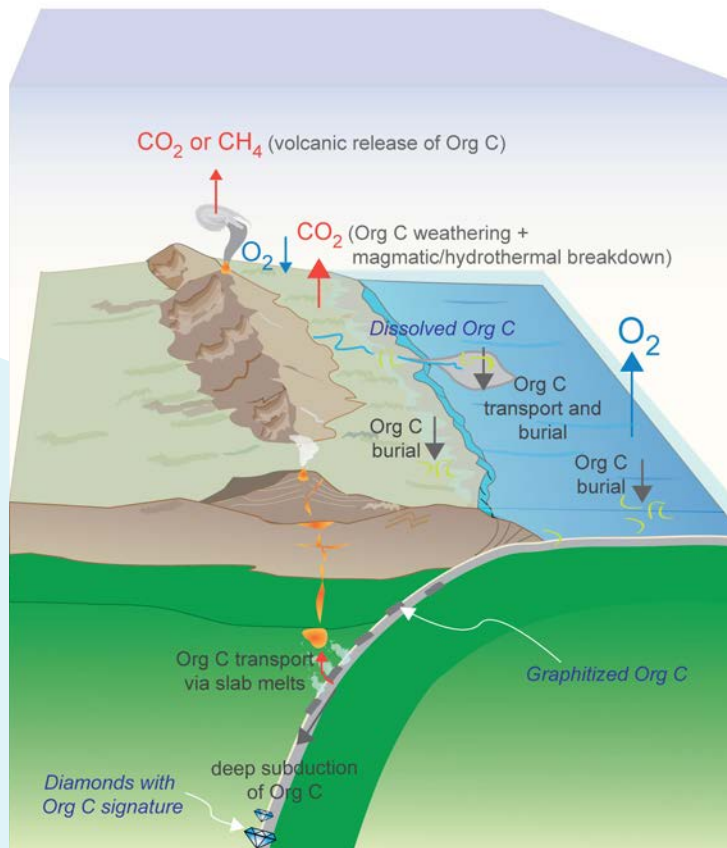
the Great Oxidation Event that added large amounts of oxygen to the atmosphere around 2.4 billion years ago. Image credit: ISS Expedition 7 Crew, EOL, NASA.

The presence of this carbon was essential for the earliest stages of life to form. These simple anaerobic organisms were able to survive without oxygen, which was initially present only at low levels in the atmosphere. Oxygen needed to be present at much higher levels for complex life to develop. About 2.4 billions years ago, there was a sharp increase in the amount of oxygen in Earth's atmosphere. Termed the Great Oxidation Event, or GOE, this increase in atmospheric oxygen — and a corresponding decrease in carbon — preceded the evolution of aerobic organisms.

In order for this shift in the relative amounts of carbon and oxygen in the atmosphere to happen, a large amount of organic carbon had to be removed from the

atmosphere and buried. In a recent study by former graduate student Megan Duncan '15, Dasgupta's group postulated that the rise of atmospheric oxygen was likely caused by burial of organic carbon into the Earth's mantle. "The mechanism for that burial comes in two parts," said Dasgupta. "First, you need some form of plate tectonics, a mechanism to carry the carbon remains of early life-forms back into Earth. Second, you need the correct geochemistry so that organic carbon can be carried deeply into Earth's interior and thereby removed from the surface environment for a long time."

Subduction zones — places where two tectonic plates collide and one is forced down into the mantle — are important locations for burying carbon in the mantle.



This schematic depicts the efficient deep subduction of organic carbon, a process that could have locked significant amounts of carbon in Earth's mantle and resulted in a higher percentage of atmospheric oxygen. Based on their high-pressure, high-temperature experiments, Dasgupta and Megan Duncan '15 argue that the long-term sequestration of organic carbon from this process began as early as 2.5 billion years ago and helped bring about a well-known buildup of oxygen in Earth's atmosphere — the Great Oxidation Event — about 2.4 billion years ago.

However, temperatures in subduction zones can be hot enough to melt rock, which can then rise back to the surface through volcanic eruptions. Any fossilized organic carbon dissolved in the melt will escape back into the atmosphere.

Dasgupta and his team sought to answer this question about the fate of carbon in subduction zones by looking at the carbon-carrying capacity of rhyolitic melts, a specific type of magma produced deep in the mantle that is responsible for carrying significant amounts of carbon to volcanoes from the downgoing surface rocks. These magmas have a high content of silicon and aluminum, but are low in iron, calcium and magnesium. This composition is key as the positively charged magnesium and calcium

ions affect how much carbon you can dissolve.

The team found that, even under extremely hot conditions, rhyolitic melts do not dissolve much carbon. This allows most of the carbon to get buried in the mantle and not carried to volcanoes to be released back into the atmosphere. "What is neat is that with the onset and the expected tempo of crustal burial into the deep mantle starting just prior to the GOE, and with our experimental data on the efficiency of deep burial of reduced carbon, we could model the expected rise of atmospheric oxygen across the GOE," Dasgupta said.


Questions like these are important not only in furthering our understanding of how our planet formed, but for knowing

how these processes shape other planetary bodies too. "All our research is ultimately curiosity driven and guided by questions such as 'Who are we?' and 'Where do we come from?'" said Dasgupta. Understanding the fundamental processes that led to favorable conditions for our planet to support life increases our knowledge of the parameters and elemental distribution that might allow for a similar sequence of events for other planets. The answers that Dasgupta seeks may ultimately guide exploration of other planets, help humans establish a colony on Mars and even lead the search for life for exoplanets. ■



Crypt-Keeper Wasp Manipulates the Behavior of Its Parasite Host

BY ELAINE SHEN



Stepping into Scott Egan's office can be quite overwhelming. Looking around, no surface is spared — animal skulls, posters, framed insects, journals, teeth, arrowheads, and live samples are just some of the objects he proudly displays in his corner of Rice University's Anderson Biological Labs.

While you might expect such an eclectic collection to be a consequence of traveling far and wide, most of the items actually come from a longtime curiosity and dedication to investigating regions of Texas and the Gulf Coast. As a lifelong Texan, he intentionally sought out local ecological systems in order to answer some of the largest questions in ecology, evolution and conservation biology.

You see, Egan, assistant professor of ecology and evolutionary biology, has been romping around green spaces in the Greater Houston area since he was a child. When he wasn't fishing or catching snakes in the San Jacinto River watershed, he was being quizzed about tree species by his father on short hikes in Jesse Jones County Park. Later, during one semester as an undergraduate at the University of Texas at Austin, he found himself taking courses in ecology, evolution, insect biology and bird biology all at once. By the end of that school year, he could not deny the connections between the process-based concepts he read about in his textbooks and the importance of classifying organisms in the field.

"After that semester, I was confident that I wanted to explore these concepts in biodiversity professionally to discover how one could find so much diversity in the patch of land that I grew up in," Egan said.

Now at Rice, just 25 miles from where he grew up, Egan is broadly interested in the origin and maintenance of biodiversity through evolutionary processes like speciation, the process by which many species evolve from one common ancestor. His lab group assembles multidisciplinary collaborations in order to tackle ecological systems from different angles, examining how animals change their genetics, behavior, natural history and geographic distribution under different manipulated experimental conditions. The model system they use involves a group of insects averaging just 1.5 to 2 millimeters in length that are as



ubiquitous as they are hard to notice — gall wasps. These tiny insects have captured Egan’s attention for over a decade and can be found in places as close as Rice’s campus.

Gall wasps are parasites that attack oak trees, laying their eggs on the undifferentiated stem cells of plants and inducing the plant to grow a home, or gall, for them. As a self-proclaimed opportunistic collector of “stuff,” Egan is always on the lookout for new and interesting gall wasp interactions to study. The dozens of covered cups scattered across his desk and office space are largely the result of these random finds.

One family vacation in particular proved to be quite fortuitous. “I was walking through the sand dunes with my daughter when I noticed a very rare gall wasp species in amazingly high abundance in one patch,” Egan said. “My daughter helped me collect some of these gall samples in a cup.” This cup joined the others on his desk, where it sat under his watchful and casual curiosity for a couple of months. Eventually, incredibly tiny iridescent wasps that Egan had never seen before were sitting at the bottom of the cup, presumably having emerged from the gall.

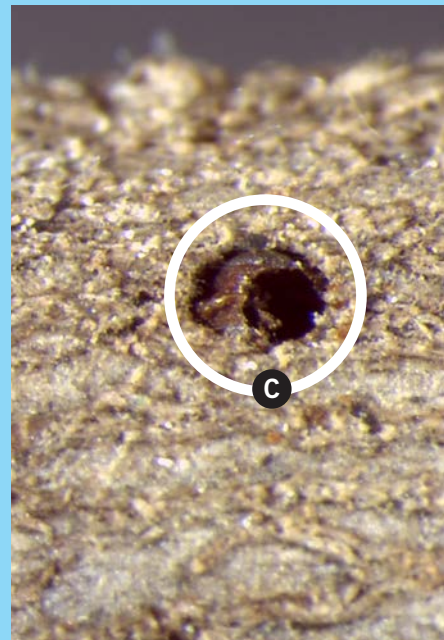
Many wasps crawl out of his collected galls all of the time. What really caught Egan’s attention is when he noticed multiple emergence holes with a dead gall wasp head from the species *Bassetia pallida* stuck in them. Some of those heads also had holes themselves. Dissecting the galls in the plant tissue revealed dead *B. pallida* with creamy white larvae inside the abdomen, the offspring of an animal he had never seen before. Teaming up with Kelly Weinersmith, adjunct faculty member and former Huxley Fellow in ecology and evolution at Rice, Egan began to make some observations about what he saw. It seemed like there was an association between the head-plugging phenomenon and the presence of the new iridescent wasp and its creamy white larvae.

To test this association, Egan and Weinersmith designed a set of experiments to see if

Scott Egan in the lab with some of the covered cups he uses to contain oak galls and other finds.



Bassettia pallida is a species of gall wasp that manipulates trees into forming a crypt in which its larva mature. Image credit: Andrew Forbes/University of Iowa.



The crypt-keeper wasp, *Euderus set*, is a parasite that takes advantage of another parasite, the gall wasp. It infects

the maturing gall wasp in its crypt and modifies its victim's behavior, forcing the gall wasp to make its escape hole too

small. *E. set* then escapes through the gall wasp's body and emerges to freedom through its head. The image shows

(A) an emergence hole made by an uninfected *Bassettia pallida* gall wasp, (B) an emergence hole plugged by the head

of *B. pallida* and (C) a head-plugged hole with a hole in *B. pallida*'s head where *E. set* emerged.



The crypt-keeper wasp, *Euderus set*.
Image credit: Ryan Ridenbaugh and Miles
Zhang/University of Central Florida.

the iridescent wasps were parasitizing the gall wasp, inducing this strange behavior and gaining a survival advantage. For example, for the galls they collected where a dead *B. pallida* head was stuck in an emergence hole, the team taped a thin strip of bark over the head to see if the iridescent wasp could still emerge once it reached adulthood. As soon as there was a barrier to emerging out of the gall, the iridescent wasp was three times more likely to die.

What they found was a rare example of hypermanipulation — the gall wasp is a parasite manipulating the host oak tree tissue that in turn has its behavior manipulated by the iridescent wasp. While *B. pallida* usually develops in its specialized gall and emerges from a small hole upon maturity, this iridescent wasp hijacks the process by laying its eggs inside the gall. The creamy white larvae are then able to control the behavior of the growing *B. pallida* wasp by making it create an emergence hole that is too small for its escape. Once the *B. pallida* wasp fails to excavate out of the gall and gets its head stuck, the iridescent wasp eats through the gall wasp's internal organs and emerges from its head.

"It kind of has a sci-fi flavor to it," Egan remarked. "I think the emergence of one animal through the head of another animal after tunneling through its body, eating it from the inside out is alarming. It makes you happy to think you are not an insect."

The team also called up entomologist Andrew Forbes from the University of Iowa, a specialist in the evolution of parasitoid wasps, to determine exactly what species the creamy white larvae and iridescent wasp belonged to. Although Forbes could narrow the classification to the genus *Euderus*, his inability to pinpoint a species suggested that they were looking at a new one. This was confirmed after digging through the scientific literature and museum sample

archives and comparing them to the insect they had. They characterized *Euderus set*, sent specimen off for preservation at the American Museum of Natural History and nicknamed it the crypt-keeper wasp. Both the scientific name and common name refer to Set, the ancient Egyptian god of evil and chaos who killed his brother Osiris by trapping him in a crypt and later retrieving the body and chopping it into small pieces.

Once you see the crypt-keeper wasp, you can't unsee it. Egan now is able to spot it at 10 or more sites along the Gulf Coast, hidden deep in the Smithsonian's archives, in his front yard and even on Rice's campus.

"Working closely and intimately in a system for a long time has allowed me to see new species and the variation in known species," Egan said. "There's always something new and exciting to discover about these critters and their morphology, behavior and interactions."

With few exceptions, it seems as though Egan's everyday life has not strayed far from his childhood days sitting, looking and observing the natural world in Houston. Although this industrial metropolis is not generally known for its abundance of green spaces, Egan's collaborative and holistic work helps unveil the hidden biodiversity and incomprehensible interactions between living things that are occurring right under our noses. It's just about knowing where to look. ■

A Chemist's Quest to Mimic Nature

BY SRIPARNA SAHA



Who would have thought that something as dreadful as venom could have life-saving properties? You might be surprised to know that snake venom can be used to stop bleeding and treat wounds. When a component of venom is combined with nanofiber hydrogels developed in the lab of Rice chemist Jeffrey Hartgerink, the resulting new material is able to stop wounds from bleeding in as little as six seconds. Make a few changes to the structure of the hydrogel and to the compound it's combined with, and you create materials that can improve cancer treatment or accelerate wound healing.

Hydrogels are 3D networks of polymers that can absorb a large amount of water. They can be made in practically any size or shape with a wide range of physical properties. Many synthetic and natural materials are hydrogels — soft contact lenses, the absorbents used in disposable diapers and water retention granules in soil all take advantage of the ability of these materials to swell with water — and hydrogels were also the first biomaterials designed for use in the human body.

Many biomaterials are designed for medical applications, where they perform or supplement natural biological functions. The suc-

cess of a bioengineered design depends primarily on how well cells interact with the artificial biomaterial. An ideal biomaterial must not only fulfill the biological functions it is tuned to perform, it also must mimic the natural environment of the body. "As a chemist, I try to mimic things that nature does, biomimetic is the term," Hartgerink said.

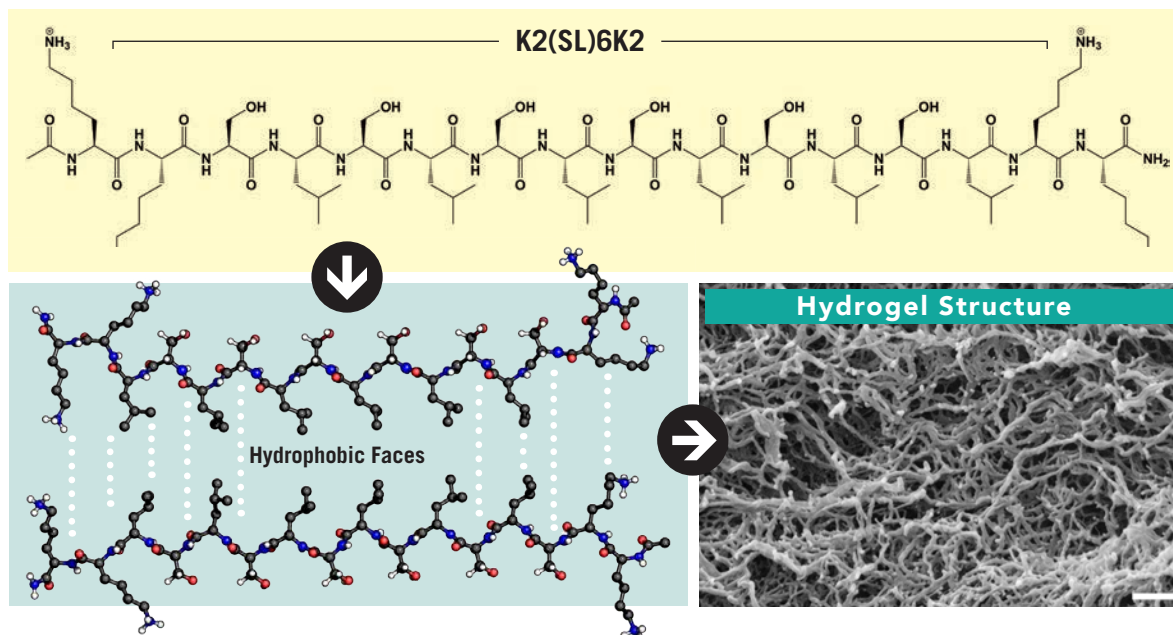
When designing biomimetic materials, chemists don't focus solely on how atoms and ions are held together by covalent bonds, but rather on the collective behavior of large organized groups of molecules. Large is, of course, a relative term. "When a chemist talks about enormous, he actually refers to things that are in nanometers or angstroms, smaller even than a fingernail," said Hartgerink. This branch of chemistry, termed supramolecular chemistry, examines reversible interactions between molecular groups. It is critical to understand these interactions, which help maintain the 3D structure of large biomolecules, in order to be able to successfully mimic biological designs.

Hartgerink's group uses these molecular interactions to direct the self-assembly of peptide hydrogels — hydrogels composed of short chains of amino acids, which are the building blocks of proteins. The peptides they make are able to self-organize into larger complicated hydrogel structures that have specific biological functions. They can be used for tissue engineering, tissue regeneration and drug delivery — someday, perhaps, they will aid in the regeneration of an entire organ. "My training as a chemist made the synthesis of peptides easy. The hardest part emerged as we started going beyond the basic science and our materials matured," Hartgerink said. "The only way to make further progress was to see how they would react when employed into biological systems."

One of the clinical problems the team wanted to address is the need to minimize bleeding during surgery. Reducing surgical bleeding helps produce the best surgical outcome, but minimizing

HYDROGEL BASICS

The 16-amino acid peptide K2(SL)6K2 forms nanofibers through the hydrophobic effect and hydrogen bonding. Nanofibers entangle and cross-link, eventually forming a hydrogel. An SEM image shows the hydrogel structure. The scale bar is equal to 200nm.



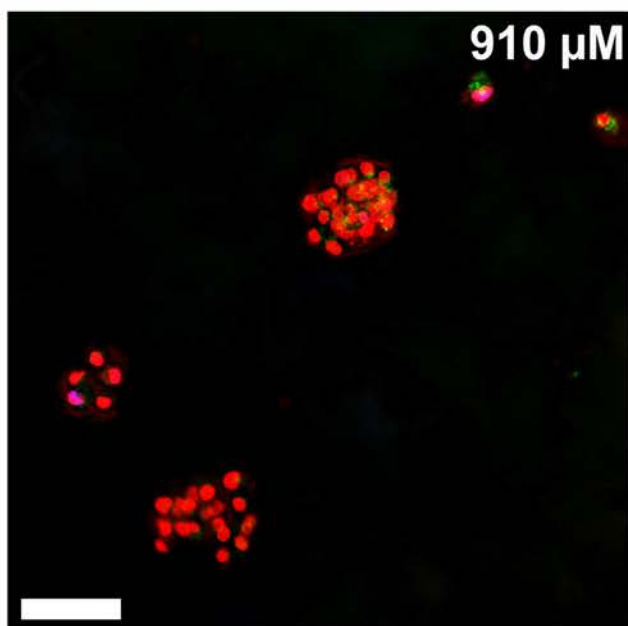
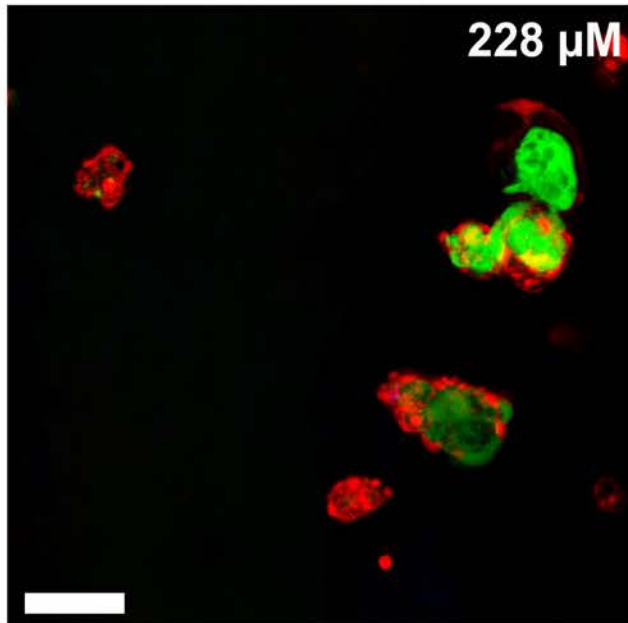
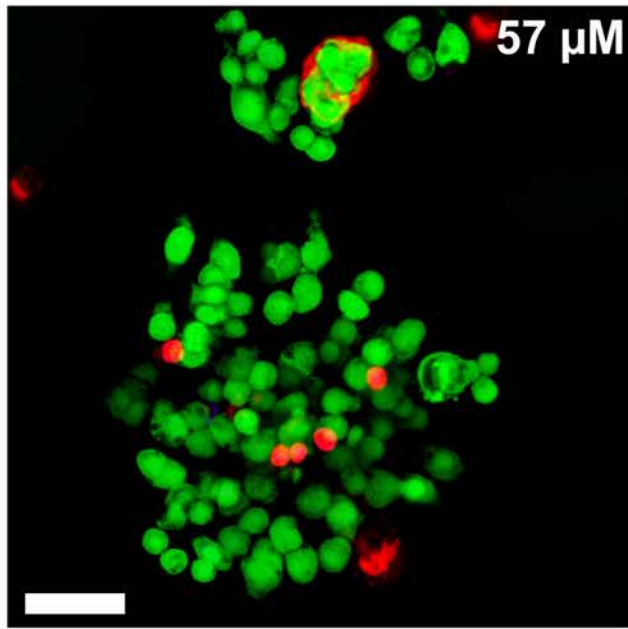


The Brazilian lancehead is one of several South American pit vipers that produce venom that has proven to be a powerful blood coagulant. Hartgerink's group combined a derivative of the venom with their injectable hydrogels to create a material that can quickly stop bleeding and protect wounds, even in patients who take anticoagulant medications. Image credit: Greg Hume.

surgical bleeding can be a problem for people on heparin, a commonly used anticoagulant. "There're a lot of different things that can trigger blood coagulation, but when you're on heparin, most of them don't work, or they work slowly or poorly," Hartgerink said. "That obviously causes problems if you're bleeding."

Batroxobin, a venom produced by two species of the South American pit viper, is a potent coagulant that is unaffected by the presence of heparin. Pure, laboratory-produced batroxobin has been approved for a few uses in medicine, but it has limited use in stopping surgical bleeding. The compound is small and very soluble, which makes it impossible to contain to just the site of the wound. Hartgerink decided to see what would happen if you combined the clotting properties of batroxobin with the targeted drug-delivery capabilities of one of their hydrogels. "To be clear, we did not discover nor do any of the initial investigations of batroxobin," he said. "Its properties have been well-known for many decades. What we did was combine it with the hydrogel we've been working on for a long time."

Once injected at the site of the wound, the self-assembling nanofibers reassemble themselves into a gel. The sponge like structure allows it to stick easily to the wound and to deliver the batroxobin only to the wound site. Lab results show that the batroxobin-loaded hydrogel, SB50, initiates the clotting process in as little as six seconds, and further prodding of the wound does not reopen it.



These images show how cancer cells responded after three days of the timed release of immunotherapy drugs from Rice's STINGel. Doses of the CDN immunotherapy drug increase from top to bottom; live green cells give way to dead red cells as the dosage increases. Scale bars are 50 microns.

"We think SB50 has great potential to stop surgical bleeding, particularly in difficult cases in which the patient is taking heparin or other anticoagulants," said Hartgerink. "SB50 takes the powerful clotting ability of this snake venom and makes it far more effective by delivering it in an easily localized hydrogel that prevents possible unwanted systemic effects from using batroxobin alone."

This type of effective drug delivery is an important challenge in many areas of modern medicine. The ability of hydrogels to provide extended and localized drug release has generated a great deal of interest in them for a variety of applications, including cancer immunotherapy. Cancer immunotherapy uses the power of the body's own immune system to treat, cure and prevent cancer, and cyclic dinucleotides, or CDN, are a new class of immunotherapy drugs known as STING (stimulator of interferon gene) agonists. CDN have shown to be strong cancer fighters in clinical trials, but they are quickly flushed from the body and currently must be injected periodically to effectively treat cancer patients.

Employing the targeted drug delivery ability of hydrogels, Hartgerink and Rice alum Simon Young '08, an assistant professor of oral and maxillofacial surgery at the University of Texas Health Science Center at Houston, developed STINGel, a peptide hydrogel that provides localized and controlled release of CDN. STINGel continuously delivers CDN directly to the tumor target as it degrades slowly over time, which avoids the need for multiple injections. "The normal approach to CDN delivery is simple injection, but this leads to very rapid diffusion of the drug throughout the body and reduces its concentration at the site of the tumor to very low levels," said Hartgerink. "Using the same amount of CDN, the STINGel approach allows the concentration of CDN near the tumor to remain much higher for longer periods of time."

Preliminary STINGel results are promising. In rodent tests, the overall chance of survival was dramatically improved for animals treated with STINGel compared to those given CDN alone via traditional injections or CDN delivered by a different hydrogel. And, STINGel-treated mice proved resistant to further tumor growth — an indication that their immune systems were trained to successfully identify and destroy both existing cancer and future reoccurrence of that cancer. "Our hydrogel provides a unique environment for the release of CDN that other gels just can't match," Hartgerink said.

In fact, even without a drug payload inside, this hydrogel — named K2(SL)6K2 after its amino acid sequence — shows promise for clinical use as it encourages healing all by itself. "This exceptional peptide allows the body to carry out healing on its own, but with a significant boost," said Hartgerink. This boost in regenerative power may prove helpful for people with diabetes, who often develop wounds in their legs and feet that are slow to heal.

Tests show that K2(SL)6K2 significantly accelerated wound healing in diabetic mice. Treatment led to wound closure in 14 days, with wounds forming new connective tissue, including dense growth of blood vessels and nerve cells, and the regeneration of hair follicles. Wounds treated with the Rice hydrogel closed twice as fast

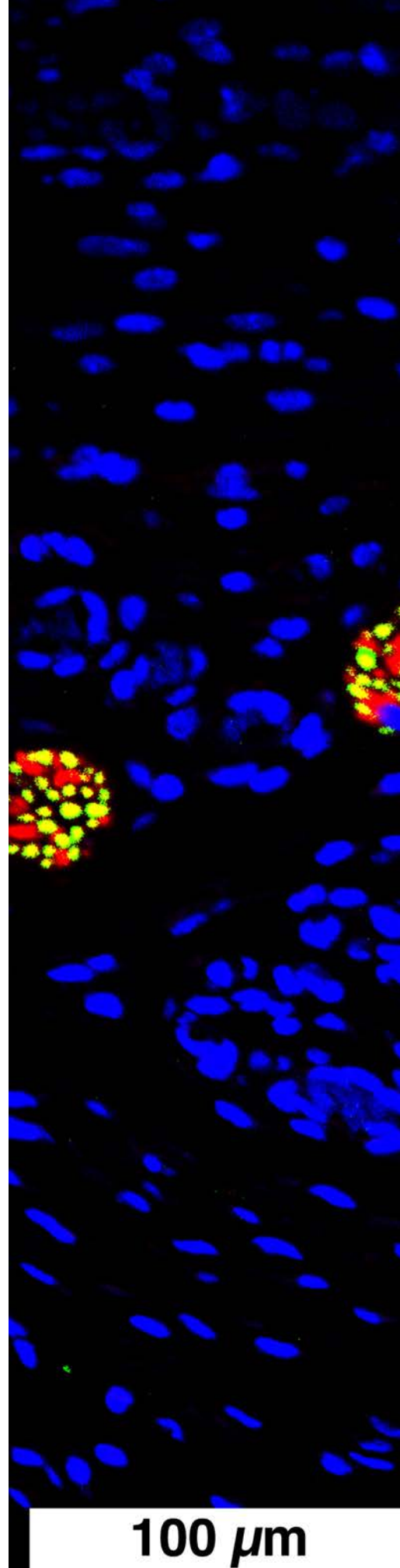
as the time required for wound closure in mice treated with a commercial hydrogel. “The results were spectacular and quite different from all what other people had published so far,” Hartgerink said.

When injected into a wound, K2(SL)6K2 rapidly helps direct healing cells to move to the wound site, where they infiltrate the hydrogel. Once these cells are on site, they produce all of the components needed for a regenerative response, including forming new blood vessels and nerve fibers. The control hydrogel, on the other hand, was not infiltrated by cells, which appears to be the key to the Rice hydrogel’s ability to accelerate wound healing.

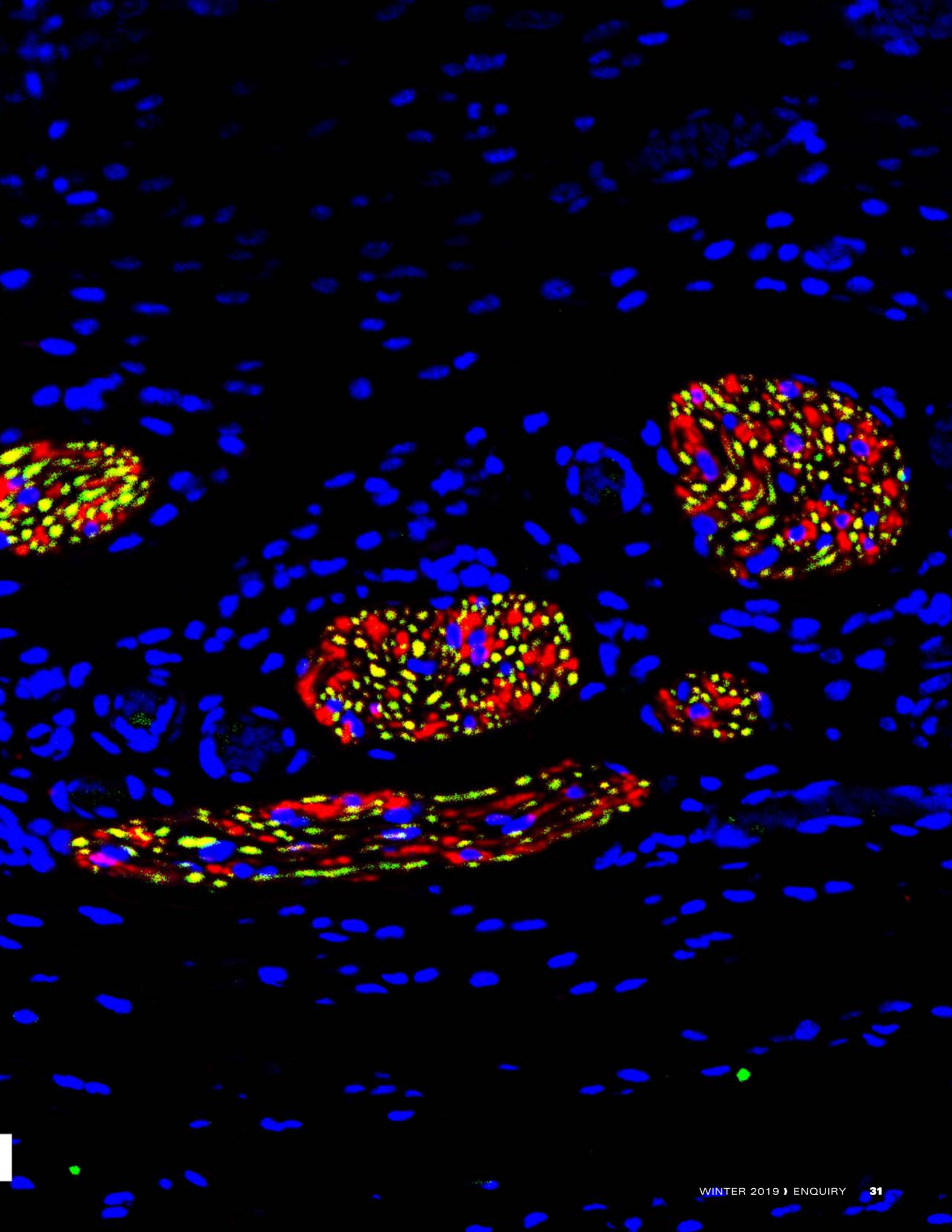
Designing effective biomimetic hydrogels fulfills both Hartgerink’s need to understand the fundamental science of supramolecular chemistry and his desire for his research to have a positive impact on society. It takes a lot of work over many years to successfully design a biomaterial that can function effectively inside living tissue. The work starts with studying molecular interactions, which can often feel highly dissociated from the effects on a living system. For Hartgerink, finally seeing that the molecules and the design work is a spectacular realization.

After many years in the lab, he retains his passion for science thanks, in part, to the energy from the students in his group. “Working with young people who are still open to the possibility of being amazed is a special feeling,” he said. Hartgerink, in turn, is passing on to his students his curiosity and sense of wonder at how the smallest molecular interactions can have such a large impact on healing damaged tissues or even possibly regenerating entire parts of an organism. ■

Treating wounds in diabetic mice with the peptide hydrogel K2(SL)6K2 results in accelerated wound healing and extensive growth of new nerve fibers and blood vessels. Here, neural fascicles from the peripheral nervous system are found within wounds. Neurofilament protein is shown in red and beta III tubulin is shown in green. Cell nuclei are stained blue. Image credit: Nicole Carrejo.



100 μm



An aerial satellite-style photograph of a hurricane over the Gulf of Mexico. The hurricane's eye and spiral bands are clearly visible. A large, semi-transparent red rectangular area is overlaid on the top half of the image, containing the title and author information. The bottom half of the image shows the coastline of Texas and the Gulf of Mexico.

THE ENVIRONMENTAL IMPACTS OF HURRICANE HARVEY

BY DORA HUANG

On Aug. 25, 2017, Hurricane Harvey smashed into the coastal town of Port Aransas, devastating everything in its path and creating an onslaught of rain and wind that led to catastrophic flooding in many regions of Southeast Texas, especially in Houston. In the days that followed the initial landfall, Harvey would unload a total of 13 trillion gallons of water onto Houston and neighboring communities, creating massive floods that destroyed roads and pushed citizens out of their homes, forcing many to a startling realization of the inadequacies of the current infrastructure in the city.

As people struggled to rebuild their lives in the aftermath of such a disastrous event, the wildlife in our natural ecosystems were likewise rebuilding their own communities. Some species suffered devastating losses and an entire environmental reset, whereas other organisms were seemingly unaffected. “Hurricane Harvey was, among other things, a grand ecological experiment,” said Tom Miller, associate professor of ecology and evolutionary biology. “It offers a unique opportunity to explore whether a single extreme-weather event can re-shuffle an entire community of organisms.”

Rice scientists are tackling short- and long-term questions about the impact of Harvey floodwaters on aquatic and terrestrial ecosystems in the coastal region of Texas. By comparing data collected in Harvey’s aftermath to samples collected before the storm, they continue to examine the lasting impacts that floodwaters can have on populations of organisms.

Adrienne Correa, assistant professor of biosciences, is a microbial ecologist who studies how different microorganisms can affect the hosts and ecosystems they reside in, particularly in the diverse habitats of coral reefs. One of the reef systems that Correa studies is the Flower Garden Banks National Marine Sanctuary, found in the NW Gulf of Mexico just 100 miles offshore of Galveston. This is a relatively healthy reef system that can be situated directly in the path of freshwater flood runoff.

When thinking about hurricane damage to reefs, people often focus more on physical damage from the battering of the storm rather than the harm caused by floodwaters. This runoff can reduce the salinity and dissolved oxygen in the water — both things that can stress corals and lead to reef die-off.

Harvey was Houston’s third 500-year flooding event in three years, following the 2015 Memorial Day Floods and 2016 Tax Day Floods. After each of these events, freshwater runoff flowed out into the Gulf of Mexico and toward the Flower Garden Banks.

A few months after the 2016 Tax Day Floods, parts of the reef experienced a localized mortality event, with low levels of dissolved oxygen in the water being the most likely contributor to this mortality. “In late July 2016, there was a partial die-off on the East Flower Garden Banks,” said Correa. “We didn’t know it was happening

until a recreational dive boat happened to go out there and see it. Because we didn’t know about the risk ahead of time, we couldn’t sample on a timeline that made it easy to figure out a mechanism for the die-off.” The team worried that Harvey’s impact on the reef would be just as bad and wanted to get to the reef quickly to assess the damage.

Just a few weeks after Harvey hit, Correa and her colleagues were onsite at the Flower Garden Banks collecting fresh coral biopsies

TOP: A massive star coral impacted by a large-scale mortality event at the East Flower Garden Bank. These corals are hundreds of years old and can be lost in a matter of days. Image credit: FGB-NMS/G.P. Schmahl.



BOTTOM: Rice University marine biologist Adrienne Correa taking samples at a Flower Garden Banks reef in 2016. (Copyrighted photo courtesy of Jesse Cancelmo for noncommercial use only.)



from three different sites. Luckily, the reefs avoided a direct hit by the Harvey floodwater. The team noted a short-lived 10 percent drop in water salinity and observed some signs of mild stress in corals and sponges, but there was no evidence of a mass mortality event like the one in 2016.

“With this project, we are trying to understand when and how floodwaters can cause trouble on reefs” said Correa. One of her main goals is to understand why the reef responded so differently to these two flooding events, especially in the context of how the waters mixed and moved following flooding in 2016, which ended in coral death, versus 2017, which had a happier ending for Texas coral reefs.

Currently, Correa is working on comparing microbial communities of healthy and diseased corals at the Flower Garden Banks, attempting to create a baseline for healthy coral and microbial communities. It is difficult to formulate this baseline from just the data sampled in 2016 and 2017 due to the lack of consistent monitoring of the reef. Future expeditions to gather more coral samples will help to create a model of what the Flower Garden Banks look like when the reef is healthy, which offers a point of reference for future events.

As this project continues to develop, Correa hopes to obtain a more global perspective on how frequently floodwaters from extreme storms impact reefs and to understand the steps that lead to reef destruction following storms. “In terms of the risks and challenges associated with these floodwaters, we’re just starting to think about how complicated this problem could be,” said Correa. “People have known about dead zones in the ocean for a long time, but we’re just starting to realize that low oxygen zones may be a growing problem for reefs.”



“WHEN THE FLOODING FROM HARVEY HAPPENED, WE WERE REALLY CURIOUS AS TO WHAT IMPACT IT WOULD HAVE ON THIS DYNAMIC BETWEEN NATIVE AND NONNATIVE ANT SPECIES.”

While the impact of Harvey’s floodwaters on marine ecosystems may not have been easily visible, it was readily apparent to all that the floods were affecting terrestrial ecosystems. Given the widespread destruction, it’s hard to believe that Harvey’s floods may have actually given a competitive boost to two of southeast Texas’ least favorite invasive species — fire ants and crazy ants. Miller, Sarah Bengston, the former Huxley Research Instructor of Biosciences, and Scott Solomon, associate teaching professor of biosciences, are evaluating whether Harvey increased opportunities for invasion by exotic ants.

Well before Harvey hit, the Rice team was already looking at ant populations in the nearby Big Thicket National Preserve, which contains many native ant species and large numbers of fire ants and tawny crazy ants. “Rice’s team has been working at these same sites for three years, and we know fire ants and tawny crazy ants, which are each invasive species, had begun to penetrate the intact native ecosystems in the park before the hurricane. We now want to know whether Harvey accelerated this invasion process,” said Bengston.

The team already had consistent data collected before the catastrophic event describing the balance between native species and nonnative species. In particular, some parts of the Big Thicket are home to large populations of tawny crazy ants. These ants provide a unique opportunity to observe how a nonnative species may spread through the preserve after an environmental reset. “When

TOP: FireAnt
Image credit: Alex Wild/University of Texas.

MIDDLE: Scott Solomon explores a leafcutter ant colony in Harris County, Texas.

BOTTOM: Sarah Bengston and Tom Miller examine ants at Big Thicket National Preserve. The researchers are studying whether Hurricane Harvey’s unprecedented floods gave a competitive boost to invasive fire ants and crazy ants.

the flooding from Harvey happened, we were really curious as to what impact it would have on this dynamic between native and nonnative ant species,” said Solomon. “It created an opportunity that is really unusual in science, which is to look at the impact of very extreme but very rare events.”

Nonnative ant species often reside in high densities due to the lack of natural enemies in the region. They are also adapted to surviving in highly disturbed environments, a survival skill that may lead to a higher population density of nonnative species in the Big Thicket region post-Harvey. “Fire ants and crazy ants are noxious invasive pests that tend to overwhelm and drive out many native ant species. If the floods cleaned the slate by drowning all the ant colonies in the area, our hypothesis is that this may provide a competitive advantage to invaders,” Solomon said.

Research teams began making monthly visits to the Big Thicket test sites just a few months after Harvey. They have been watching the dynamic between native and nonnative species in the region to see how the diversity of ant populations changes over time. They also are interested to find out whether any changes in response to the hurricane are temporary or if the severe flooding reset the balance of the ant community.

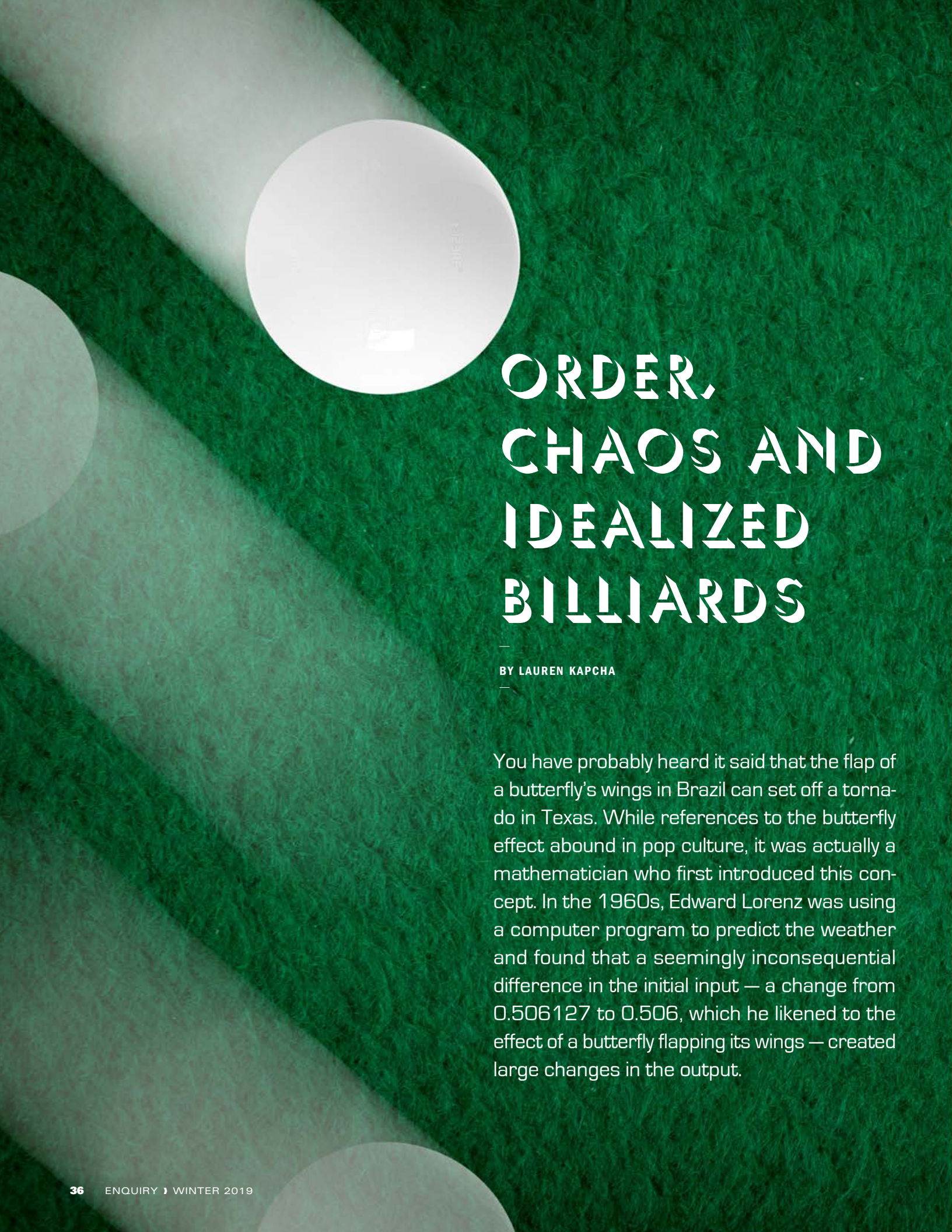
Preliminary findings suggest that the extreme flooding associated with Hurricane Harvey did not radically alter the distribution of

red imported fire ants. However, after about one year, there was a sudden and dramatic collapse of crazy ants at one of the study sites. Prior to Harvey, crazy ants had been extremely abundant at this site, and other ant species — including fire ants — were rare. The research team’s monthly sampling after Harvey showed this pattern continue for several months after Harvey’s floodwaters receded. But, by September 2018, the crazy ants suddenly disappeared. The team is currently working to understand what caused this apparent collapse, whether or not it was associated with the effect of the flood (for example, by impacting the prey species that crazy ants depend on for food), and whether or not the collapse is temporary.

Much like the inhabitants of these ecosystems, many members of the Rice community have also faced the task of rebuilding after Harvey. Rice faculty, staff and students came together to provide support and help clean out the flooded homes of the 1,450 Rice employees who received water damage to their homes. Despite the fact that Harvey flooded both Solomon’s and Correa’s homes with 20 inches of water, they, like many others, choose to keep their focus on the bright side. “For me, having the opportunity to conduct research on the effects of Harvey flooding on ants is like making lemonade out of lemons,” Solomon said. “At least something positive can come from a terrible experience.” ■

A map showing the locations of Houston, Flower Garden Banks National Marine Sanctuary and Big Thicket National Preserve.





ORDER, CHAOS AND IDEALIZED BILLIARDS

—
BY LAUREN KAPCHA
—

You have probably heard it said that the flap of a butterfly's wings in Brazil can set off a tornado in Texas. While references to the butterfly effect abound in pop culture, it was actually a mathematician who first introduced this concept. In the 1960s, Edward Lorenz was using a computer program to predict the weather and found that a seemingly inconsequential difference in the initial input — a change from 0.506127 to 0.506, which he likened to the effect of a butterfly flapping its wings — created large changes in the output.

At first glance, this extreme sensitivity to starting conditions makes the predictions look completely random. The system is, however, governed by the rules of physics. Given the present conditions, the system will evolve over time according to these rules in a predictable way. Underlying the chaotic behavior, there is a mysterious order that we cannot see.

This is true of many dynamical systems, systems that evolve in time by a mathematical set of rules. There are many interesting examples of dynamical systems all around us — weather, the solar system, the stock market and the formation of traffic jams, to name a few. Mathematicians often use simplified model systems to understand the fundamental behavior underlying these very complex systems. Ronen Mukamel, assistant professor of mathematics at Rice University, has recently been working with one classic mathematical example of a dynamical system: idealized billiards.

Idealized billiards looks a lot like normal billiards, with a few key exceptions. The ball travels around the table following the same rules as a normal billiard ball — it bounces off of a wall at the same angle that it hit the wall. But, the ball has no mass, so it doesn't experience any friction, and there are no pockets to end the trajectory. With no friction and no pockets, the ball will keep bouncing around the table forever. And there's one last difference: the table doesn't have to be the familiar rectangle, but rather can be any polygon whose angles are rational multiples of π — i.e., of the form $p/q * \pi$, where both p and q are integers.

Like Lorenz's weather predictions, small changes to the starting speed or angle of the ball have a dramatic impact on its path. This unpredictability is what makes the game fun to play, and it also provides an interesting system for mathematicians to study. "Since

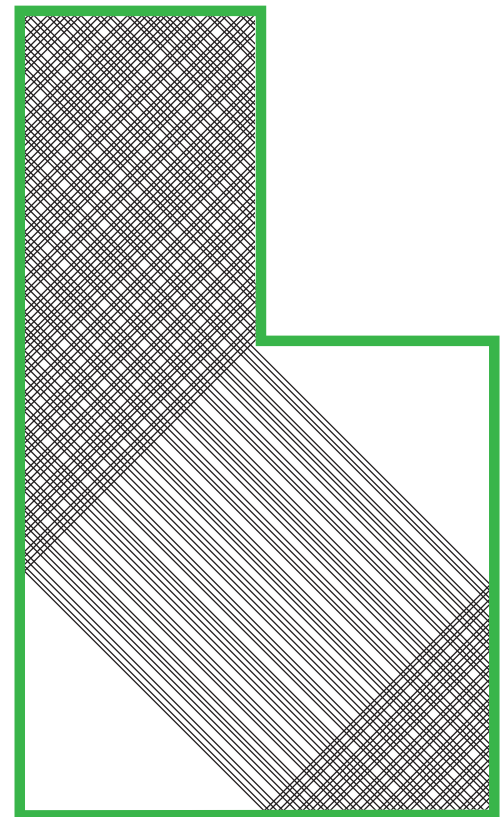
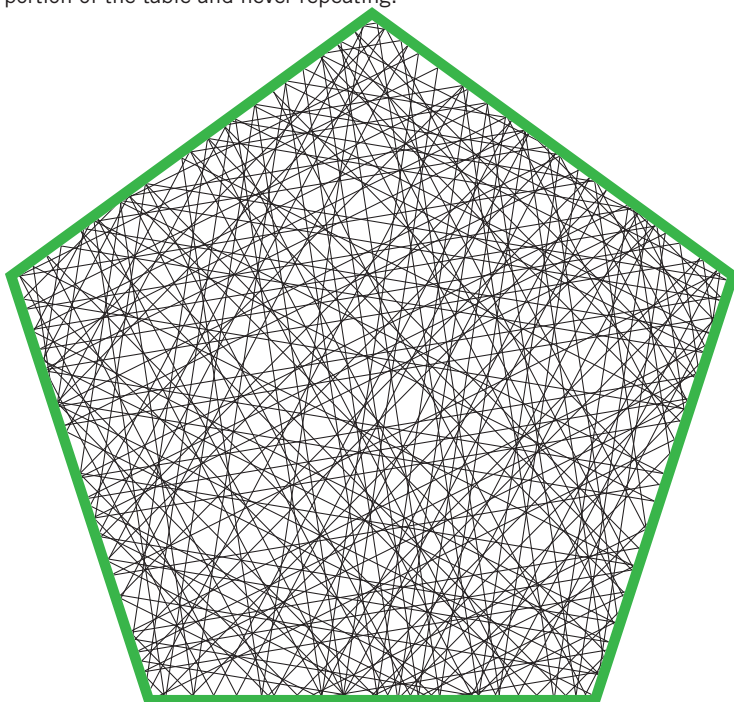
we're mathematicians and not physicists, we want to understand the infinite behavior and not any particulars of friction or spin," said Mukamel. Instead, he is concerned with the long term behavior of the ball.

A range of possibilities could occur. The ball could bounce off of the table walls several times and return to its starting position and direction, tracing out the same periodic path over and over again. Or, the ball could chaotically go over the entire table, its path uniformly distributing so that it spends an equal amount of time at every part of the table. These extremes — complete order or complete chaos — are the two simplest things that could happen. Intermediate scenarios are also possible. The path could uniformly distribute only over a small corner of the table or the path might cover the entire table, with the ball spending more time on the left-hand side of the table than the right.

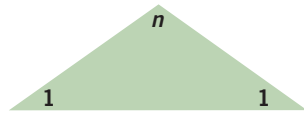
It turns out that every path is either periodic or uniformly distributed for the familiar rectangular pool table. None of the intermediate scenarios that favor one part of the table over the other ever happen. The behaviors of trajectories on these tables are completely classified, and it seems natural to consider which polygons have this optimal dynamics.

The late Rice mathematician William Veech found the first non-rectangular examples of shapes that satisfy what is now known as the Veech dichotomy. The simple tables that he discovered with optimal dynamics were the regular n -gons — a shape with n sides, where all sides are the same length and all angles are the same. "These billiard tables are very symmetric, like gems. The amazing thing about these very special tables is that none of the potentially wild intermediate behavior can happen for them," Mukamel said.

(left) On an optimal billiard table, every path will either be periodic — repeating its path around the table over and over again — or it will uniformly distribute over the entire table. (right) Paths are less predictable on a nonoptimal billiard table, for example covering only a portion of the table and never repeating.



The eight families of triangles with optimal dynamics are shown here. Numbers indicate the ratio of each triangle's angles.



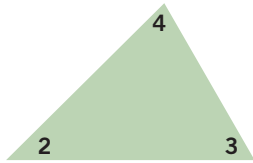
Ratio: 1:1:n



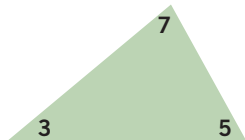
Ratio: 1:2:n



Ratio: 3:4:5



Ratio: 2:3:4



Ratio: 3:5:7



Ratio: 1:4:7



Right angled triangles
Ratio: 2:(n-2):n



Acute isosceles triangles
Ratio: 2:n:n

"Every trajectory is either uniformly distributed or periodic."

After Veech's seminal finding, mathematicians started looking for more examples of these special shapes that form optimal billiard tables. "It's all a little mysterious," said Mukamel. "Mathematicians would very much like to classify all of these gems, these billiard tables satisfying the Veech dichotomy."

People have made progress toward this goal in two ways: by finding examples of polygons with optimal dynamics and by finding constraints saying that there shouldn't be many examples. Eight families of triangles with optimal dynamics are known. "It had been a while since the last example was found, and I think people were hoping that we'd found all of them," Mukamel said.

Then, Mukamel, along with Curt McMullen of Harvard University, Alex Wright of Stanford University and Alex Eskin of the University of Chicago, identified two new infinite families of quadrilaterals with optimal dynamics. The families of quadrilaterals are specified by the ratio of their angles, and these two dart-shaped families of quadrilaterals are identified by the ratios 1:1:1:9 and 1:1:2:8.

You may be wondering how you go about determining if a polygon is an optimal billiard table. Clearly, you can't just sit down and start carefully tracing out the exact angle of every impact and reflection for an infinite number of starting conditions. Mathematicians use a couple of tricks to study these complicated billiard trajectories.

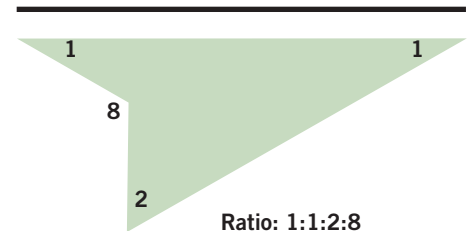
The first trick is a process called unfolding, which turns trajectories that bounce off of walls all over the table into straight lines on a surface. To unfold a polygon, you reflect it through its sides, continuing until any further reflections produce a polygon you already have. You can metaphorically tape all of the reflections together to build what's known as a translation surface. "The downside is that you made the area larger," said Mukamel. "But, the upside is that now all you have to do is consider straight lines."

Unfolding works for any rational polygon, taking complicated billiard trajectories and turning them into a question about dynamics on a surface with a specific geometry.

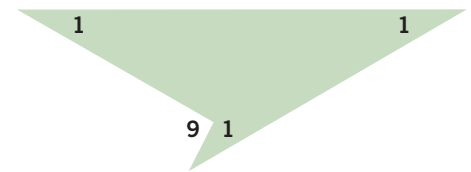
The next trick is to shift your thoughts of trajectories on surfaces in our 3D world into moduli space — a high-dimensional space consisting of all possible geometries that enables mathematicians to find solutions to geometric classification problems. In moduli space, mathematicians are able to study surfaces as one of a continuous family of related geometries rather than as an individual object.

To navigate in moduli space, one deforms a surface by altering the edges of the polygons in a way that is compatible with the taping instructions. One specific way to do this is to apply a two-by-two matrix to all of the constituent polygons, which has the effect of stretching the polygons in a uniform way across the entire surface. The lines on the new surface correspond to the original billiard paths, and the dynamics on the new surface are closely related to those on the original surface.

Each matrix you apply produces a new surface, and for each new surface you can ask the question: is that surface the same as the orig-



Ratio: 1:1:2:8

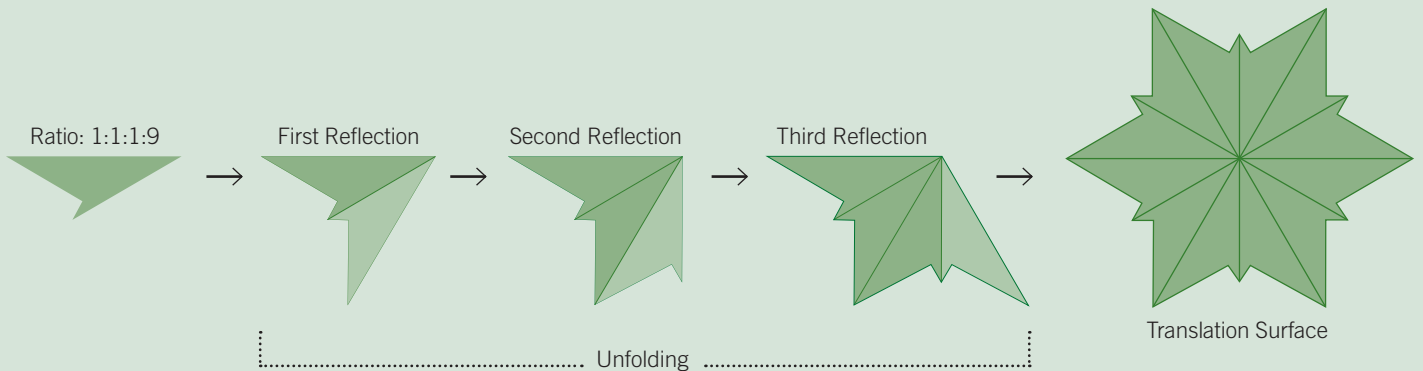
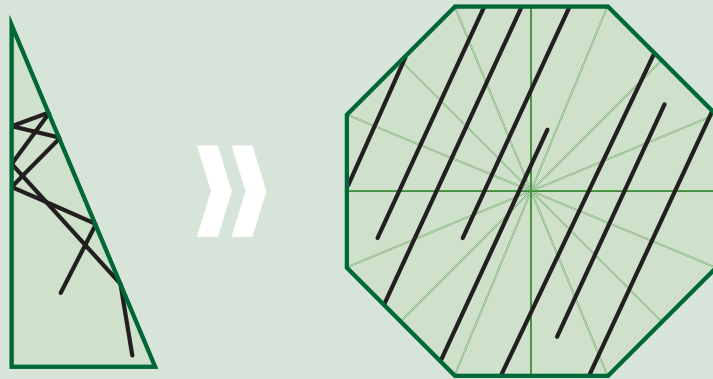
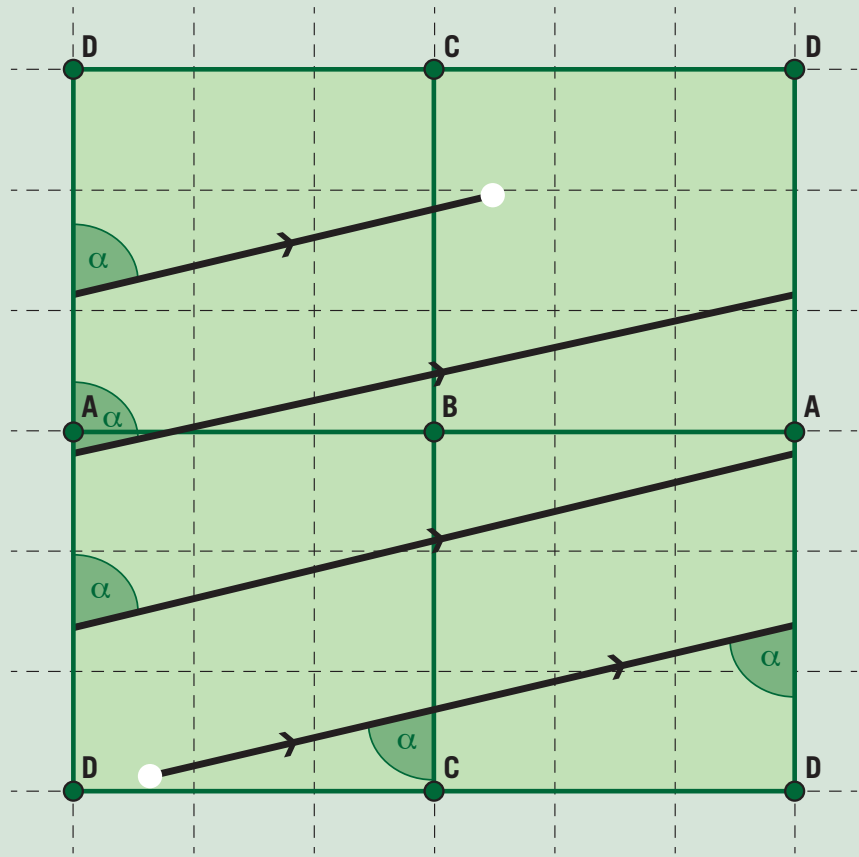


Ratio: 1:1:1:9

Two new families of quadrilaterals found to have optimal dynamics are shown here. Numbers indicate the ratio of each quadrilateral's angles.

UNFOLDING

In order to understand how unfolding works, consider a square with its corners labeled A, B, C and D. Imagine starting a billiard ball on the bottom side of the square, headed toward the right side. Instead of letting the ball bounce off of the wall, reflect the square through the right wall and tape the corresponding corners together. Now, the ball continues on a straight path into the reflected square. Repeat this process of reflecting the square a few times until any further reflections result in a square with its corners labeled in exactly the same order as an existing square. The resulting surface is known as a translation surface. The unfolding process and resulting translation surfaces are also shown for a triangle and a quadrilateral.



inal? Imagine applying a transformation matrix to an octagon that compresses everything in one direction giving you a new octagon that is very long and thin. Now you want to know if it's the same surface. "Well, of course it doesn't look like the same octagon. It will never look like the same octagon," said Mukamel. "But, what you can do is you can cut up the long and thin octagon and try to rearrange the pieces to recover the regular octagon." If you can do that, then the matrix is in the symmetry group. A randomly chosen initial billiard table or surface will have very few symmetries. But, if you have enough symmetries, then your polygon is an optimal billiard table.

This is how Veech identified regular n-gons as the first optimal billiard tables. "Veech discovered the first examples by explicitly computing a large enough collection of matrices that were in the symmetry group," Mukamel said. "But, that wasn't really a practical approach in this case."

Mukamel and his collaborators used one final trick to show that these two families of quadrilaterals have optimal dynamics: they took this polygonal approach to identifying symmetries and recast it as an algebraic problem. "One reason I really like moduli spaces is that there are a lot of perspectives on them. One perspective is this polygonal description, but it wasn't really practical to just use polygons to show that the symmetry group was large," said Mukamel. "Instead, there's another perspective on them as algebraic curves."

Using this approach, the team identified the two new families of quadrilaterals as optimal billiard tables by finding the algebraic

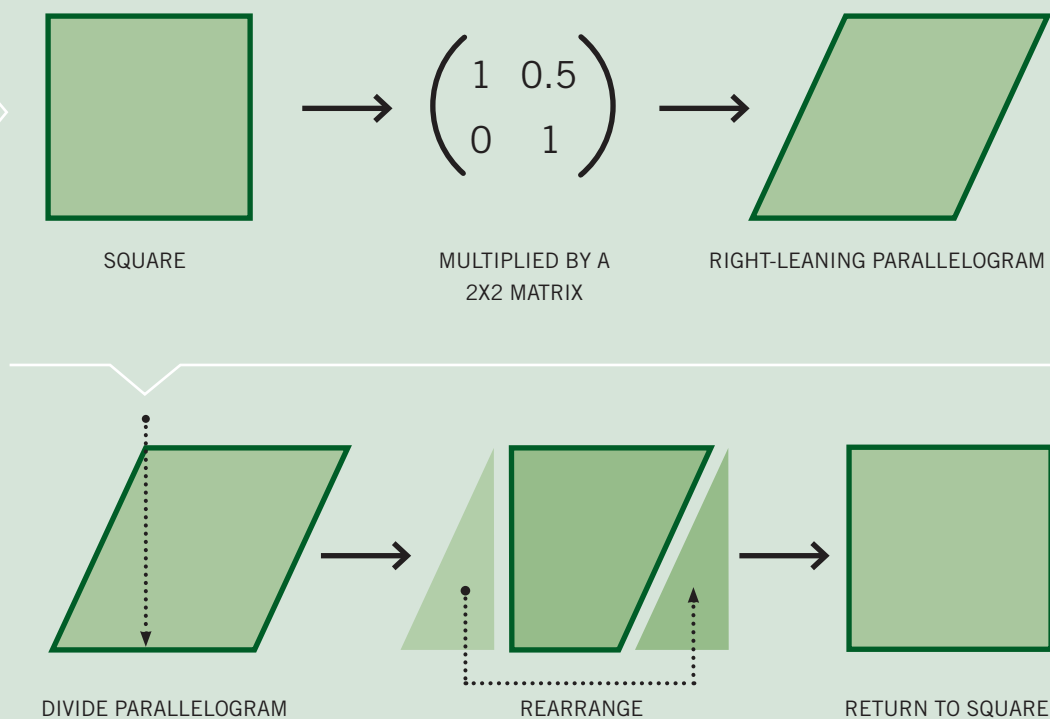
equations that defined them in their moduli spaces. This required studying what's known as an orbit—the set of surfaces that you get from deforming a translation surface with a matrix. Where moduli space contains all possible geometries, you can think of the orbit as the group of geometries that are related to the original surface of interest.

Normally, the orbit is large, spreading out as a dense set in moduli space, just like a random trajectory of the billiard ball normally uniformly distributes as a dense path covering the entire table. "Equivalent to having all of these symmetries is that the orbit is very small. So, rather than distributing over all of moduli space, it distributes over a subset of moduli space," Mukamel said.

Mukamel and his collaborators found the algebraic equations describing that subset of moduli space, proving that the orbit was small — 1D, to be precise — thus identifying two new families of quadrilaterals with optimal dynamics. These very well may be the last examples of optimal billiard tables that will be found. Only time will tell if there are more varieties of these symmetric gems that show an exquisite balance between order and chaos.

"On the one hand, there's lots of chaos involved in what we just described. But on the other hand, it's very ordered. The trajectories are not chaotically distributing in some very exotic sense, but in the simplest possible sense," said Mukamel. "It's stemming from this very ordered, this very symmetric billiard table — this gem-like object. Somehow the order of the object, the symmetry and beauty of the object kind of forces this chaos, but it's very controlled chaos." ■

Applying a matrix to a square produces a right-leaning parallelogram. If you cut the parallelogram into pieces and rearrange them, you return to the regular square. This indicates that the matrix applied is an element of the square's symmetry group.



Assessing the Pollination Success of Rare Trees

In the dark, pungent understory of a Smithsonian tropical science research plot in Cameroon, seven different species of the same tree genus flower simultaneously. Working with Amy Dunham, associate professor of ecology and evolutionary biology at Rice, graduate student Andrea Drager selected this location to collect pollen samples in order to understand the pollination success of less abundant tree species.

Since trees generally prefer not to pollinate themselves, having few members of the same species nearby in the vast and dense tropical forest presents a possible obstacle to successful reproduction. This dilemma interested Drager, as some of these rare trees are important to local communities. “I started wondering, how are they exchanging pollen and finding each other?” she said. “Do these less abundant species have some kind of adaptation that allows them to pollinate successfully at such low densities?”

By collecting pollen samples from the trees’ flowers, Drager was able to determine how much pollen the trees received, as well as the pollen’s species of origin. With this information and the help of former undergraduate researcher Laura Nicholson ’18, she worked to map a pollen network — tracking how the pollen is transferred in the community from donor to recipient while noting if the transaction is between trees of the same species or the same genus.

The catch? This required the identification of each individual pollen grain. “It’s been a steep learning curve,” Nicholson said. “I spent an entire summer working on three slides. There are still two species we can’t tell apart.” After examining over 60,000 grains of pollen under the microscope, they now possess a pollen library, an ample knowledge of pollen morphology and enough data to sink their teeth into.

While they expected to see that pol-

len receipt by trees of the same species increases as the species becomes more abundant, preliminary results show no significant correlation between the two variables. Drager and Nicholson are still analyzing data, but this preliminary finding indicates a complex relationship between pollen receipt — which is required but not sufficient for pollination — and tree density for these rare trees. Other variables, such as how attractive a species’ flowers are to pollinators, could also contribute to these species’ reproductive success.

“We’re excited to see how this pollen receipt translates into pollination,” Drager said. “Are rarer species getting a lot of pollen because pollinators are just moving from male to female flowers on the same tree? If so, we should see no or low pollination. Or are they bringing in high-quality pollen from other trees, leading to high rates of pollination?” ■

— SOPHIA STREETER



A portion of the plant stigma is seen under a light microscope. Tiny tentacle-like arms are poised to capture pollen landing on the stigma.

“I started wondering, how are they exchanging pollen and finding each other?” Do these less abundant species have some kind of adaptation that allows them to pollinate successfully at such low densities?”

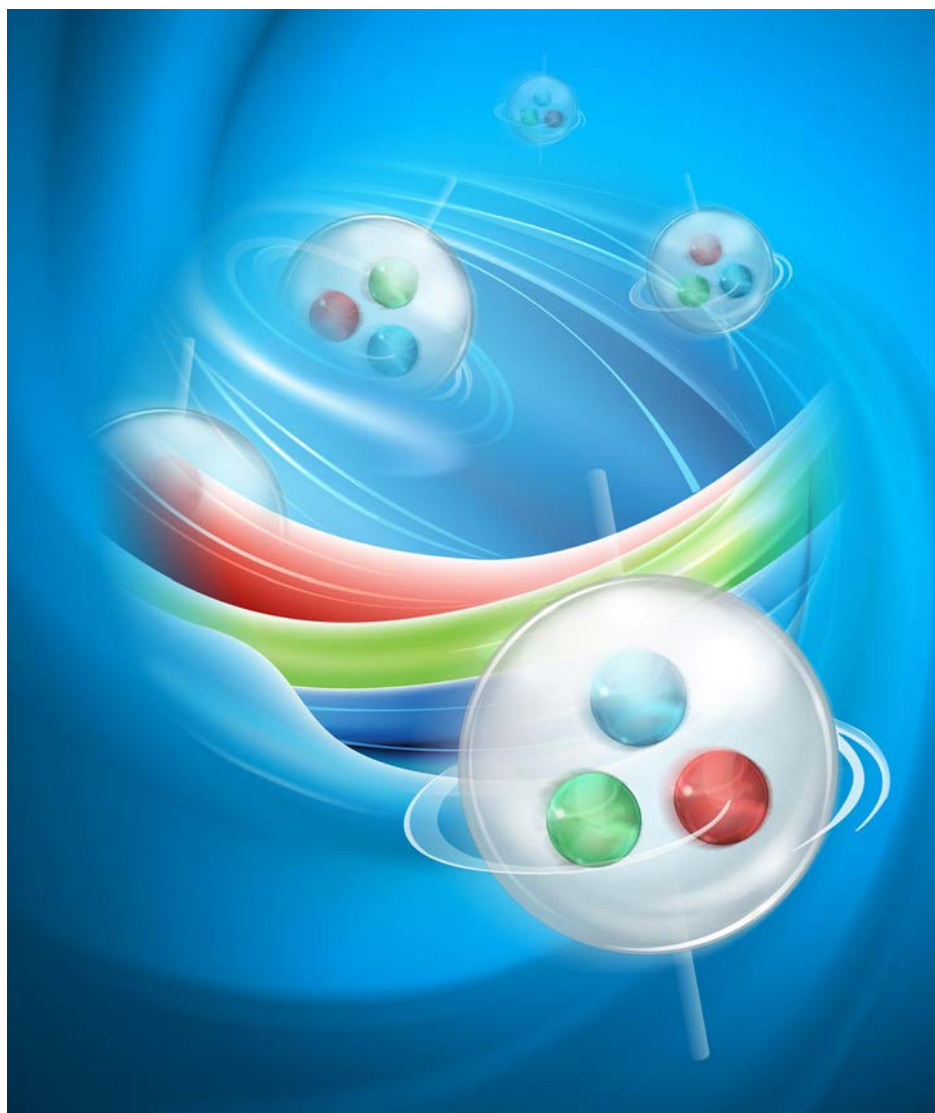
Heavy Ion Collisions Produce Speediest Vortex

From colliding neutron stars to the Big Bang, quark gluon plasma (QGP) may exist only in environments of the most extreme temperatures or density. Frank Geurts, associate professor of physics and astronomy at Rice and deputy spokesperson of the STAR collaboration, and his associates at the Brookhaven National Lab Relativistic Heavy Ion Collider (RHIC) create environments in which QGP can exist in order to study some of the most basic components of matter.

Quarks and gluons are fundamental particles of better-known atomic constituents such as protons and neutrons, where they are confined within atomic nuclei and found in groups of three quarks and the gluons that hold them together. QGP, however, is a state of matter in which quarks and gluons are unbound from their confinement and can behave as asymptotically free particles. By colliding gold ions at 99.995 percent of the speed of light, Geurts and his colleagues create a QGP that lasts only a few tens of a trillionth of a trillionth of a second at temperatures of 4 trillion degrees Celsius. The free particles leaving the QGP are then analyzed to gain insight into their traits and behaviors. “QGP is a fantastic vehicle for testing questions pertaining to why quarks and gluons are not found by themselves in nature and how nuclear matter behaves under extreme conditions. We are studying the strong nuclear forces that govern their nature,” said Geurts.

QGP has been identified as the hottest and least viscous fluid ever produced in a laboratory setting. Members of the STAR collaboration have made recent discoveries regarding its properties by selecting off-center trajectories instead of the typical head-on collisions of the heavy ions in RHIC. Off-center collisions generate a QGP with extremely high levels of angular momentum, which, paired with QGP’s extremely low viscosity, creates a swirling vortex that is the fastest spinning fluid ever recorded. This fluid spins at 10 billion trillion revolutions per second, a rotation that dwarfs that of the fastest tornados.

In the future, Geurts and his colleagues



Tracking particle spins reveals that the quark-gluon plasma created at the Relativistic Heavy Ion Collider spins faster than the cores of supercell tornadoes, Jupiter’s Great Red Spot or any other fluid, according to researchers at Brookhaven National Laboratory. Image credit: Brookhaven National Laboratory.

hope to use their knowledge of the properties of fundamental particles gained in their research to ultimately examine the internal dynamics of protons and how quarks and gluons come together to form protons and neutrons.

“Humankind has a strong desire to figure out what is behind the things they see. This type of fundamental physics is really touching on the very small scale and at a cosmic scale. If you expand your world and you look at the night sky, in the

end, everything is still made of quarks and gluons,” Geurts said. “I am attempting to understand the most fundamental in order to explain the phenomena of the world around me, but also astrophysical and cosmological ideas as well.” ■

— THOMAS ETHERIDGE

Model May Help Reveal CRISPR-Cas9 Mechanisms

Anatoly Kolomeisky, a Rice professor of chemistry and chemical and biomolecular engineering, has developed a computational model to quantify the mechanism by which CRISPR-Cas9 proteins find their genome-editing targets.

In its natural state, CRISPR is the biological mechanism by which bacteria protect themselves from viral infections. In recent years, researchers have begun to adapt the mechanism for use in genome editing, which has the potential to cure disease and enhance organisms, including humans. But a stumbling block has been the risk that CRISPR-Cas9 proteins, one of the systems that utilize the CRISPR approach, will cut and replace the wrong target sequences, introducing mutations.

The Rice model found it likely that CRISPR-Cas9 locates good targets more efficiently when these off-target edits are allowed to happen, because the proteins don't waste time disassociating from off-targets to continue searching.

"The error rate is sometimes 10–20 percent," Kolomeisky said. "We have two ideas about this: One is that viruses mutate very quickly and maybe bacteria are trying to cut targets that are only slightly mutated as a way to be more flexible. The other is that there are proteins that can correct mistakes, so if there aren't many wrong cuts, the system can tolerate them."

According to CRISPR pioneer Jennifer Doudna, CRISPR-Cas9 initially recognizes three-nucleotide PAM (for protospacer adjacent motif) sequences that mark the location of potential targets. "CRISPR finds and binds to PAM and then its associated RNA explores the adjacent DNA to see if this is the target," Kolomeisky said. "If it is, the protein starts to cut. If not, it disassociates and looks elsewhere."

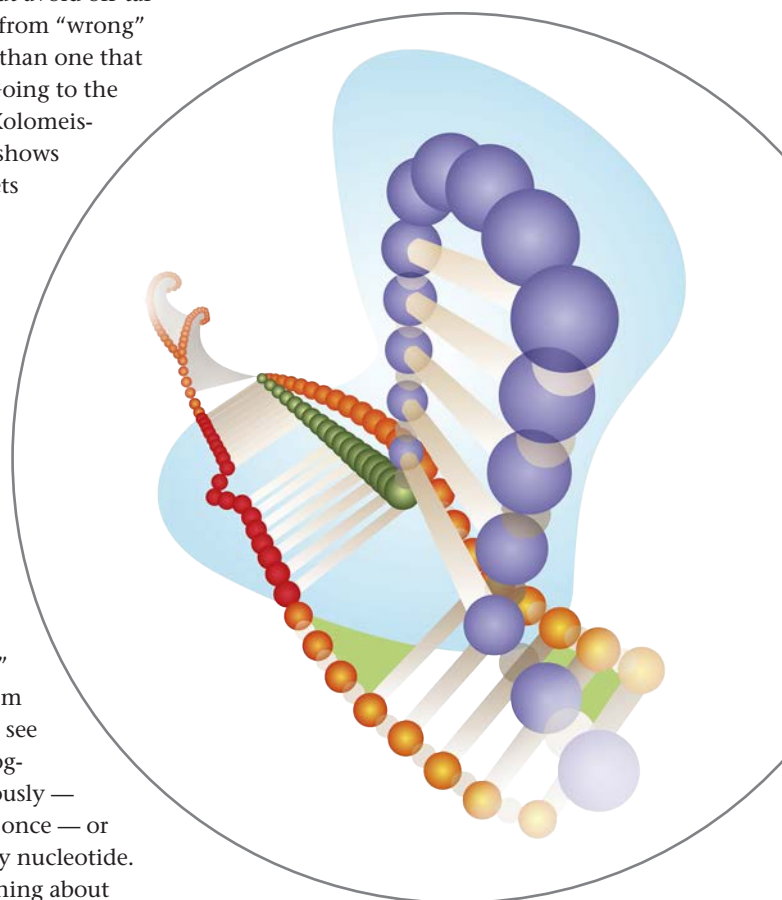
In Doudna's subsequent experiments with PAM sequences removed, CRISPR-Cas9 proteins could not find their targets at all. So PAMs have an important role and are not just a generic spacer, he said.

The theoretical model looks at first-passage processes — those that happen when a system crosses a physical or chemical threshold, like finding a relevant PAM — to track CRISPR-Cas9 proteins inserted into a cell as they first survey PAM sequences and then, while bonded to PAMs, search for the DNA target that matches the Cas9's RNA.

They found CRISPRs that avoid off-target cuts by disassociating from "wrong" DNA take longer to settle than one that simply cuts off-targets. "Going to the wrong PAM takes time," Kolomeisky said. "Our calculation shows CRISPR can find real targets faster when it sometimes cuts in the wrong places. The fraction that goes to the right targets may be smaller, but you will cut them eventually."

"It's a simple model and exactly solvable," Kolomeisky said. "If somebody wants to test, the model can provide specific predictions and in some cases offer trends for what should be observed." What remains missing from the model is the ability to see whether the RNA key recognizes its target simultaneously — binding to the DNA all at once — or sequentially, nucleotide by nucleotide.

"The most impressive thing about CRISPR is the fact that it has created a revolution in biotechnology, because it means that in any cell we can cut any DNA at a specific location, very precisely," Kolomeisky said. "I hope our work will stimulate more fundamental studies, because I like the CRISPR method very much. But I am not happy when people apply it without understanding how it works at the molecular level." ■



A Cas9 protein (light blue) with guide RNA (purple) and DNA (red) shows a DNA bulge, marking a sequence that would be considered off-target for CRISPR-Cas9 editing. Image credit: Gang Bao.

— MIKE WILLIAMS

More Efficient Catalysts for Water Splitting

The simplest and most abundant element in the universe — hydrogen — has the potential to fuel our cars, power our homes and reduce our contribution to global warming. Hydrogen is a much more cost-effective energy carrier than coal and synthetic fuels and, when combusted, its only emission is water vapor. If hydrogen is to become a substitute for fossil fuels, we need to significantly increase production in an efficient and environmentally friendly way.

“Hydrogen right now is primarily produced from fossil fuels such as coal and natural gas. These are not carbon neutral or green processes,” said Rice graduate student Desmond Schipper. “You have to find catalysts to take electricity from solar and wind energy that you can convert into chemical energy and store.” However,

er, there is still too much overpotential, or energetic cost, associated with most catalysts that limits their use for commercial hydrogen production from water.

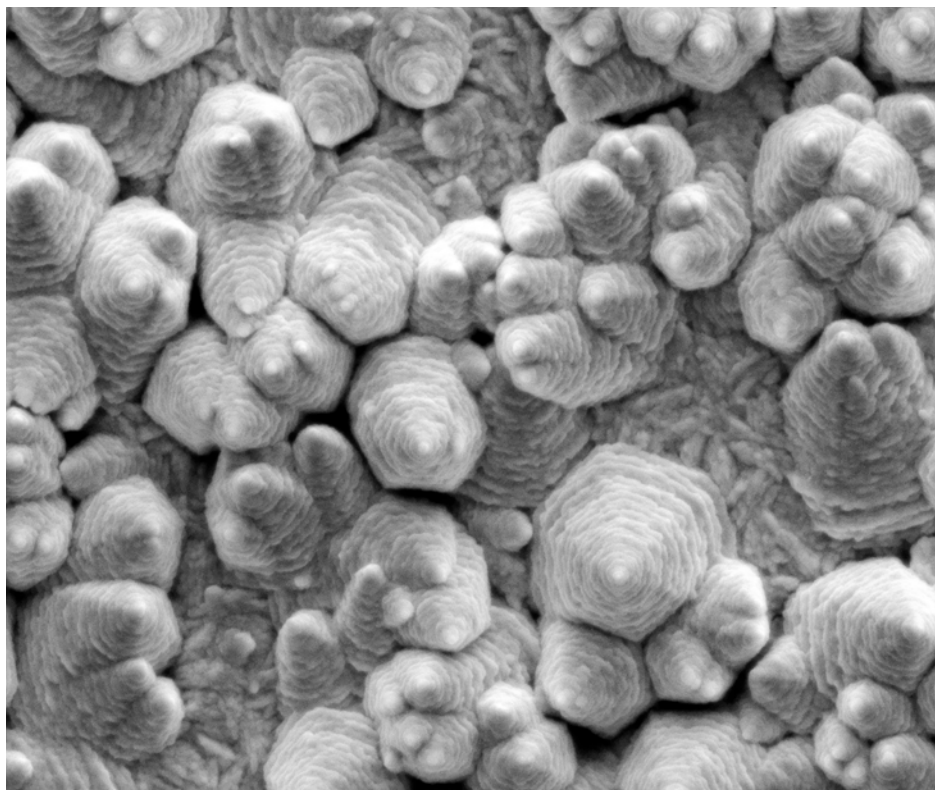
To solve this problem, Schipper and Kenton Whitmire, professor of chemistry, looked at metal phosphides, a promising family of earth abundant catalysts, to see which ratio of iron to phosphorus was most effective at producing hydrogen from electricity and water. “Knowing which kind of metal phosphides work best is very influential and very impactful in future catalyst design. If you know which system works most effectively, you can work on tuning up the Fe₃P system instead of working on the FeP system,” Schipper said.

To test the effectiveness of different ratios of iron to phosphorus, specifically

1:1, 1:2 and 1:3 ratios, or FeP, Fe₂P, and Fe₃P respectively, Schipper grew these metals on electrodes and looked at the hydrogen evolution reaction. He found that the metal rich phosphides greatly outperformed FeP. “The jury was out on which one (metal rich phosphides or FeP) was better. Part of this arises from how difficult it is to make these materials. How you make them affects their performance and surface chemistry,” said Schipper. This finding will help guide catalyst design for hydrogen evolution and, perhaps, many different reactions, which could make cleaner hydrogen production commercially viable. ■

— RUCHI GUPTA

“Hydrogen right now is primarily produced from fossil fuels such as coal and natural gas. These are not carbon neutral or green processes. You have to find catalysts to take electricity from solar and wind energy that you can convert into chemical energy and store.”



Fe₂P was grown on an electrode surface from an organometallic precursor. Due to the cleanliness of the method, the hexagonal symmetry of the Fe₂P is expressed, resulting in the garden of hexagonal nanotowers.

Protein Spies: A New Proteomics Tool

Scientists at Rice have found a more precise method of labeling cells for scientific study. Postdoctoral researcher Emily Thomas '18; Jonathan "Joff" Silberg, professor of biochemistry and cell biology; and their colleagues have discovered a novel enzyme for labeling proteins inside cells that displays switch-like activity. This enzyme enables greater precision over the labeling of cells with useful chemical groups for visualization and characterization.

Thomas and Silberg built upon established methods that attach an artificial amino acid to transfer RNA (tRNA), which carries amino acids to the ribosomes that synthesize proteins. The enzyme used by Thomas and Silberg is a fragmented and mutated variant of methionyl tRNA synthetase (mutant MetRS) that only attaches artificial amino acid labels to newly synthesized proteins when it binds to a

specific chemical that it encounters within a cell. This switch can be turned on and off with presence and absence of the chemical, functioning as a unique and effective identifier of proteins produced in specific cell types within a complex population. Thomas characterized this technique as a "protein spy."

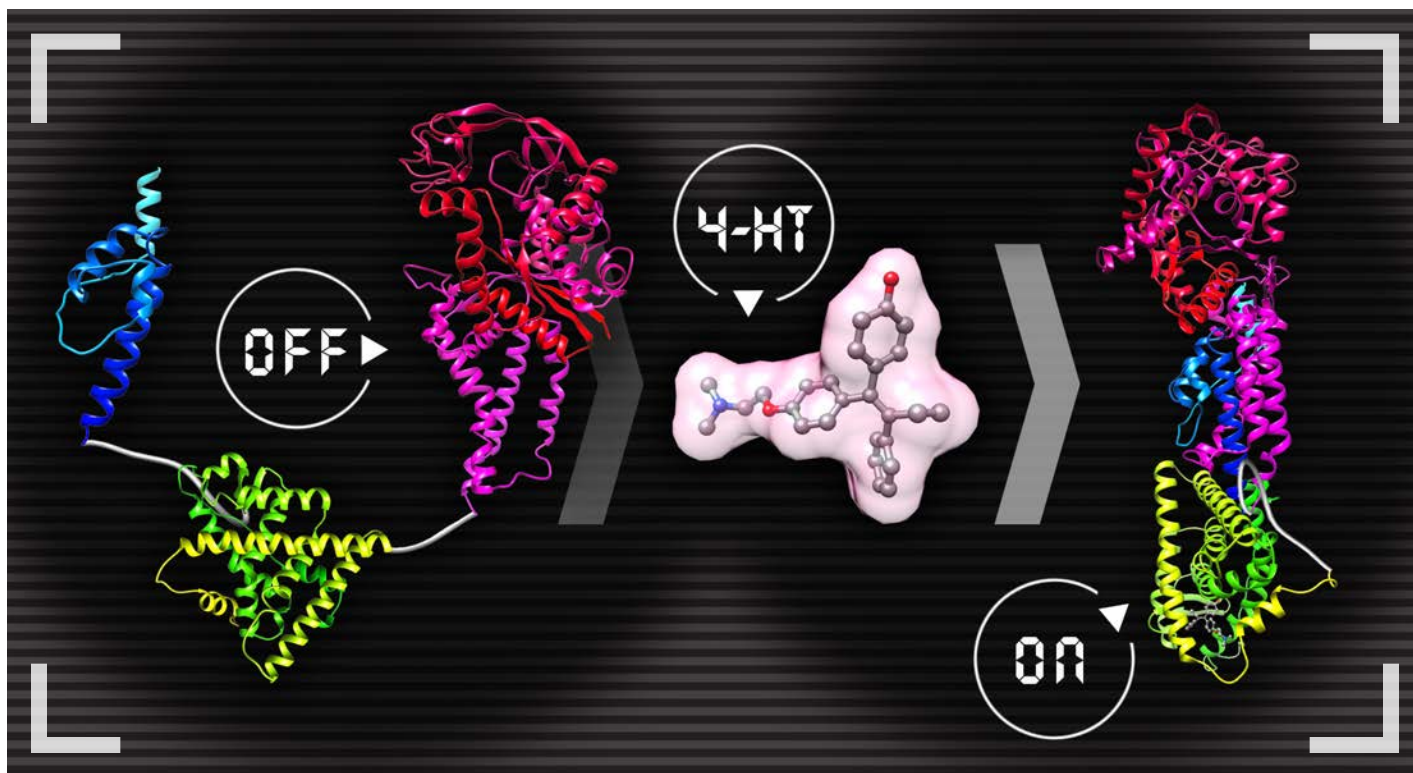
"It spies on what proteins are being made inside the cell," she said. "Current technologies just spy on everything, but I want to be more specific. I want more control over when I turn my spy on or off, so I can track only the cells I'm interested in."

Thomas developed two different methods to take advantage of this ability to regulate protein labeling. In the first method, a unique chemical binds to bisected MetRS and brings the two fragments together, allowing them to label newly synthesized proteins. In the second, both mutant MetRS fragments are attached to a second

chemical-binding protein, but they are separated from each other. When a molecule binds to this switch, the interaction causes a change in the 3D shape, bringing the fragments together. This allows the labeling to be turned on and off by the presence of a user-defined chemical, providing an additional level of control and increasing precision.

"Increasing the specificity of labeling techniques can have huge implications," Thomas said. "By developing tools like this, we are able to better understand what is happening in cells, specifically small groups of cells and even single cells. We are building this tool as a proof of concept. Now that it is complete, not only can people use it, but they can improve upon it. There is a large amount of potential for its future." ■

— THOMAS ETHERIDGE



Rice scientists have discovered a method to tag proteins with a controllable enzyme switch. When a molecule (here, 4-HT) binds, fragments of a tRNA synthetase come together, allowing a tRNA to be charged with an artificial amino acid, which is inserted as a recognizable tag into all subsequent proteins made in the cell.

Unexpected Enrichment of Heavy Nitrogen in Earth's Atmosphere

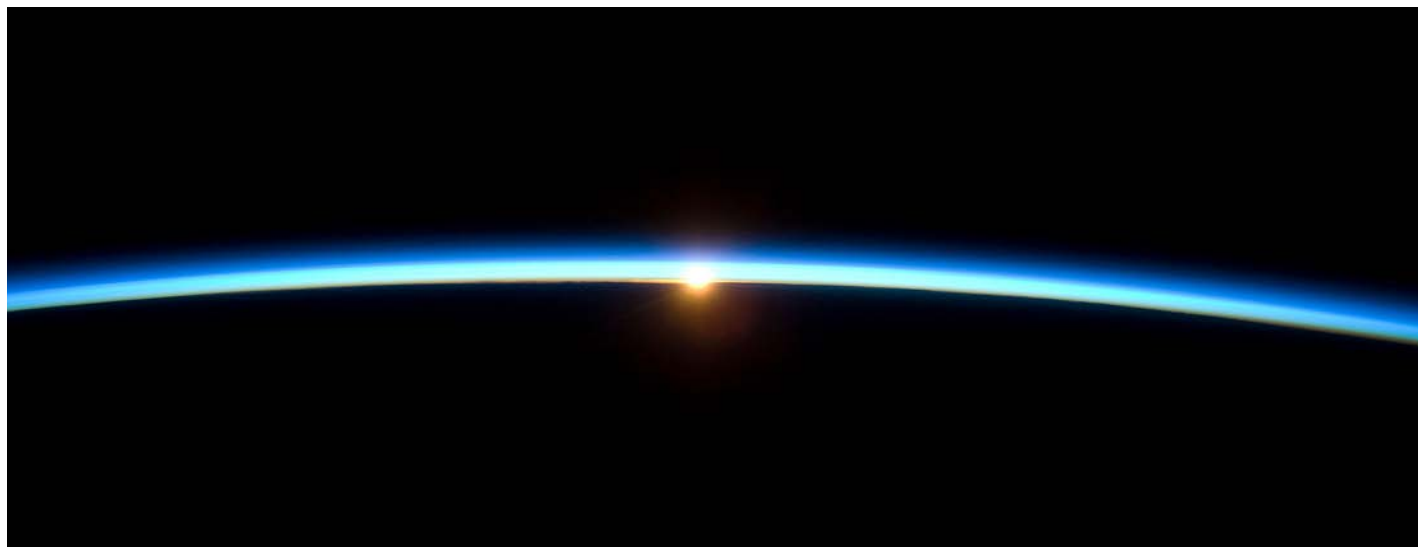
When he began measuring that our planet's atmosphere is exceptionally enriched in heavy nitrogen, it was difficult for Laurence Yeung, assistant professor of earth, environmental and planetary sciences, to believe his finding. He and his collaborators assumed that their results must be wrong. After a rigorous period of experiments reacting air with electricity in the laboratory, however, they were able to simulate the high-energy conditions in the upper atmosphere that can create heavy nitrogen enrichment.

found in atmospheric nitrogen is 10 times greater than what thermodynamic equilibrium theory would predict, according to Yeung.

The atmospheric nitrogen isotopic composition can be potentially explained by a balance of nitrogen cycling at Earth's surface and the upper atmosphere. In the upper atmosphere, cosmic rays, light and free electrons break N₂ molecules apart. Nitrogen atoms are quickly recombined, producing an enrichment in heavy nitrogen by either making ¹⁵N¹⁵N prefer-

"If you can figure out how a planet 'should look' in terms of its ¹⁵N¹⁵N if no life were there, and you could somehow measure the atmosphere, you can compare the two," said Yeung. "If they're the same, maybe there's no life. If there's a lot less ¹⁵N¹⁵N than you're expecting, that's a pretty good chance that somewhere on that planet, there is an active nitrogen cycle; something that is fast enough to compete with the atmospheric cycles."

Yeung's research suggests that atmospheric nitrogen can change its isotopic



The amount of nitrogen molecules in Earth's atmosphere that contain only heavy isotopes results from a balance between nitrogen chemistry that occurs in the atmosphere, at the surface due to life and within the planet itself. Image credit: NASA

"We were finally able to generate the signal in the lab and take it away. That final step convinced me that this is real," said Yeung.

Nitrogen makes up three-quarters of Earth's atmosphere and is predominantly found in the form of N₂ gas. Each atom of nitrogen that composes N₂ can be either a lighter isotope, ¹⁴N, or a heavier isotope, ¹⁵N. Heavy nitrogen is made up of two ¹⁵N atoms bonded together, also known as a "clumped" isotope signature when rare heavy isotopes stay together. Although a slight preference for heavy isotopes to bind has been observed for other atmospheric gases such as O₂ and CO₂, the unusually large amounts of ¹⁵N¹⁵N

entially or not breaking heavy nitrogen apart. Meanwhile, biological cycles at the surface release N₂ into the lower atmosphere, generating an isotopic signal only slightly enriched in heavy nitrogen.

"On one hand, you have bugs making ¹⁵N¹⁵N somewhat randomly from their constituents and in the upper atmosphere, ¹⁵N¹⁵N prefers to stay together. So it's always this tug-of-war between these two sides," said Yeung.

Other planets in our solar system, including Mars and Venus, also have nitrogen in their atmospheres. Yeung argues that the contrasting signatures of biological and atmospheric nitrogen cycles might be a biosignature on these and other planets.

composition every 10 million years or so — much more quickly than previously thought. Based on these results, it has been most remarkable to Yeung how "fragile" molecules are.

"The chemistry around us is so much more vigorous than we ever give it credit for. Even in the absence of changing compositions of our atmosphere, molecules are wild all day, every day. That is something that has changed how I look at the world." ■

— JULIANA SPECTOR

Toward Long-Lasting Influenza Immunity

From influenza to HIV to hepatitis, viruses cause many of the world's deadliest acute diseases. Without the option of antibiotics, the most dependable way to prevent viral infections is vaccination. Vaccination introduces noninfectious antigens to the body, prompting the creation of antibodies specifically designed so that if the actual, full-strength virus is encountered, the immune system already has the tools to fight it. The problem is that viruses mutate. Antibodies are not able to identify and bind to their altered surface proteins. One striking example is the flu. Every year, a new flu vaccine must be created based on scientists' predictions. With its varying arrangements of surface proteins like hemagglutinin and neuraminidase (the source of the H and N in names like H1N1 and H3N2), antibody response to influenza has been ineffective. Rice undergraduate Hector Chaires '19 is working in the lab of Harvard Medical School's Stephen C. Harrison to address this problem.

Chaires started gaining research experience his freshman year when he began working with George Phillips, Rice's Ralph and Dorothy Looney Professor of Biochemistry and Cell Biology. His ongoing work with Phillips involves analyzing the structure of beta-lactamase — an important enzyme in antibiotic-resistant bacteria — and its inhibitors. Specializing in structural biology, Chaires focuses on the shapes and structures that form biological molecules like beta-lactamase, hemagglutinin and other important biological macromolecules. Chaires joined the Harrison group during summer 2017 as a Howard Hughes Medical Institute Exceptional Research Opportunities Program fellow with the hope of broadening his experience in structural biology by solving the mysteries of antibody production in response to antigens.

Tracking specific structural features of an antibody to their ancestral lineage is an important first step toward characterizing how antibodies are created in response to antigens. In one of the team's studies, rhesus macaque monkeys were exposed to influenza and their serum analyzed to find



Hector Chaires '19

something unique. "Ultimately, we found a disulfide bond in the region that binds to hemagglutinin," said Chaires. "It's what we predict stabilizes the interaction between the antibody and hemagglutinin and what gives it such a high affinity for this surface protein of the virus." Building on studies like this and many others, they hope to understand how antibodies respond to multiple exposures to an antigen over time, while also making use of rational antigen design.

Multiple exposures to a virus over time is one way that people can acquire high-affinity antibodies through antibody affinity maturation. Are the immune systems of people who naturally have antibodies that grant them broad immunity to multiple strains of a virus just genetically better? Or could they have been exposed to different strains of the antigen with just the right sequencing and timing to create a robust antibody? "If we understand how our bodies are responding to immunogens such as vaccines, we'll be able to conceptualize ways to rationally engineer the antigen to produce broadly neutralizing antibodies," Chaires said. In other words, if we could direct our bodies to make these cross-reactive, neutralizing antibodies,

everyone might eventually be able to have such wondrous immunity.

Rationally designing antigens to generate the desired immune response might be possible with an understanding of antibody affinity maturation. Viral surface proteins are 'decorated' with glycans, or polymers of sugars, that can physically block antibodies from binding. Varying viral strains might have different glycans in distinct locations. "An investigator in our group put 40 years of influenza strains together. A normal strain would only have a few glycans, but this one has its entire surface decorated with glycans," Chaires said. "Our collaborators immunized mice with these strains, and then we are going to look at what antibody repertoire they produce." These tests could possibly lead to the creation of antibodies that can withstand many viral mutations, thus granting long-lasting resistance.

Understanding how antibodies and antigens interact is one way to work toward disease immunity. During his senior year, Chaires will continue working with Harrison, this time attempting to evolve cross-reactive antibodies that neutralize the most recent strains of influenza A — further understanding how antibody affinity matures in the body and perhaps leading to a successful therapy. ■

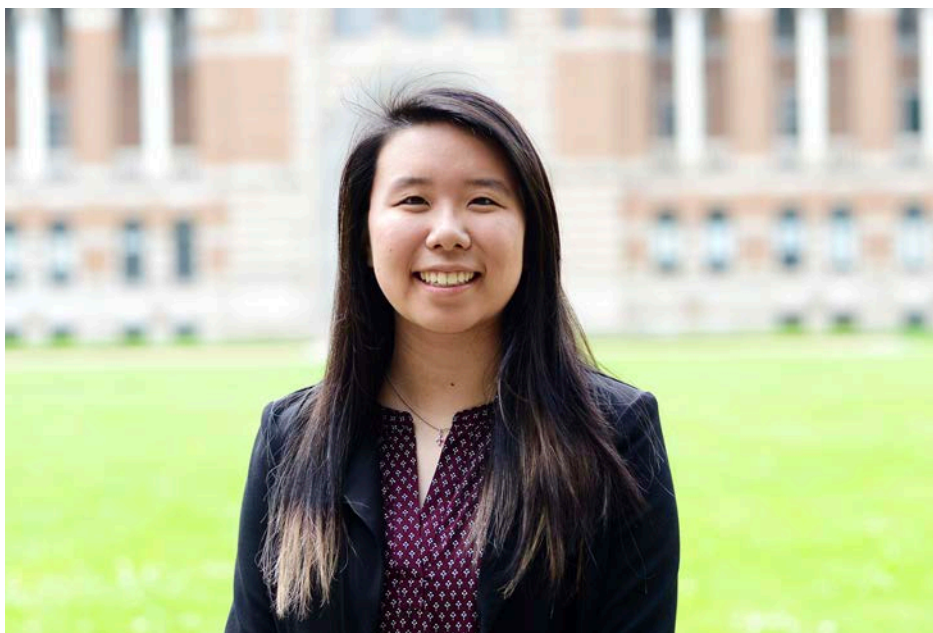
— OLIVER ZHOU

A Superior Dietary Assessment Method for Cancer Patients

If you've ever used a fitness or diet app, you are familiar with their pitfalls: tediously entering every calorie into a clumsy device is time-consuming and requires a level of patience known only to kindergarten teachers. For Susan Schembre, former director of the Bionutrition Research Core at The University of Texas MD Anderson Cancer Center and now at University of Arizona College of Medicine-Tucson, this presents more than a mere annoyance. It is an obstacle to efficiently collecting data in her research on obesity-related cancer and to providing important dietary feedback to study participants. Rice undergraduate Annie Shen '19 has been working with Schembre to overcome these problems by developing a new tool to collect personal dietary information that can be evaluated quickly and meaningfully.

There are a number of problems with the current dietary assessment methods, Shen explained. They collect a ton of data, including every macronutrient consumed. This is not only tedious for the patient to complete, but also a lot of data for researchers to process. Even the National Cancer Institute's self-administered 24-hour recall the ASA24, which Shen described as "basically the gold standard of dietary assessment," is guilty of these shortcomings. "Even I hated filling out the ASA24," Shen said. "Our ultimate goal was to develop a tool that didn't need to collect so much data."

To design a superior dietary assessment tool, the team referenced the FDA manual, grouping commonly consumed foods with similar American portion sizes and caloric densities. This was a key step in the design as grouping by these criteria allowed for important distinctions between categories, like the distinction between ice cream and frozen yogurt, which are similar in portion size yet drastically different in caloric density. Their tool, currently named the Abbreviated Food Screener (AFS), uses an average caloric value for each category, which allows for the researcher or physician to track the frequency of consumption of specific food groups and the proportions of empty calories being



Annie Shen '19

consumed in a way that is convenient for both the patient and the researcher.

In a preliminary test, which focused on the consumption of high-fat and high-sugar foods, the AFS was found to be consistent with the more burdensome ASA24. The secret to its success rests in its user-friendly design. Before the participant goes to sleep, the AFS sends a text that prompts them to take a short (10-30 second) survey about their consumption of specific groups that day. In contrast, the ASA24 requires the user to document everything they eat for the prior 24 hours, which often takes an hour to complete and is less accurate because users have a difficult time remembering what they ate over such a long period of time. "People were more likely to document their snack foods on the AFS," said Shen.

Schembre and Shen are excited about the potential applications of their work. The convenience of the AFS makes it a prime candidate for development into an app, while its versatility will give Schembre and many other researchers a better method for gathering data and developing healthy eating interventions as part of their research on reducing obesity-related cancer risk.

Shen will continue to work on this project during her senior year, expanding the AFS to include additional food categories such as sugar-sweetened beverages, fruits and vegetables and developing feedback that can help motivate positive dietary behavior changes.

This experience was Shen's first exposure to the field of public health and was an opportunity for her to gain exposure to the clinical side of research, specifically instrument development, program planning and biostatistics. Being able to visualize and apply many of the concepts taught in her public health classes further fostered her interest in the public health field and led her to join the Rice-UT Public Health Scholars Program, accelerating her path to a Master of Public Health degree. "This program allows me to pursue not just my interest in the health field, but also to further my appreciation for all aspects of science, research and innovation," said Shen. ■

— SOPHIA STREETER

LIGHT SHOW: USING LIGHT-ACTIVATED METAL COMPLEXES TO COMBAT ALZHEIMER'S

By Oliver Zhou

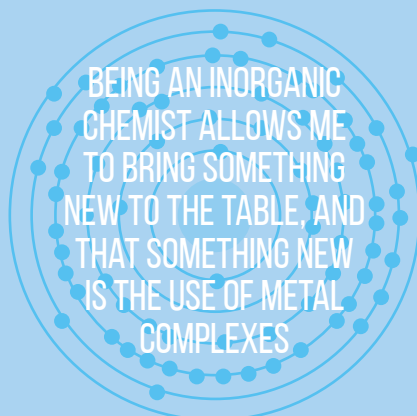
Imagine slowly losing your memory, motivation, and communication skills—the things that make you who you are. These are just a few of the effects of Alzheimer's disease, and occur over the course of only a few years. When someone has Alzheimer's, amyloid beta proteins, which are products of a normal protein recycling process in their brain, improperly join together to form long strands called fibrils.¹ Even though the individual protein monomers are harmless, these fibrils can then stick together to become toxic plaques that inhibit neuron function and cause cell death, thus leading to the debilitating effects of Alzheimer's on the brain.¹ Although the molecular mechanisms of Alzheimer's are understood, the causes of these microscopic failures are unclear, and no treatment to stop or reverse its progression currently exists. In addition, there are no definitive practices or measures to significantly decrease risk of developing Alzheimer's.^{2,3} As Alzheimer's patients deteriorate over the course of several years, supportive and palliative care are the only means of assistance, leading to higher and higher costs of patient care. Altogether, Alzheimer's disease is one of the most costly and serious diseases⁴ that plagues the world today.

Enter Dr. Angel Martí. An inorganic chemist from Puerto Rico, Dr. Martí has spent his whole life dreaming of being a scientist. Dr. Martí began his career studying the photophysical properties of metal complexes at the University of Puerto Rico. In 2004, he joined a research group at Columbia University, where he contributed to the development of fluorescent probes formed from metal complexes for detection of DNA and RNA. In 2008, he joined Rice University's Department of Chemistry, where he now combines his past knowledge of metal complexes and biological proteins for use in the area of neurodegenerative diseases. This combination of the building blocks of inorganic chemistry with the fundamentally biological issues of proteins and diseases is what makes his research exciting. As Dr. Martí put it, since "people don't tend to study amyloid beta through the eyes of an inorganic chemist...being an inorganic chemist allows me to bring something new to the table, and that something new is the use of metal complexes."

Metal complexes have special photophysical properties that allow Dr. Martí to study the amyloid beta buildup of Alzheimer's in new ways. A metal complex is essentially a metal

atom, such as iron, or ruthenium, or rhenium, surrounded by and bound to organic molecules—a "hybrid of organic and inorganic materials," as Dr. Martí describes. An earlier project of his involved the use of ruthenium metal complexes, which would increase in fluorescence over 100 fold when bound to amyloid beta aggregates. This complex is useful in the detection and assessment of the extent of amyloid beta protein aggregation in the brain, and with its higher visibility and long lifetime, it holds numerous advantages over the more commonly used indicator, thioflavin T.

Ruthenium metal complexes have many great uses, but Dr. Martí discovered something even greater. "[When] we changed that metal [in the metal complex] to rhenium",



Dr. Martí describes, "very strange and wonderful things started happening." Once irradiated with blue light, rather than merely fluorescing, the rhenium metal complex could actually oxidize the parts of the amyloid beta aggregate that it bound to. This new discovery is called footprinting, and it can reveal exactly where hydrophobic compounds like the rhenium metal complex bind, making it easier to engineer drugs to bind to those sites and combat Alzheimer's. However, this is not all the rhenium metal complex can do. When binding to the large amyloid beta aggregates, the oxidizing effects of the metal complex were insignificant for purposes other than simply signaling where they could bind. However, when bound to the harmless, monomeric form of amyloid beta, the oxidation can significantly change their individual shapes. This is enough to prevent them from forming fibrils and aggregating altogether. If there were some way to preemptively insert and activate this rhenium metal complex in the brain before symptoms of Alzheimer's began to show, the amyloid

beta monomers would never begin to aggregate at all. This technique could lead to a potential "vaccine" to prevent Alzheimer's.

This Alzheimer's vaccine is the end goal of Dr. Martí's research, but there are still many challenges that the lab faces. Currently, the only way to activate the metal complexes after they bind to amyloid beta is by irradiating them with blue light. This would be impossible in a human, since our tissues are not transparent to blue light, only red. Think about what happens when you shine a light through your hand—the light appears red. If the rhenium metal complex could be altered in a way so that it could be activated by red light, it would allow for potential use inside humans. Another challenge is ensuring that the rhenium metal complexes are not toxic to humans. This also brings up the question of how the rhenium metal complexes would make it to the brain. Most drugs are delivered via the bloodstream, and the brain is separated from the blood by a highly selective blood-brain barrier. Currently, the metal complex would not be able to get through this membrane to the brain.

Despite these challenges, Dr. Martí's research presents a beacon of hope in the fight against Alzheimer's. Knowledge of the binding sites of hydrophobic substances on the amyloid beta aggregates is critical in design of future drugs that may be able to neutralize or disintegrate them. And if a rhenium metal complex that can absorb red light and make it into the brain could be synthesized, the progression of Alzheimer's could be stopped or even prevented altogether.

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IMAGE: NASA

ALUMNI SPOTLIGHT

Whitson Returns From ISS With New US Space Record

Astronaut and Rice alumna Peggy Whitson '85 set a new mark of 665 days in space — the most by a U.S. astronaut — upon returning Sept. 3, 2017, from her third long-endurance mission aboard the International Space Station (ISS).

Whitson, who earned her Ph.D. in biochemistry at Rice and is an adjunct associate professor of biosciences at the university, performed four spacewalks during Expedition 52, bringing her career total to 10, also a record for the most spacewalks ever performed by a woman. At 57, she is the oldest woman to ever fly in space, and her cumulative time in space is by far the most ever by a woman.

Whitson's no stranger to being first. In her initial six-month stint aboard the space station with Expedition 5 in 2002, she became the station's first science officer and the first NASA astronaut ever to hold that title on any mission. On Expedition 16 in 2007, she became the first woman to command the station, and in 2009 she became the first woman and the first nonpilot to serve as chief of the Astronaut Office at NASA's Johnson Space Center. ■

— JADE BOYD