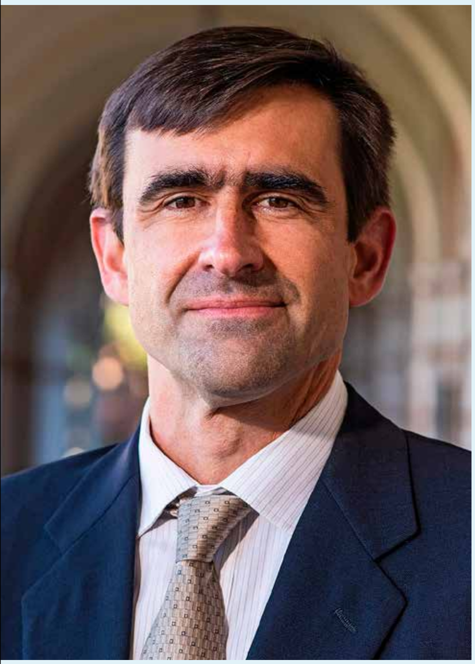
The Magazine of the Wiess School of Natural Sciences at Rice University ◣ Winter 2022

ENQUIRY

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

A LETTER FROM THE DEAN



THOMAS C. KILLIAN
Dean, Wiess School of Natural Sciences

"THROUGH PATHBREAKING RESEARCH, WE ARE CHANGING OUR VIEW OF THE UNIVERSE AND LAYING THE FOUNDATIONS FOR TOMORROW'S TECHNOLOGICAL REVOLUTIONS IN THE REALMS OF SUSTAINABILITY AND CLIMATE, ENERGY AND HUMAN HEALTH."

Dear Friends of the Wiess School,

It is my pleasure to present to you this issue of ENQUIRY, the magazine of the Wiess School of Natural Sciences at Rice University. The stories presented here will take you on journeys of scientific discovery with talented students and faculty who share an intense curiosity about the natural world and courage to explore the unknown. You will read about the chemical ingredients needed for a planet to support life, material properties at the nanoscale, new therapeutics that attack mitochondria in cancer cells and the quest to unravel the mystery of dark matter in the universe.

This is just a snapshot of the breadth of work in the school hunting the smallest subatomic particles, investigating the unfathomable distances of our cosmos and undertaking inquiries at all scales in between. Through pathbreaking research, we are changing our view of the universe and laying the foundations for tomorrow's technological revolutions in the realms of sustainability and climate, energy and human health.

I am also proud to announce new faculty who have joined Rice and to highlight national and international accolades earned by members of the school during the last year, including senior faculty celebrating a lifetime of achievement and young students representing the future of their disciplines. Don't miss the biographies of the amazing student authors who possess a love of science and a gift for writing. They make it possible to share frontier scientific research with a broader audience.

I hope you enjoy this magazine and that it inspires you to learn more about the people and the programs of the Wiess School. We love nothing more than sharing the excitement of scientific discovery with friends and supporters, so please come back to Rice for a visit.

Best regards,

Thomas C. Killian

ENQUIRY

EDITOR
Lauren Kapcha

PHOTOGRAPHY, DESIGN AND EDITORIAL BY THE OFFICE OF PUBLIC AFFAIRS

For information about supporting the natural sciences at Rice, please contact Jackie Macha at 713-348-4268 or jackie.macha@rice.edu.

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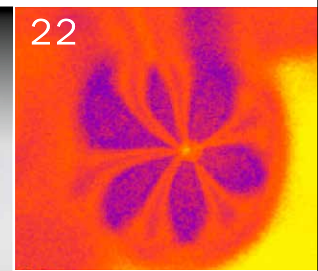


DEPARTMENTS

On the cover: A high-oxygen environment induces a condition resembling retinopathy of prematurity (ROP) in the retinas of mouse pups. ROP affects premature infants and is a leading cause of childhood blindness. Images of the flat-mounted retina, like the one shown here with endothelial cells stained in red, can be quantified to assess the severity of hallmark ROP features in different mutant or treated mice. Image credit: Megan Shen

CONTRIBUTORS

HENRY BARING '20 ("Coral-Eating Predators May Boost Reef Health by Moving Helper Algae") was a science media intern for the School of Natural Sciences, focusing on photography and videography. He completed his bachelor's degree in materials science and nanoengineering and was a video journalist for the Rice Thresher, the official undergraduate newspaper at Rice, and historian and eco-representative for Lovett College. During the pandemic, he produced videos for his YouTube channel and cooked a lot of food. Outside of academics, Baring enjoys playing soccer, eating all kinds of food, watching "Avatar: The Last Airbender" and exploring Houston. He now is a junior videographer and animator at Lumen Technologies.

GRACE BEILSTEIN ("Mitochondrial Mechanisms May Power Down Cancer") is a senior at The Kinkaid School in Houston. Beilstein is an accomplished writer, serving as the editor for her school's literary magazine, Falcon Wings, and a regular contributor to the online literary journal Marías at Sampaguitas. She has received numerous Scholastic Awards, Gold Key and Silver Key awards for her poetry, short stories and flash fiction. Beilstein also enjoys running, playing basketball and lacrosse, vegan baking and listening to music. She hopes to become a cardiovascular surgeon and is particularly interested in deepening her knowledge of the medical field and how this can be applied to her aspirations as an author.

SIQI DU ("Alumni Adventures in Galápagos") is a fourth-year graduate student, pursuing a Ph.D. in biosciences under the supervision of Aryeh Warmflash. During her free time, Du enjoys writing and hiking, which help with both concentration and relaxation. She has a broad interest in biology and especially enjoys when new challenging questions arise or conceptual accomplishments are met. She hopes to convey this excitement through her writing. Du is still exploring future career paths but is interested in science communication and teaching.

RISHAB DUTTA ("Magnets Delay the Escape of Laser-Cooled Plasma") is a fifth-year graduate student, pursuing a Ph.D. in chemistry under the supervision of Gustavo Scuseria. As a theoretical chemist, he works on developing accurate computational chemistry methods with potential applications in better chemical design and understanding. Dutta is interested in teaching, discussing and communicating about science outside of his research area. He plans to continue contributing to scientific research, education and communication in the future. In his spare time, Dutta plays the guitar and maintains a blog on STEM and music.

JACOB GOELL ("Tracking Nerve Cells in the Gut Through Development and Disease") is a fourth-year graduate student, pursuing a Ph.D. in bioengineering under the supervision of Isaac Hilton. He is interested in the business of science and translating basic research to practical applications in cancer immunotherapy. Goell became interested in science communication through his struggles trying to communicate his research to people outside of his lab. Outside of the lab, Goell enjoys reading, running and being outdoors.

MAGGY NINO '23 ("Envisioning an Effective Therapy Future for Eye Diseases") is a senior at Will Rice College completing a dual degree with a B.S. in biosciences with a concentration in integrative biology and a B.A. in English. She enjoys running, kickboxing, playing squash, dancing and baking and is interested in animals, nature, medicine, writing and coffee. She plans to attend medical school and has an interest in pediatric surgery.

HALLIE TRIAL '22 ("Better Building Blocks for Nanomaterials," "Enabling Advances in Aluminum Nanoparticle Applications," "The Quest for Dark Matter Goes Deep Underground," "Wave Function-Based Models for Strongly Correlated Electrons" and "Searching for Life Origins on Rocky Planets") was a senior chemistry major at Will Rice College and is a science writing intern for the School of Natural Sciences. In addition to her dual passion for science and writing, she explores nature by studying and identifying interesting plants, mushrooms and insects and reading novels, especially those of Kurt Vonnegut and Isabel Allende. Trial began working toward her Ph.D. in chemistry this fall and hopes to work as a professor and researcher, applying the power of chemistry to projects that advance the cause of sustainability.

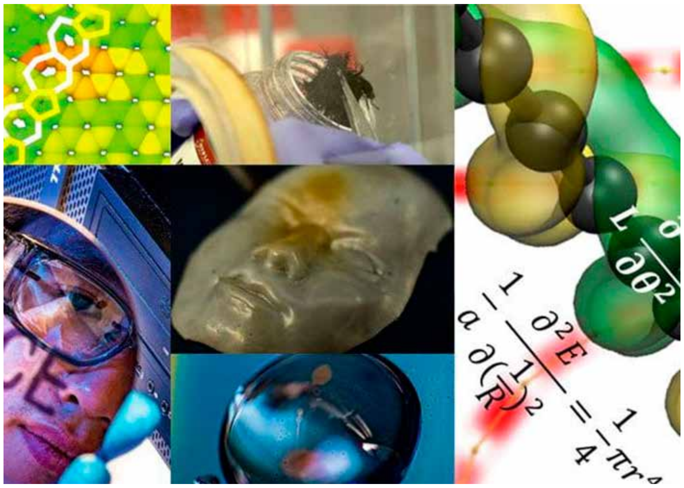
AKSHAYA VENKATESH '22 ("Knowledge of a Knot") completed a major in cognitive sciences and minors in biochemistry and cell biology and business. Venkatesh enjoys reading and art and plans to become a physician-scientist.

DOUGLAS WALKER '21 ("Getting a Closer Look at the Ocean Floor") completed his Ph.D. in chemistry at Rice under the supervision of Jeffrey Hartgerink. He now holds a position as a postdoctoral researcher at Oregon State University. In his spare time, Walker enjoys biking, playing soccer, rock climbing, writing, fiction, Zelda and NMR. ■

Accolades

LARGEST GIFT IN RICE HISTORY ESTABLISHES THE WELCH INSTITUTE

The Robert A. Welch Foundation has announced the largest single gift in the history of Rice University to establish The Welch Institute, a "sweeping strategic partnership" on campus that will focus on world-leading advanced materials research. The $100 million underwriting the new institution will empower Rice researchers across campus, as well as colleagues from around the world, to accelerate discovery, design and manufacture of new materials for the benefit of all. The gift is also the largest in the 65-year history of the foundation, which expects it will lead to next-generation materials for energy systems, sustainable water, space systems, biomedical materials, telecommunications, manufacturing, transportation, security and more.



RICE CHEMIST NAMED TO FORBES 30 UNDER 30

Julian West, assistant professor of chemistry, was named to the 10th annual Forbes 30 Under 30, a gathering of people under 30 years old whom the publication considers the "brightest young entrepreneurs, innovators and game-changers." West, who joined Rice in 2019 with the backing of a $2 million grant from the Cancer Prevention and Research Institute of Texas, was nominated in science. His chemical synthesis lab develops bioactive molecules through creative advances in catalysis, with a particular focus on precursor molecules that will ease the design and manufacture of anti-cancer and other drugs.

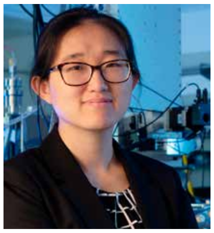
POPE PICKS RICE PROFESSOR FOR SCIENCE ACADEMY

Rice University physicist José Onuchic has been appointed to the Pontifical Academy of Sciences by Pope Francis. Onuchic, the first Rice faculty member to be named to the academy, is the Harry C. and Olga K. Wiess Chair of Physics and a professor of physics and astronomy, of chemistry and of biosciences, and co-director of the National Science Foundation-backed Center for Theoretical Biological Physics. Onuchic is expected to contribute to the academy's biennial plenary sessions and to participate in scientific meetings of relevance to his research. The academy's 80 members are chosen on the basis of their original scientific studies and their moral personality, "without any ethnic or religious discrimination." Members are nominated for life by the pope.

MARK TORRES AWARDED SLOAN FELLOWSHIP

Mark Torres, assistant professor of Earth, environmental and planetary sciences, was selected as a 2019 Alfred P. Sloan Research Fellow in ocean sciences. Torres' research concerns how concentrations of carbon dioxide and oxygen in the atmosphere are regulated over geologic time and what makes planets habitable. His research has focused on how rivers influence ocean chemistry and atmospheric carbon dioxide, and future work will also focus on the way in which chemical elements get removed from ocean water.

MING YI AWARDED SLOAN FELLOWSHIP



Ming Yi, assistant professor of physics and astronomy, was selected as a 2019 Alfred P. Sloan Research Fellow in physics. Yi's research lab, an experimental condensed matter physics group, aims to advance the fundamental understanding of exotic properties in materials using spectroscopy tools such as angle-resolved photoemission spectroscopy and X-ray scattering. Yi will also focus on ways to control and tune exotic material properties.

FACULTY HONORS

ALEXANDER VON HUMBOLDT FOUNDATION

David Damanik, the Robert L. Moody, Sr. Chair of Mathematics, received a Humboldt Research Award from Germany's Alexander von Humboldt Foundation. The award provides funds for Damanik to undertake collaborations with colleagues at Bielefeld University in Germany.

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

Richard Gordon, the W.M. Keck Professor of Earth, Environmental and Planetary Sciences, has been named a fellow of the American Association for the Advancement of Science (AAAS). He was selected "for distinguished contributions to the fields of tectonic geophysics and geodesy through forefront research on diffuse oceanic plate boundaries and true polar wander."

AMERICAN INSTITUTE FOR MEDICAL AND BIOLOGICAL ENGINEERING

Jeffrey Hartgerink, professor of chemistry and of bioengineering, was inducted into the American Institute for Medical and Biological Engineering's College of Fellows Class of 2020 for "outstanding contributions to the area of peptide-based, nanostructured materials, which have tremendous potential for a variety of biomedical applications."

AMERICAN INSTITUTE OF PHYSICS AND AMERICAN CRYSTALLOGRAPHIC ASSOCIATION

George Phillips, the Ralph and Dorothy Looney Professor of BioSciences, has been named editor-in-chief of the journal Structural Dynamics, a joint publication of the American Institute of Physics and the American Crystallographic Association. Phillips has served as associate editor of the journal since its launch.

AMERICAN MATHEMATICAL SOCIETY

Anthony Várilly-Alvarado, professor of mathematics, has been named a fellow of the American Mathematical Society (AMS). He was selected for "contributions to algebraic and arithmetic geometry, in particular to the study of rational points on varieties."

Várilly-Alvarado also gave an AMS invited address titled "The geometric disposition of Diophantine equations" at the 2020 Joint Mathematics Meetings, hosted by the AMS and the Mathematical Association of America.

AMERICAN PHYSICAL SOCIETY

Karl Ecklund, professor of physics and astronomy, has been named a fellow of the American Physical Society (APS). The society's Division of Particles and Fields cited him "for leadership in high-precision particle-tracking detectors using pixel technology, and in the measurement of top- and bottom-quark properties in both e+e- and hadron collider experiments."

DEPARTMENT OF ENERGY

The Department of Energy's Office of Basic Energy Sciences selected **Ming Yi**, assistant professor of physics and astronomy, as one of 76 Early Career awardees in 2020.

GEOCHEMICAL SOCIETY AND THE EUROPEAN ASSOCIATION OF GEOCHEMISTRY

Cin-Ty Lee, the Harry Carothers Wiess Professor of Geology and professor of Earth, environmental and planetary sciences, was named a 2019 Geochemistry Fellow by the Geochemical Society and the European Association of Geochemistry. Lee was chosen for "diverse, creative and prolific work, his provocative ideas that have inspired debate and action, and his fundamental contributions to the understanding of our planet's continents."

Carrie Masiello, the W. Maurice Ewing Professor of Biogeochemistry and professor of Earth, environmental and planetary sciences, delivered a plenary lecture at Goldschmidt 2019, an international geochemistry conference jointly organized by the Geochemical Society and the European Association of Geochemistry. The Paul Gast Lecture award honors a mid-career scientist's outstanding contributions to geochemistry.

INTERNATIONAL UNION OF PURE AND APPLIED CHEMISTRY

Julian West, assistant professor of chemistry, was named winner of a 2019 inaugural Early Career IUPAC-Zhejiang NHU International Award for Achievements in Green Chemistry.

MOORE FOUNDATION

Ming Yi, assistant professor of physics and astronomy, is one of 20 U.S. scientists awarded a 2020 Emergent Phenomena in Quantum Systems (EPiQS) experimental investigator grant from the Gordon and Betty Moore Foundation.

NATIONAL SCIENCE FOUNDATION

The National Science Foundation named **Melodie French**, assistant professor of Earth, environmental and planetary sciences; **Kaden Hazzard**, associate professor of physics and astronomy; **Rosa Uribe**, assistant professor of biosciences; and **Laurence Yeung**, the M. Ewing Career Development Associate Professor of Earth, Environmental and Planetary Sciences, as recipients of Early Career Awards.

ROYAL SOCIETY OF CHEMISTRY

Naomi Halas, the Stanley C. Moore Professor of Electrical and Computer Engineering and professor of chemistry, of bioengineering, of physics and astronomy, and of materials science and nanoengineering, was awarded the 2019 Spiers Memorial Award by the Royal Society of Chemistry. The award recognizes Halas' "pioneering research at the intersection of optics and nanoscience and the demonstration of optical property manipulation by nanoparticle geometry. Halas was also named a fellow of the Royal Society of Chemistry.

Angel Martí, professor of chemistry, of bioengineering, and of materials science and nanoengineering, has been named a fellow of the Royal Society of Chemistry. He was honored for his impact in the chemical sciences, particularly in his investigations into how nanomaterials and biomolecules interact.

James Tour, the T.T. and W.F. Chao Professor of Chemistry and professor of materials science and nanoengineering, has won a Royal Society of Chemistry Centenary Prize. Tour was named for innovations in materials chemistry with applications in medicine and nanotechnology.

SIMONS FOUNDATION

David Damanik, the Robert L. Moody, Sr. Chair of Mathematics, was awarded a 2020 Simons Fellowship.

STUDENT ACCOMPLISHMENTS

APPLIED MATHEMATICS, MODELING AND COMPUTATIONAL SCIENCE

Siran Li, a former postdoctoral researcher and G.C. Evans Instructor of Mathematics, was awarded the 2019 AMMCS Kolmogorov-Wiener Prize for Young Researchers, which recognizes and supports innovative interdisciplinary research carried out by researchers at an early stage of their career in the areas of mathematical, natural and applied sciences where methods and tools of mathematical modeling are decisive.

BURROUGHS WELLCOME FUND

Víctor García-López '16 was awarded a 2019 Burroughs Wellcome Fund (BWF) Career Award. The award provides five years of funding as a financial bridge between advanced postdoctoral training and the first three years of faculty service. García-López was a postdoctoral fellow in Rice's Department of Chemistry from 2018 to 2020, when he joined Louisiana State University as an assistant professor.

CHURCHILL SCHOLARSHIP

Alex Hwang '19 was one of 15 Americans to win a 2019 Churchill Scholarship, which provides one year of graduate study at the University of Cambridge, based at Churchill College.

DEPARTMENT OF ENERGY

Sophia Andaloro, graduate student in physics, is the first Rice student to win a Department of Energy National Nuclear Security Administration Stewardship Science Graduate Fellowship (NNSA SSGF). The NNSA is a federal agency tasked with national security through nuclear science, and the SSGF program seeks to bring financial and professional development opportunities to highly trained scientists and engineers in areas of study related to nuclear science.

FULBRIGHT SCHOLARSHIP

Four natural sciences graduates received Fulbright grants to study, teach and conduct research in foreign countries. In 2019, **Elizabeth Asonye '19** served as an English teaching assistant in Mexico, **Amy Kuritzky '19** conducted sociocultural anthropology research in Cuenca, Ecuador, and **Ricky Lozoya '19** studied defects of a specific region in human DNA that has been implicated in several neuropsychiatric diseases at Heidelberg University in Germany. **Adolfo Carvalho '19** received a 2020 Fulbright grant to study protoplanetary disks at the Universidad de Chile in Santiago.

GOLDWATER SCHOLARSHIP

Takuma Makihara '20 was awarded a Goldwater Scholarship for the 2019–2020 academic year.

HERTZ FELLOWSHIP

Yakub Grzesik '20 was selected for the 2020 cohort of Hertz fellows, which funds five years of graduate research and offers lifelong professional support through the Fannie and John Hertz Foundation.

INTERNATIONAL PHYSICISTS' TOURNAMENT

Rice University undergraduates represented the United States in the International Physicists' Tournament, the "World Cup of physics." The juried "physics fights" mimic the peer-review process for research, with each team alternating the roles of reporter, opponent and reviewer. Rice's team won the national tournament and finished third in the global tournament, held as a two-day online tournament due to the coronavirus pandemic.

Members of the Rice national team included **Matheus Barbosa '22** (captain), **Poom Kritpracha '23**, **Xinyun Liu '21**, **Ayush Sachdeva '23** and **Kevin Zheng '22**. Members of the Rice international team included **Bob Bao '22**, **Matheus Barbosa** (captain), **Poom Kritpracha**, **Ayush Sachdeva**, **Carlos Silva** and **Kevin Zheng**.

THE NATIONAL GEM CONSORTIUM

Olivia Del Guercio, graduate student in mathematics, has been named a 2020 Full Fellow of the National GEM (Graduate Education for Minorities) Consortium. The awards include full tuition and fees, stipends and internships.

NATIONAL INSTITUTES OF HEALTH

Joshua Moore, graduate student in biochemistry and cell biology, has been awarded a National Institutes of Health National Research Service Award (NRSA) Fellowship for his work studying early development of the enteric nervous system in zebrafish.

NATIONAL INVENTORS HALL OF FAME

Kinesiology majors **Lauren Payne '20** and **Sanika Rane '20** were members of the "At Your Cervix" team that took home first prize and $10,000 in the 2020 Collegiate Inventors Competition, an initiative of the National Inventors Hall of Fame sponsored by the U.S. Patent and Trademark Office and Arrow Electronics. At Your Cervix won the undergraduate division for its device, the UFO (Universally Friendly Obturator), which helps guide needles carrying radiation seeds directly to late-stage cervical tumors.

NATIONAL SCIENCE FOUNDATION

Brandee Carlson '20, **Tian Dong '20** and **Andrew Moodie '20** have won postdoctoral fellowships from the National Science Foundation's Division of Earth Sciences.

Arzeena Ali, graduate student in chemistry; **Catherine Arndt**, graduate student in applied physics; **Scott Carlsten '16**; **Vanessa Espinoza**, graduate student in chemistry; **Alexander Hwang '19**; **Andrew Ligeralde '18**; **Haihao Liu '18**; **Jaime Moya**, graduate student in applied physics; **Elena Musteata**, graduate student in systems, synthetic and physical biology; **Grant Stec '17**; **Tiffany Tang '18**; and **Kevin Wyss**, graduate student in chemistry, were selected for the 2019 National Science Foundation Graduate Research Fellowship Program.

Sophia Andaloro, graduate student in physics; **Jacob Beckham**, graduate student in chemistry; **Anecia Gentles '18**; **Kevin Gonzalez '20**; **Jin Young Kim '20**; **Audrey Odwuor '17**; **Takuma Makihara '20**; **Alexander Nolte**, graduate student in mathematics; and **Elaine Shen '18** were selected for the 2020 National Science Foundation Graduate Research Fellowship Program.

UNIONE MATEMATICA ITALIANA

Andrea Tamburelli, a former postdoctoral researcher and Lovett Instructor in Mathematics, was the winner of the Premio Franco Tricerri 2019 of the Unione Matematica Italiana. This biennial prize is awarded to the best thesis in the previous three years in differential geometry by an Italian mathematician.

WATSON FELLOWSHIP

Ilana Nyveen '19 was awarded a 2019 Thomas J. Watson Fellowship, providing support for a year of international travel and research visiting great apes in Asia and Africa as well as meeting researchers in Germany.

New Faculty

CAROLINE AJO-FRANKLIN

Professor of BioSciences

Caroline Ajo-Franklin uses biophysics and synthetic biology to engineer and explore the nanoscale interface between living microbes and inorganic materials. She is particularly interested in the basic mechanisms underlying charge transfer and assembly of materials at this living/nonliving interface. Ultimately, her research has applications in carbon capture and sequestration, bio-solar energy generation and hierarchical assembly of nanostructures.

Before coming to Rice, Ajo-Franklin was a staff scientist at Lawrence Berkeley National Laboratory's Molecular Foundry. She received her Ph.D. in chemistry from Stanford University and completed postdoctoral training in synthetic biology at Harvard Medical School. Ajo-Franklin comes to Rice as a Cancer Prevention and Research Institute of Texas scholar in cancer research.

JONATHAN AJO-FRANKLIN

Professor of Earth, Environmental and Planetary Sciences

Jonathan Ajo-Franklin is an applied geophysicist who works on problems in the environmental and energy domains, including geological carbon storage, geothermal energy production and near-surface hydrogeophysics. His group specializes in new acquisition techniques for time-lapse seismology, including distributed acoustic sensing, permanent seismic source development and ambient noise approaches. He also works on rock physics relevant to interpreting seismic datasets, particularly the properties of fractures, ice and unconsolidated materials.

Prior to joining the faculty at Rice University, Ajo-Franklin was a staff scientist and the Geophysics Department head at Lawrence Berkeley National Laboratory. Ajo-Franklin received his M.Sc. and Ph.D. in geophysics from Stanford University and obtained postdoctoral training at the Massachusetts Institute of Technology's Earth Resources Laboratory.

KORY EVANS

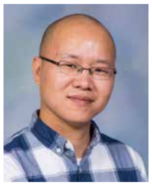
Assistant Professor of BioSciences

Kory Evans studies skull shape evolution in teleost fishes, the most species-rich assemblage of vertebrates on the planet. He integrates data from developmental biology, ecology, biomechanics and phylogeny to study the origins of phenotypic diversity and the interface between phenotype and the environment.

Evans was awarded a Southern Regional Education Board doctoral fellowship and completed his Ph.D. in biological sciences at the University of Louisiana at Lafayette. He obtained postdoctoral training at the University of Minnesota, Twin Cities as a CFANS postdoctoral fellow and at Brown University as a Presidential Postdoctoral Fellow.

YANG GAO

Assistant Professor of BioSciences



Yang Gao is interested in unraveling the molecular mechanisms of DNA replication and maintenance. He combines biochemical, biophysical and structural techniques to obtain atomic details of the DNA replication and maintenance process. His research will aid the rational drug design against important cancer targets.

Gao received his Ph.D. in biochemistry from Iowa State University and completed his postdoctoral training at the National Institutes of Health. He comes to Rice as a Cancer Prevention and Research Institute of Texas scholar in cancer research.

ANNA-KARIN GUSTAVSSON

Norman Hackerman-Welch Young Investigator and Assistant Professor of Chemistry

Anna-Karin Gustavsson designs innovative and versatile imaging tools and analysis algorithms in order to gain detailed information about cellular nanostructure, dynamics and molecular mechanisms. Her work is focused on the development and application of 3D single-molecule tracking and 3D super-resolution imaging throughout mammalian cells. Her research aims to improve our understanding of cellular function and pathogenesis and to answer biophysical questions related to aging and cancer.

Gustavsson was selected to receive an NIH Pathway to Independence Award, the 2018 PicoQuant Young Investigator Award and the 2012 FEBS Journal Richard Perham Prize.

Prior to joining the Rice faculty, Gustavsson completed her Ph.D. in physics at the University of Gothenburg, Sweden. She was awarded a Swedish Research Council international postdoctoral fellowship and obtained postdoctoral training at Stanford University. She comes to Rice as a Cancer Prevention and Research Institute of Texas scholar in cancer research.

CHRIS LEININGER

Professor of Mathematics

Chris Leininger is a mathematician whose research interests include geometry, topology, group theory and dynamics in low dimension.

Leininger completed a Ph.D. at the University of Texas at Austin and was an NSF Postdoctoral Fellow and assistant professor at Barnard College, Columbia University before joining the University of Illinois at Urbana-Champaign faculty as an assistant professor of mathematics in 2005. He was promoted to associate professor in 2010 and to full professor in 2016 before joining the Rice faculty in 2020.

ANDREW LONG

Assistant Professor of Physics and Astronomy

Andrew Long uses the lens of high-energy particle physics to study the extreme environment of the early universe in the first fractions of a second after the Big Bang. By better understanding the physics that guided this period in our cosmic history, he hopes to learn how the universe developed into what we see today. To do so, observations of high-energy phenomena at collider experiments and in astrophysical systems are invaluable for testing and refining our theories.

Long completed his Ph.D. in theoretical particle physics and cosmology at the University of Wisconsin, served as a postdoctoral researcher at Arizona State University, and held the position of KICP Fellow at the University of Chicago before joining the Rice faculty.

MATTHEW MCCARY

Assistant Professor of BioSciences

Matthew McCary is an ecologist who studies how environmental disturbances such as biological invasions, urbanization and climate change alter the relationship between soil biodiversity and ecosystem health. His research is interdisciplinary, including field and lab experiments, mathematical and statistical modeling, and molecular tools.

McCary completed his Ph.D. in ecology and evolution at the University of Illinois Chicago. His postdoctoral training consisted of an NSF Postdoctoral Research Fellowship in Biology at the University of Wisconsin–Madison and a Ford Foundation Postdoctoral Fellowship at Yale School of the Environment.

GUIDO PAGANO

Assistant Professor of Physics and Astronomy

Guido Pagano is an atomic physicist working with cold atoms and trapped ions in the field of quantum computing and quantum simulation. His work focuses on the manipulation of individual atoms with electromagnetic fields, to perform quantum algorithms and to simulate models that challenge classical computers.

Prior to joining the Rice faculty, Pagano earned his Ph.D. at Scuola Normale Superiore di Pisa and at European Laboratory for Non-Linear Spectroscopy in Florence, working with ultracold fermionic ytterbium gases in optical lattices. He was awarded the Intelligence Community Postdoctoral Research Fellowship to work on large-scale quantum simulation with trapped ions at the University of Maryland.

CHELSEA WALTON

Associate Professor of Mathematics

Chelsea Walton is a mathematician whose research interests are in various aspects of noncommutative algebra, including quantum symmetries, algebras with origins in physics, noncommutative algebraic geometry, noncommutative invariant theory, deformation theory, representation theory and homological methods.

Walton completed her Ph.D. at the University of Michigan and as a visiting student at the University of Manchester, U.K. She was awarded an NSF Postdoctoral Fellowship and obtained postdoctoral training at the University of Washington, the Mathematical Sciences Research Institute (MSRI) and the Massachusetts Institute of Technology, where she was a Moore instructor. She held positions as the Selma Lee Bloch Brown Early Career Assistant Professor at Temple University and an associate professor and Karen and Brad Smith scholar at the University of Illinois at Urbana-Champaign before joining the Rice faculty.

JULIAN WEST

Norman Hackerman-Welch Young Investigator and Assistant Professor of Chemistry

Julian West designs new chemical tools for making the molecules of modern life. He and his group seek to identify new catalyst systems that can expedite the synthesis of important cancer therapeutics and diagnostics, agrochemicals, and advanced materials and also permit their improvement via late-stage functionalization reactions.

Prior to joining the Rice faculty, West received his Ph.D. in chemistry as an NSF Graduate Research Fellow from Princeton University. He pursued his postdoctoral training as an NIH and Resnick postdoctoral fellow at the California Institute of Technology. West comes to Rice as a Cancer Prevention and Research Institute of Texas scholar in cancer research.

Faculty Retirements

GERALD DICKENS
Earth, Environmental and Planetary Sciences

Gerald Dickens received a B.S. from the University of California, Davis and an M.S. and Ph.D. in oceanography from the University of Michigan. He held positions as a lecturer and then a senior lecturer at James Cook University in Australia before joining the Rice faculty as an associate professor in 2001.

Dickens' research was in the areas of paleoceanography, marine geology and low-temperature geochemistry, and he was well known for his work on methane gas hydrates in the oceans. Dickens was elected a fellow of the Geological Society of America and was awarded a Distinguished Lecturer from the Joint Oceanographic Institutions and the American Association of Petroleum Geologists. He was actively involved with undergraduate life on campus, serving as magister of Martel College from 2005–2010.

Dickens is now a professor of geology and mineralogy at Trinity College in Dublin.

ANDRÉ DROXLER
Earth, Environmental and Planetary Sciences

André Droxler received his M.S. from the University of Neuchatel in Switzerland and his Ph.D. from the University of Miami. After postdoctoral research at the University of South Carolina, he joined Rice as an assistant professor in 1987.

Droxler's research focused on coral reefs and carbonate platforms and surrounding sediments and preserved records of ancient climates and sea levels. Much of his work was conducted in the Bahamas, offshore Jamaica, along the Belize margin, in the Maldives, along the Australian Great Barrier Reef and in the Gulf of Papua. He participated in many marine surveys and ocean drilling cruises, including a 2018 mission to map the interior of the famous Blue Hole in Belize. More recently, he began studying ancient microbial reefs in Mason County, Texas, a project that he continues today.

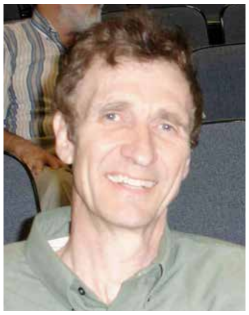
Droxler is now a professor emeritus of Earth, environmental and planetary sciences.

RUI-RUI DU
Physics and Astronomy

Rui-Rui Du was born in Shanghai, China. After graduation from Fudan University, he came to study in the United States and received a Ph.D. in physics from the University of Illinois at Urbana-Champaign. After postdoctoral research work at Princeton University, he joined the faculty at the University of Utah. He joined Rice as a professor of physics and astronomy in 2004.

Du is an experimental condensed matter physicist, who had active research programs in the fractional quantum Hall effect, low temperature physics, topological insulators and superconductors. His contributions to the field include many papers, among which some are considered quite influential. His teaching at Rice included the introduction to sciences and technologies at nanoscale course. He was named an Alfred P. Sloan Research Fellow and a fellow of the American Physical Society.

Du is now a professor emeritus of physics and astronomy.



ROBERT HARDT
Mathematics

Robert (Bob) M. Hardt received a B.S. from the Massachusetts Institute of Technology and a Ph.D. from Brown University. From September 1971, he held various positions at the University of Minnesota until joining the Rice faculty as the W. L. Moody Professor of Mathematics in 1988. He served as chair of the Department of Mathematics from 1993–96. He has also held visiting positions at premier research institutes across the world, including the Institute for Advanced Study, Institut des Hautes Études Scientifiques and the Max-Planck-Institut für Mathematik.

Hardt has published widely in areas of analysis and geometry, particularly in the areas of partial differential equations, geometric measure theory and analytic varieties. His research was recognized by an invitation to speak at the 1986 International Congress of Mathematicians. This conference is the largest conference in mathematics, meeting once every four years, and where the Fields Medals are awarded. The invited talks are intended to be a reflection of the current state of the art on mathematics, and being invited to talk at the ICM is regarded as a high honor.

Hardt is now the W. L. Moody Professor Emeritus of Mathematics.

HUEY HUANG
Physics and Astronomy

Huey W. Huang received a B.S. from National Taiwan University and a Ph.D. from Cornell University. After postdoctoral work at Columbia University and a lectureship at Yale University, he joined the Rice faculty in 1972.

He was trained as a theoretical physicist in particle physics but soon changed his interests to liquid crystals and biophysics. The emergence of synchrotron radiation and neutron facilities allowed him to develop his experimental work on membrane biophysics. He was the first to perform cryo-EXAFS (extended X-ray absorption fine structure) on pho-excited carboxy-myoglobin. He developed the technique of in-plane scattering by neutron/X-ray for detecting pores in membranes and invented the technique of oriented circular dichroism for measuring the orientation of proteins in membranes. His discoveries included the dynamical orientation change and pore formation by antimicrobial peptides in membranes and the intermediate-structure of membrane fusion proteins.

He was elected a fellow of the American Physical Society and awarded the Avanti Award in Lipids of the Biophysical Society.

Huang is now the Sam and Helen Worden Professor Emeritus of Physics.

LON WILSON
Chemistry

Lon Wilson obtained a B.S. from Iowa State University and a Ph.D. from the University of Washington. After two years as an NIH postdoctoral fellow at the University of Illinois, he joined the Rice faculty for a career that spanned 47 years at the university.

Wilson's early work focused on the field of bioinorganic chemistry where carefully designed small model compounds were synthesized, structured and studied to help decipher the chemical structures and reactivities of complex metalloprotein active sites. After the discovery of fullerenes, his interests expanded to include the application of fullerenes and related nanomaterials to the field of biology and medicine. Foremost among these studies was the discovery and development of the "gadonanotubes."

Wilson was always actively involved in the daily lives of Rice undergraduates, serving as a faculty associate at Sid Richardson College for 45 years and as the first RA of the college for eight years. The Lon Wilson Service Awards, which are awarded to deserving Sid students every year, were established by the college in his honor.

Wilson is now professor emeritus of chemistry.

In Memoriam

ALBERT BALLY

The Harry Carothers Wiess Professor Emeritus of Geology

Geologist Albert Bally, a beloved teacher and mentor, pioneer in the field of seismic structural geology and former chief geologist at Shell Oil Co., died July 30, 2019, in Houston after a short illness. He was 94.

As a petroleum geologist, Bally was a pioneer in integrating the methods of reflection seismology with stratigraphic and structural geology. In 1966, he was tapped to head Shell's Research and Development Laboratory in Bellaire, and a decade later he became chief geologist of Shell's U.S. division.

Bally retired from Shell in 1981 and took his expertise to academia, joining Rice as chair of the Department of Geology and Geophysics. He was appointed the Harry Carothers Wiess Professor of Geology, a position he occupied until his retirement from Rice in 1996.

Bally was born in The Hague, Netherlands, and spent his early years in Indonesia, Italy and Switzerland. He received his doctorate in geology from the University of Zurich in 1952 and joined Shell in 1954 after a postdoctoral appointment at the Lamont-Doherty Earth Observatory at Columbia University.

His many honors included the German Geological Society's Gustav-Steinmann Medal, the Geological Society of America's Career Contribution Award, the American Association of Petroleum Geologists' Sidney Powers Memorial Award and the Geological Society of London's William Smith Medal.

CALVIN CLASS

Professor Emeritus of Physics

Calvin Class, a professor of physics at Rice for 34 years, died April 14, 2020, in Houston at the age of 96.

He was a native of Baltimore and earned his undergraduate degree and doctorate from Johns Hopkins University. During World War II, he served in the Army Air Corps Enlisted Reserve as a physicist with the National Advisory Committee for Aeronautics in Hampton, Virginia. He joined the Rice faculty in 1952.

Class and his late wife, Bernice, were the first magisters of Jones College, serving from 1957 to 1965. He was also a featured speaker at Rice Centennial UnConvention in 2012.

Class researched nuclear physics, particularly the structures of atomic nuclei, through the Van de Graaff accelerator acquired by the Rice Nuclear Laboratory (later the Bonner lab).

Class won a Guggenheim Fellowship in 1955, and that year he spent six months working alongside Niels Bohr at the Institute for Theoretical Physics of the University of Copenhagen, now the Niels Bohr Institute.

JABUS ROBERTS

Professor of Physics and Astronomy

Jabus (Jay) Roberts, a professor of physics and astronomy at Rice, died Nov. 22, 2019. He was 76.

Roberts, who joined Rice in 1975, was a core member of the university's Tom W. Bonner Nuclear Laboratory and became a full professor in 1985. A native of Alabama, he earned a bachelor's degree from Columbia University in 1965 and his Ph.D. from the University of Pennsylvania in 1969.

Roberts' research included work with detectors at both the Relativistic Heavy Ion Collider at Brookhaven National Laboratory and the Compact Muon Solenoid detector at CERN, directly contributing to both the quark-gluon plasma and the Higgs boson discoveries. Over the years, he taught at all levels of the curriculum and had advised undergraduate, doctoral and postdoctoral researchers. Most recently, Roberts had been overseeing the senior honors thesis course and providing support to the 100-level general physics courses.

Outside the department, Roberts had served as the faculty sponsor of the Rice rugby club for the last 36 years.

DALE SAWYER

Professor Emeritus of Earth, Environmental and Planetary Sciences

Geophysicist Dale Sawyer, a respected scientist, dedicated educator and former magister of Will Rice and Sid Richardson colleges, died peacefully Sept. 15, 2020, after a long illness. He was 65.

Sawyer, professor emeritus of Earth, environmental and planetary sciences, joined Rice in 1988 and retired in 2020. He was well-known and esteemed around the world for his scientific leadership in marine geophysics, particularly his work on the origins of continental margins, and he was beloved at Rice for his spirit, good humor and dedication to students and scholarship.

Sawyer was born in St. Louis, Missouri, traveled the world as a child and graduated from the International School of Bangkok before earning his bachelor's degree in Earth science from Purdue University in 1976 and his doctorate in marine geophysics from the Massachusetts Institute of Technology in 1982.

He was a pioneer in the numerical modeling of crustal deformation and an expert in the acquisition and interpretation of active source seismic profiles. He frequently went to sea to collect seismic data aboard research ships, and because of his calm leadership skills and expertise, he was tapped to serve as either chief scientist or co-chief scientist on half of the shipboard expeditions in which he participated.

Sawyer was named outstanding faculty associate at Will Rice College from 1990–1997; was a distinguished alumnus of the Purdue Department of Earth, Atmospheric and Planetary Sciences; and was a member of the American Geophysical Union, the American Association of Petroleum Geologists, the Society of Exploration Geophysicists, the American Association for the Advancement of Science and Sigma Xi.

STANISLAV SAZYKIN

Associate Research Professor of Physics and Astronomy

Stanislav Sazykin, an associate research professor of physics and astronomy who was highly respected in his field of space science, died unexpectedly May 3, 2021, at age 49.

Sazykin joined Rice in 2000 as a postdoctoral researcher, rising quickly to associate research professor.

After completing bachelor's and master's degrees at the Moscow Institute of Physics and Technology, Sazykin came to the United States in 1993 as an exchange student as part of the Bush-Gorbachev Exchange Program. He earned an additional bachelor's degree and a Ph.D. from Utah State University under the direction of Bela Fejer.

"Stan was an active member of the space science community, convening sessions at meetings and focus groups, chairing sessions with good humor and penetrating comments," said Frank Toffoletto, a professor of physics and astronomy. For five years, he was a member of the steering committee of the National Science Foundation's Geospace Environment Modeling program.

He was a member of Rice's committee on faculty and staff benefits and served for seven years on the Faculty Senate, where he helped develop policies for research and teaching professors.

Sazykin leaves his wife, Ying, and three sons, Andrew, Logan and Victor.

RONALD STEBBINGS

Professor Emeritus of Space Physics and Astronomy

Ronald Stebbings, professor emeritus of space physics and astronomy, died Aug. 27, 2020, in Rockport, Texas, where he lived after his retirement. He was 91.

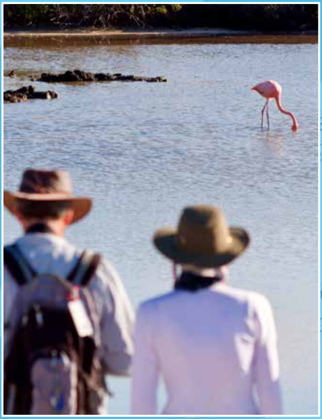
Stebbings was an early member of Rice's pioneering space science department, established in 1963 by Alexander Dessler, professor emeritus of space physics and astronomy, shortly after President John F. Kennedy's moon speech at Rice Stadium. Dessler recruited Stebbings to the university in 1968.

Stebbings served as chair of the Department of Space Physics and Astronomy from 1969 to 1974, became Rice's dean of undergraduates in 1983, and in 1984 was appointed the university's first vice president for student affairs. He returned to the Department of Physics and Astronomy faculty in 1993 and retired in 1995.

A native of London, Stebbings earned a bachelor's degree and doctorate from the city's University College London, the latter in 1956. He worked at General Atomics (GA) in San Diego from 1958 to 1965 before returning to University College as a faculty member until his recruitment to Rice.

He and his late wife, Mona, were magisters of Jones College from 1977 to 1982 and presided over Jones' transition from all women to coed in 1980. Both were awarded the Association of Rice Alumni's Gold Medal, the organization's top honor, in 2000.

Alumni Adventures



The Galápagos Islands, located about 600 miles off the coast of Ecuador, are known for their diverse array of endemic plant and animal species that have evolved over time due to their isolation from the mainland. Charles Darwin first visited Galápagos in 1835 on the HMS Beagle. His studies of birds, such as finches, that adapted to the available habitat, inspired his theory of evolution by means of natural selection.

in Galápagos

BY SIQI DU

Places change a lot. Even somewhere as peaceful as Rice, roads extend and buildings rise. "There are a lot more buildings than when I was there, twice as many as before," Alan Jackson '76 recalled to his wife, Susan.

Alan Jackson '76 and his wife, Susan

Jackson completed his undergraduate degree in mathematics and physics at Rice many years ago but recently continued his adventures with the Rice community on a Traveling Owls alumni trip to the Galápagos Islands.

When I asked him about his experience at Rice, he laughed pleasantly as memories of the old days came back. "There are so many interesting experiences!" he said, mentioning how he spent time on the rooftop of Sid Rich and how he found a large slingshot in the closet and used it to launch water balloons. With memories flowing, Alan and Susan started talking to each other. When Susan mentioned hearing that the old Sid Rich building might be demolished, their voices softened.

After graduating from Rice, Alan continued his studies earning a master's degree in astrophysics at the University of Colorado Boulder in 1979. He then started working for Shell, where he worked for about 35 years until his recent retirement. At Shell, he tried field exploration, lab research and software development, bouncing between different roles and traveling to numerous places, from the Gulf of Mexico to Alaska. But during all these years, Alan and Susan have continued to come back to the Rice campus, to take classes and use the library.

I was not surprised when I found out that both Alan and Susan have a passion for traveling. Alan told me proudly, "In 2019, Google Maps told me during that year we had traveled the equivalent of going around the planet two and half times." Through their words, it was as if a map opened up in front of me. I learned that the Netherlands is as flat as Texas. "The Netherlands is really known for its architecture and not for its landscape," Susan laughed. They have visited many scenic places together — places as cold as Iceland and as warm and tropical as the Caribbean Sea — but among all those experiences, Galápagos really stands out. "One of the most fabulous trips we have ever been on. It was just," Susan paused, "wonderful!"

The beginning of an adventure is always unexpected, and this one started from a typical day: Alan received a mailer from the Association of Rice Alumni and showed the brochure to Susan. The trip would be in December, close to Susan's birthday. They had already visited Australia and New Zealand earlier in the year. Susan's original thought was "I'm just going to do this for Alan." But in retrospect, they are happy they decided to go — even with a tedious and troublesome three-transfer flight.

The Traveling Owls program is familiar to Alan and Susan; they have been on several Rice trips and are quite fond of traveling in the company of other Rice alumni. "Everyone is comfortable in their own skin," said Alan. Another attractive feature of the Traveling Owls program is that each trip has a faculty host. Scott Solomon, an associate teaching professor of biosciences at Rice, hosted this trip to the Galápagos Islands — a place where he was convinced to become a biologist.

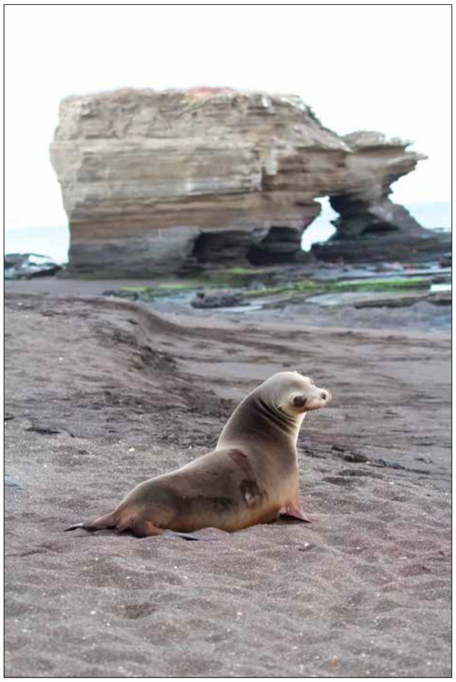
Solomon had been to Galápagos twice before, first as a tourist and then as a student, and now for a third time as an instructor. "Even though as a scientist, I don't believe in magic, there's just this feeling you get there," Solomon said. "This is where Darwin conducted one of the first studies to demonstrate that you can observe natural selection happening in a wildlife population in real time. This is an opportunity to see things that look very similar to the way Darwin saw them, to literally walk in his footsteps."

Undeniably, the Galápagos Islands are famous for being a source of inspiration for Darwin's theory of evolution. This is a big draw for many people — including Alan. When I asked what made them choose to visit Galápagos, he responded immediately. "Darwin! But we didn't really see the finches, strangely enough." Alan and Susan enjoyed Solomon's lectures about Darwin and the development of the field of evolution since Darwin's time and found traveling with a faculty host to be an interesting experience. Although he was trained as a geophysicist, Alan's scientific interests aren't limited just to that field. "Science is science," he said. "There is a framework for how things are done that remains the same across disciplines. A lot of it is learning a new language."

If history is one attractive aspect of the Galápagos Islands, then nature is definitely another. Alan and Susan described the islands as pristine, undeveloped and clean with animals that are naïve, since they haven't learned to be afraid of people. Generations of islanders maintain similar lifestyles, as if someone has managed to halt time. This is one of the reasons why so many are fascinated by the Galápagos Islands.

Surrounded by sea, there is easy access to amazing snorkeling locations, providing a great opportunity to get closer to the islands' underwater residents. Alan and Susan are quite experienced snorkelers, having swum the reefs in Belize, Hawaii, Australia and more. However, the Galápagos Islands still managed to surprise them. "Oh gosh, it was awesome!" said Alan. "We went snorkeling almost every day during the trip." Human-size sharks, sea turtles, starfish, sea cucumbers and the unique Godzilla-like marine iguanas were among the innumerable species they saw underwater.

On land, flaming red Sally Lightfoot crabs, curious sea lion pups waddling around tourists, gigantic 20-foot-high black lava tubes that can accommodate groups of people walking through, and



“This is where Darwin conducted one of the first studies to demonstrate that you can observe natural selection happening in a wildlife population in real time. This is an opportunity to see things that look very similar to the way Darwin saw them, to literally walk in his footsteps.”

— SCOTT SOLOMON

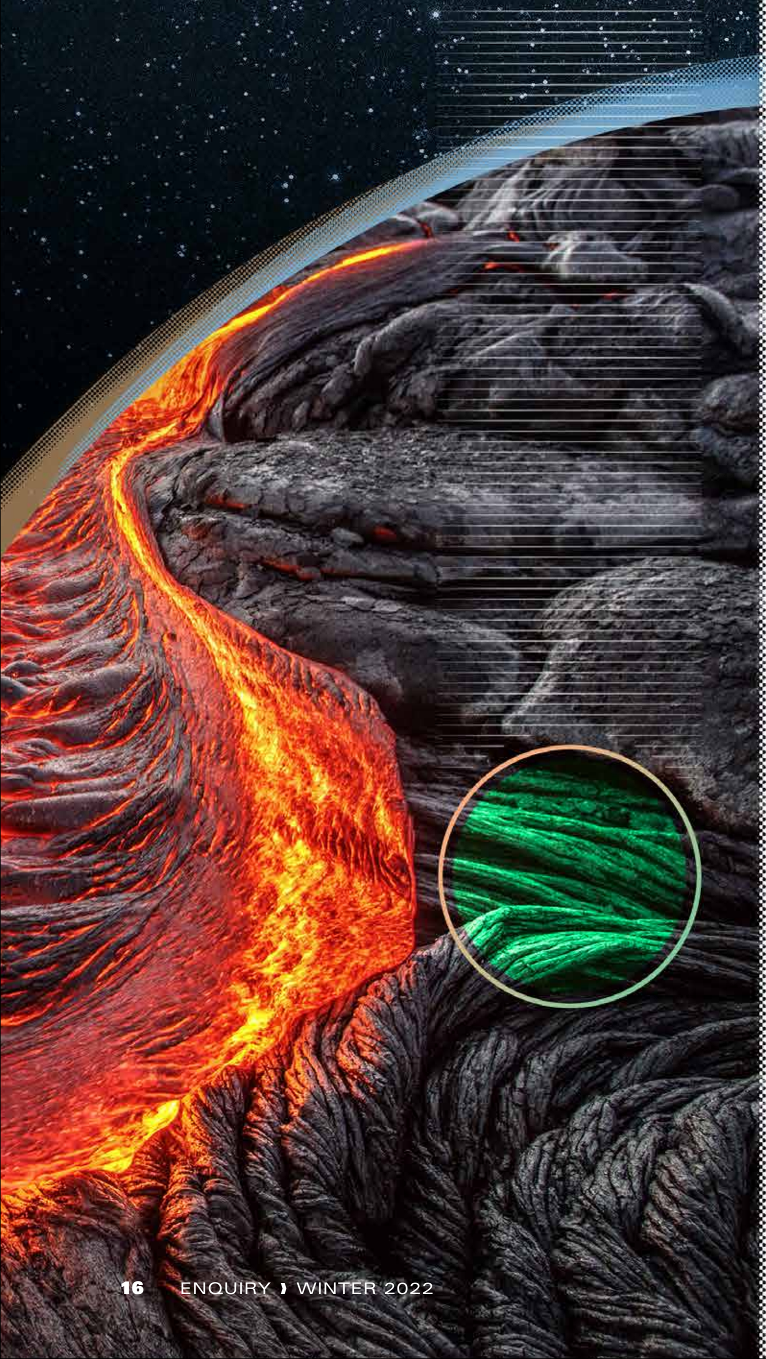
land iguanas make up a totally different, but equally amazing, world. Moving deeper into the center of one of the islands, a mountain rises, a forest appears, and gigantic Galápagos tortoises feast on grass, while birds jump and dance on tree branches. The landscape and ecology change so quickly, and each island offers a unique history and wildlife population.

The beauty and diversity showcased in this Traveling Owls trip captured Alan and Susan’s imagination and heart. “I have to go back,” Alan said. ■

Images courtesy of Scott Solomon

Searching for Life Origins on Rocky Planets

BY HALLIE TRIAL



THE SEARCH FOR LIFE BEYOND OUR OWN PLANET CAPTURES OUR CURIOSITY LIKE ALMOST NO OTHER SCIENTIFIC QUEST. WITH MORE THAN 400 BILLION STARS IN OUR GALAXY ALONE AND AT LEAST ONE PLANET PER STAR, HOWEVER, IF WE EVER HOPE TO FIND LIFE ELSEWHERE IN THE UNIVERSE, WE NEED TO KNOW WHERE TO LOOK. TO DO THAT, WE NEED TO KNOW WHAT MAKES A PLANET HABITABLE.

Rajdeep Dasgupta, Rice's Maurice Ewing Professor of Earth, Environmental and Planetary Sciences, has brought together a team of researchers in diverse disciplines from multiple institutions to address one portion of this vital mystery: How do rocky planets like our own obtain the correct chemical "ingredients" for life as we know it?

This interdisciplinary project is called the Cycles of Life-Essential Volatile Elements in Rocky Planets, or CLEVER Planets, research program. "For the CLEVER planets project, we are focusing on understanding the chemical aspects of habitability," Dasgupta explained. "We want to know, 'How do rocky planets gain and process the key chemical ingredients we need for carbon-based life to flourish?' and 'How do we get a sufficient abundance of those ingredients on the surface of a young planet so that some initial processes can take place and life can originate?'" Dasgupta hopes that the project, currently funded by a five-year NASA grant, will serve as a seed for an ongoing collaborative research initiative at Rice and other involved institutions to address these questions.

CLEVER Planets researchers have made several exciting breakthroughs about how Earth — and by extension, similar rocky planets — accumulated life-essential volatile elements like carbon, oxygen, hydrogen, nitrogen, sulfur and phosphorus. Scientists from Dasgupta's group revealed in 2019 that the violence of Earth's early existence likely allowed the planet to later become a cradle for life. The same collision between early Earth and a Mars-sized body believed to have formed the moon may have delivered many ingredients for life on Earth.

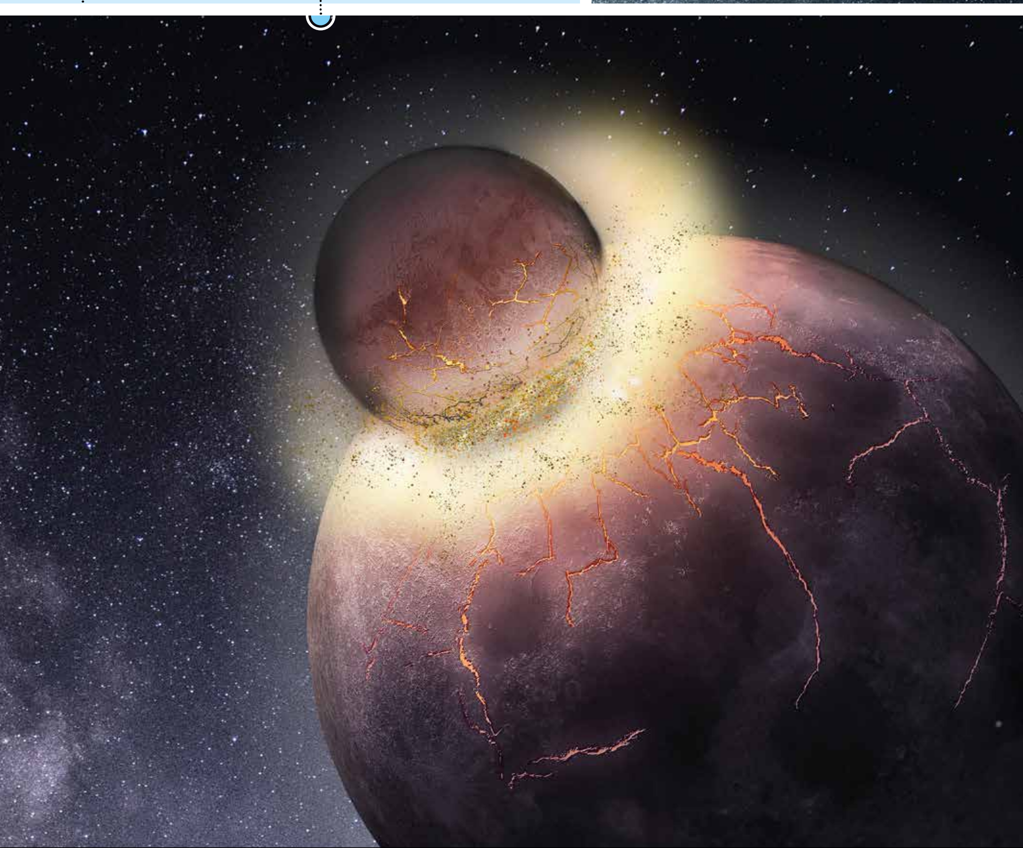
Based on scientists' understanding of how proto-Earth formed, it would be very challenging to obtain the existing absolute and relative amounts of life-giving elements like carbon, nitrogen and sulfur within proto-Earth alone. "The major makeup of the present-day state of our planet and the elements' relative abun-

Left: Rajdeep Dasgupta, the Maurice Ewing Professor of Earth, Environmental and Planetary Sciences; center: Andrea Isella, associate professor of physics and astronomy; right: Adrian Lenardic, professor of Earth, environmental and planetary sciences

Above: Planets undergo stages of evolution as they become suitable for life. Here, a methane atmosphere and magma oceans give way to blue oceans, green plants and shifting tectonic planets. Image credit: Mejs Hasan

Below: Rice University petrologists have found Earth most likely received the bulk of its carbon, nitrogen and other life-essential volatile elements from the planetary collision that created the moon more than 4.4 billion years ago.

> "PEOPLE ASSUME THAT THESE LARGE COLLISIONS ARE ALWAYS LIFE-THREATENING EVENTS, BUT THIS GIANT IMPACT EVENT COULD HAVE BEEN A LIFE-GIVING EVENT ON EARTH."
>
> – DAMANVEER GREWAL



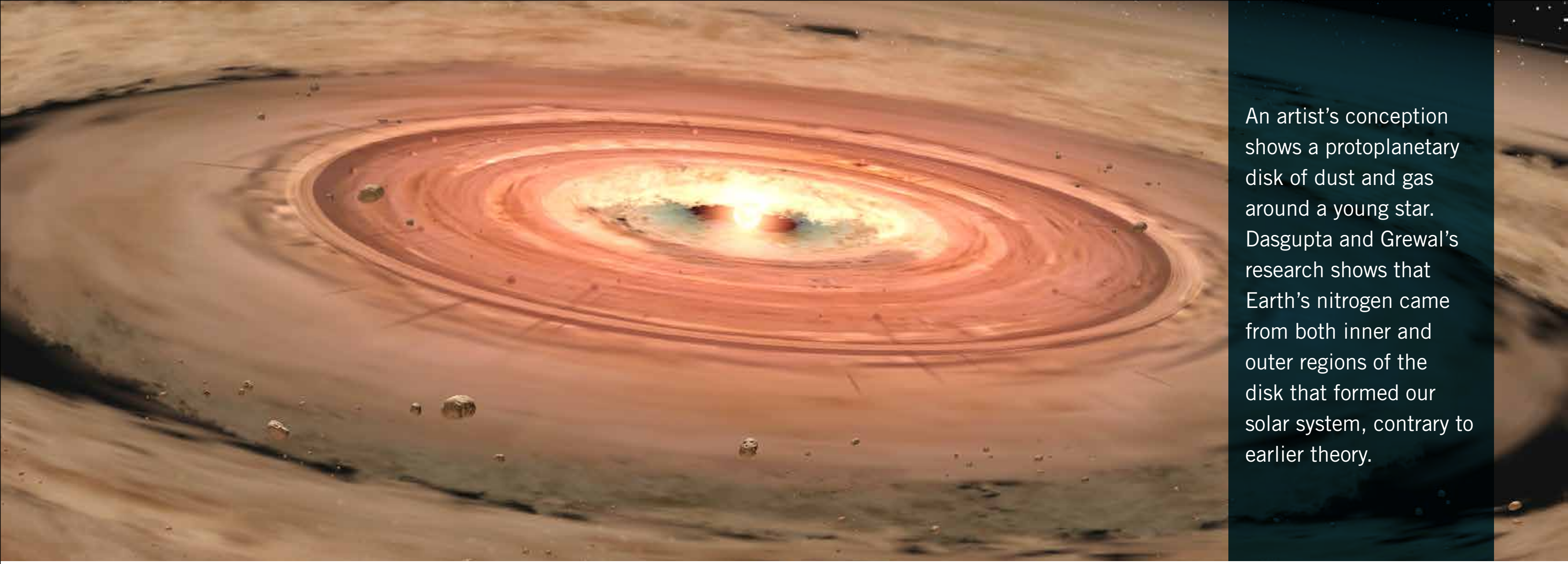
dance probably needed an external input, which could fractionate these elements in a way that's different from that of our own planet," Dasgupta explained. "We went through our modeling exercise and said yes, under a certain set of circumstances we can create another planetary embryo — a Mars-sized planetary embryo — in which the right relative abundance level of these life-essential elements could be established more easily than it could be in our Earth."

Because previous dynamical models had already established that a collision with a Mars-sized impactor probably formed the moon, the study authors suggested that the same impact could have created the chemical makeup of Earth today. "People assume that these large collisions are always life-threatening events, but this giant impact event could have been a life-giving event on earth," commented graduate student Damanveer Grewal, the lead author of the study.

This year, Grewal authored another study that overturned assumptions about which part of the solar system volatile elements found in rocky planets come from. Scientists had long thought that the dust in the inner solar system was too hot for any carbon, water, nitrogen, or other volatile elements or compounds to condense in solid form. Therefore, the protoplanets formed in the inner solar system would start out almost volatile element-free, and life-essential elements would be delivered later from the outer solar system.

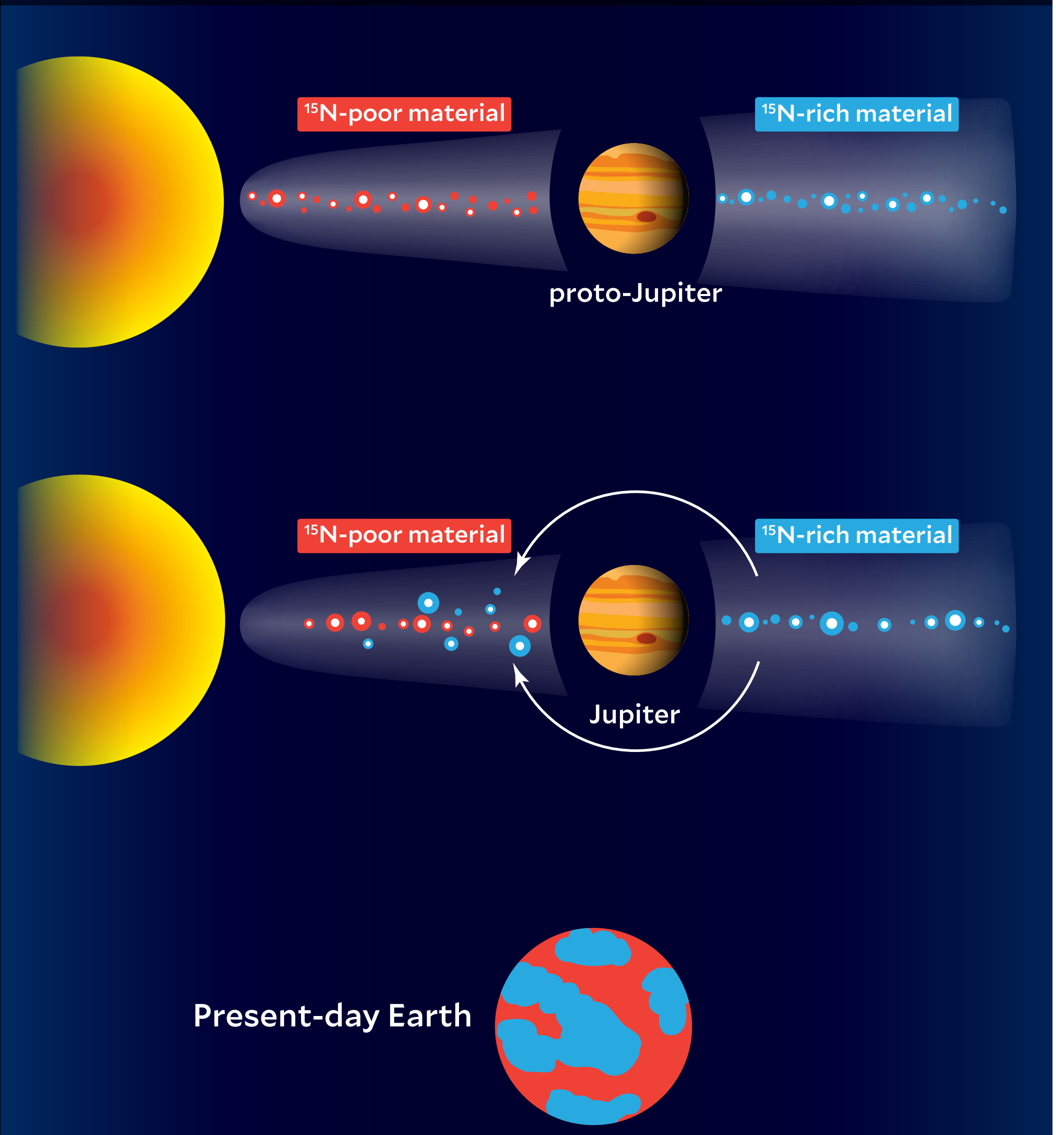
Grewal identified a clever way to test this traditional assumption. "There's a very special class of meteorites called iron meteorites. Iron meteorites are the remnants of the metallic cores of the first formed protoplanets in our solar system. The remnants of those cores can fall on our planet, and because they are made of iron, they don't burn up in the atmosphere," he explained. There are two different classes of iron meteorites: those from the inner solar system, which today consists of the rocky planets and the asteroid belt, and those from the outer solar system, the region outside the asteroid belt. "By measuring certain kinds of isotopes of heavier elements, people now can decipher whether a certain iron meteorite was formed in the inner part of the solar system or the outer part," he continued.

When Grewal compiled the data on isotope ratios of iron meteorites from the



An artist's conception shows a protoplanetary disk of dust and gas around a young star. Dasgupta and Grewal's research shows that Earth's nitrogen came from both inner and outer regions of the disk that formed our solar system, contrary to earlier theory.

The solar protoplanetary disk was separated into two reservoirs, with the inner solar system material having a lower concentration of nitrogen-15 and the outer solar system material being nitrogen-15 rich. The nitrogen isotope composition of present-day Earth lies in between, according to a CLEVER Planets study that shows it came from both reservoirs.



"We see a dichotomy, and this dichotomy suggests that these two groups of meteorites in the belt today were formed in different locations, and they did not mix for a few million years. This is very hard to explain using the current understanding of planet formation."

– André Izidoro Ferreira da Costa

inner and outer solar systems, he found that inner solar system iron meteorites have a very different nitrogen isotope composition than outer solar system iron meteorites. "This actually tells us that the protoplanets that formed in the inner part of the solar system not only had nitrogen, but they accreted nitrogen that was isotopically distinct from the nitrogen in the outer solar system reservoir," stated Grewal. "That demonstrates that there was a nitrogen-bearing source in the inner solar system from the very beginning." The authors believe that the nitrogen may have been bound up in less volatile organic compounds, allowing it to accumulate in dust even at the high temperatures of the inner solar system.

Having disentangled these two nitrogen reservoirs, Grewal and his co-authors could then compare nitrogen isotope ratios in Earth to the two sources and see where Earth's nitrogen came from. They found that "the nitrogen isotope composition of Earth lay exactly in the middle between these two reservoirs, so this means that these inner solar system protoplanets not only had nitrogen, but some of this nitrogen survived all these accretion and collision events to the final day Earth," Grewal said. These results expand where astronomers can expect to find planets suitable for Earth-like life because we now know that large-scale migration of material from the outer solar system to the inner solar system may not be necessary for delivery of volatile elements.

These results also illustrate how events in both the inner and outer solar system influenced the formation and composition of Earth. A major force driving those events during the early years of the solar system was Jupiter. CLEVER Planets postdoctoral researcher André Izidoro Ferreira da Costa recently investigated how the growth of Jupiter could have influenced the types of bodies that coalesced to produce Earth.

When scientists study the composition of these meteorites, they find that they fall into two groups: carbonaceous meteorites from the outer solar system and noncarbonaceous meteorites from the inner solar system. "We see a dichotomy," Izidoro said, "and this dichotomy suggests that these two groups of meteorites in the belt today were formed in different locations, and they did not mix for a few million years. This is very hard to explain using the current understanding of planet formation."

It has been suggested that a "pressure bump" in the ring of gas and dust surrounding the early sun (the protoplanetary disk) caused by a proto-Jupiter pulling large quantities of gas toward itself could have divided the dust and gas in our early solar system into two distinct regions: the one outside the pressure bump and the one inside the pressure bump. This divide prevented mixing of material early on.

Izidoro and his co-workers modeled how a pressure bump like this one would influence growth of inner rocky planets. He found that it necessitates planet formation by collision of 100-km-diameter objects, rather than gradual accretion of small dust particles onto a single 100-km object. This has implications for the chemical makeup of planets because planetesimals of different sizes fractionate volatile elements in different ways, so the size of the planetesimals that accumulate into a larger planet influences the composition of the final planet.

Because the growth of large planets like Jupiter shapes the growth of rocky planets like Earth, developing a fundamental understanding of Jupiter's growth can shed light on the evolution and habitability of exoplanetary systems. Researchers in the lab of Andrea Isella, an observational astronomer and associate professor of physics and astronomy at Rice and co-investigator on the CLEVER Planets project, have studied the diffuseness of Jupiter's core, which influences the planet's gravitational field and its consequent interactions with other bodies in the solar system.

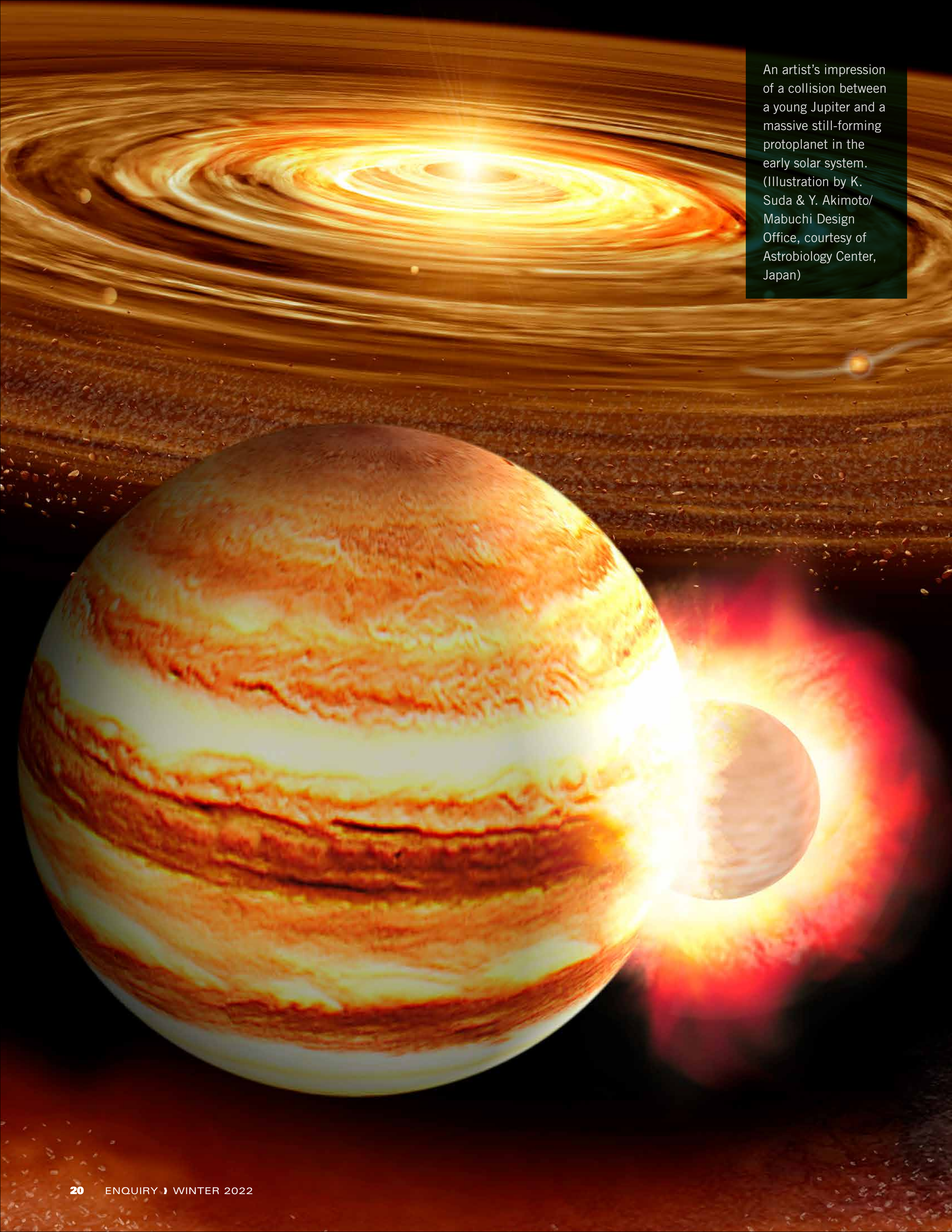
When NASA's probe Juno returned unexpected data on Jupiter's gravitational field suggesting that the planet's core was far less dense than originally thought, scientists rushed to provide explanations. Shang-Fei Liu, a former graduate student in Isella's group, postulated that a head-on collision between Jupiter and a planetary embryo about 10 times more massive than modern Earth could have shattered and diluted Jupiter's core, creating a diffuse structure. It would take many billions of years for the core to contract back to something resembling its original form, explaining why we continue to observe a less-dense core today. Were it not for Jupiter, the inner solar system might have another rocky "inhabitant."

Discovering the processes that formed the solar system and originally delivered volatile life-essential elements to the rocky planets, however, is only half the battle. Those ingredients also have to be available in the appropriate forms at the planet's surface for organisms to utilize them. Another CLEVER Planets researcher, Rice geodynamicist Adrian Lenardic, uses numerical models to interrogate tectonic activity and the cycling of key volatile elements between the interior of a planet and its surface. A collaboration between Dasgupta's and Lenardic's lab groups led by James Eguchi, a former graduate student in Dasgupta's group, revealed a compelling model that explains both the oxygenation of early Earth and a quirk in the carbon isotopes from carbonate minerals formed around the same time.

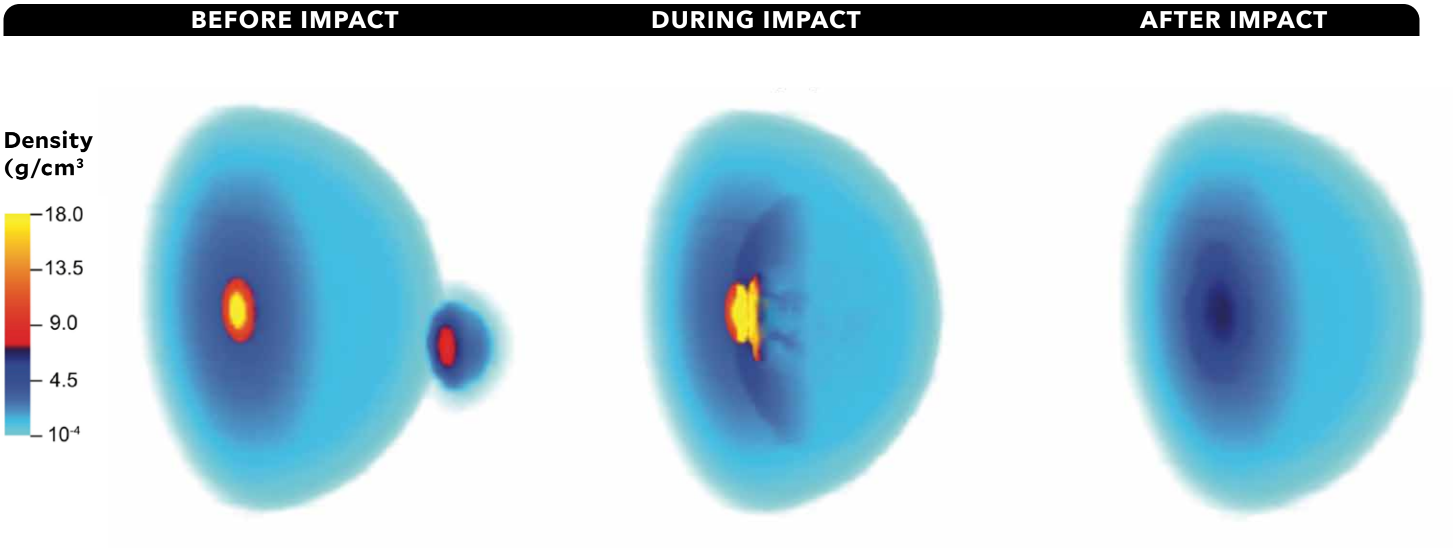
Earth's early atmosphere contained very little oxygen, and it was not until the Great Oxidation Event (GOE) about 2.5 billion years ago that significant quantities of this vital gas entered the atmosphere. Scientists have long postulated that a boom in the population of primitive photosynthetic organisms called cyanobacteria caused this massive atmospheric transition. The problem is that cyanobacteria emerged up to 500 million years before the GOE. What, then, caused their population to increase so dramatically at the time of the GOE?

Yet another mystery in the geological record complicates the picture. Around the same time as the GOE, carbonate minerals began showing much higher-than-normal concentrations of the isotope carbon-13 compared to carbon-12. Researchers have proposed that cyanobacteria caused this change, too, by preferentially incorporating carbon-12 into their cells and leaving behind more carbon-13 to accumulate in inorganic minerals. This theory, however, fails to explain why carbon isotope ratios in carbonate minerals only changed tens of millions of years after the GOE.

Eguchi proposed that increased tectonic activity could have released large quantities of carbon dioxide into the atmosphere, warming the climate and increasing rainfall. This would have weathered minerals into the ocean, fertilizing cyanobacteria and increasing the quantity of inorganic carbonate minerals that precipitated from the water. Because the amount of organic carbon from the cyanobacteria and the amount of inorganic carbonate both increased at the



An artist's impression of a collision between a young Jupiter and a massive still-forming protoplanet in the early solar system. (Illustration by K. Suda & Y. Akimoto/ Mabuchi Design Office, courtesy of Astrobiology Center, Japan)



A rendering shows the effect of a major impact on the core of a young Jupiter, as suggested by Isella's research group and their collaborators at Sun Yat-sen University. The collision about 4.5 billion years ago could explain surprise readings from NASA's Juno spacecraft.

same time, a change in the carbon isotope composition of minerals was not observed immediately. After sediments reentered the mantle through tectonic activity, the carbonate minerals — which were higher in carbon-13 — tended to be recycled back to the surface faster than the organic carbon, causing an increase in the ratio of carbon-13 to carbon-12 at the surface. Therefore, we observe a lag between the GOE and the change in carbon isotope composition in the crust.

Isotope ratios did not return to normal until the organic carbon originating from the cyanobacteria returned to the surface. How plate tectonics influence the early evolution of life and whether they are necessary for rocky planet habitability "is a million-dollar question," said Dasgupta, "and this study provides us with one more piece to the puzzle of the answer."

In addition to multiple co-investigators at Rice, the CLEVER Planets project involves co-investigators from other institutions, including University of California, Los Angeles; University of California, Davis; University of Colorado Boulder; and NASA Johnson Space Center. For example, Hilke Schlichting from UCLA has taken part in some projects with CLEVER Planets studying how oxidized or reduced the interiors of exoplanets are — a challenging undertaking given that direct observation primarily informs us about the composition of exoplanetary atmospheres rather than interiors. The redox state of the planet's interior dramatically impacts the types of compounds formed by life-essential volatile elements and how these compounds move between the surface and the interior.

Each institution and researcher brings differing tools and expertise to a massive, multifaceted question. "To really tackle a question like how life-essential chemical elements are delivered and sustained on planets, we need contributions from astrophysics, astronomy, cosmochemistry, geochemistry, petrology; we need dynamics of planet formation as well as chemical aspects of planet formation," Dasgupta illustrated. "The questions that we are really asking demand communication across disciplinary boundaries. My hope is that down the line when newer generations are trained on these types of things, they will be trained in a way that takes certain knowledge and training from one discipline and another discipline, and new disciplines will be created. At that time, you may not call it interdisciplinary anymore because those boundaries will be so permeable."

"These are some tough problems. It requires a lifelong effort to really make a dent in this," Dasgupta continued. Although the NASA grant for CLEVER Planets only lasts for five years, Dasgupta hopes that the research initiatives; collaborations; and, most importantly, the communication pathways across disciplines established during that time will persist for decades, with Rice University being at the center of it. ■

> "THE QUESTIONS THAT WE ARE REALLY ASKING DEMAND COMMUNICATION ACROSS DISCIPLINARY BOUNDARIES."
>
> — RAJDEEP DASGUPTA

Matthew Jones, Rice's Norman and Gene Hackerman Assistant Professor in Chemistry

BETTER BUILDING BLOCKS FOR NANOMATERIALS

BY HALLIE TRIAL

Nanoparticles are larger than most molecules but smaller than bulk material, and they exhibit exciting size-dependent properties not observed on any other length scale.

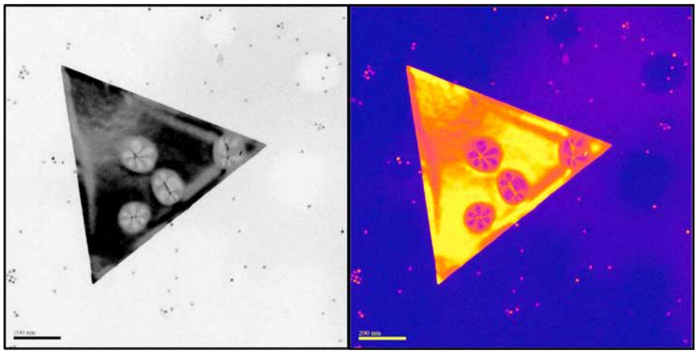
For example, collective oscillations of electrons in metal nanoparticles caused by interactions with light lead to light scattering and absorption at specific frequencies. The absorption of light in the visible range gives solutions of nanoparticles rich color and drives applications in pigments and electronic screens. The oscillations also cause heating at the nanoparticle surface and produce high-energy electrons, effects that have been harnessed to power reactions using solar energy and to thermally destroy cancer cells.

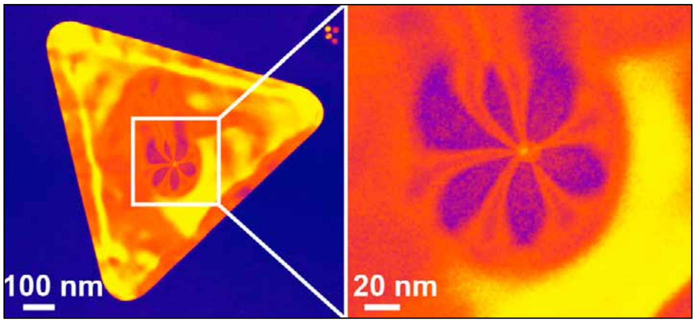
"There's this new length scale, new properties and new applications, but that also means a whole new set of rules we have to learn to use," explained Matthew Jones, Rice's Norman and Gene Hackerman Assistant Professor in Chemistry and assistant professor of materials science and nanoengineering. "In traditional organic chemistry, you learn that atoms are your building blocks," Jones continued. "You learn all the different reaction mechanisms, all these rules for how you can combine them to construct molecules or materials. What my group is interested in is learning those same kinds of rules, but rather than atoms being our building blocks, nanoparticles are our building blocks."

The Jones lab seeks to fundamentally understand how nanoparticles grow and how they interact to form materials, and much of this is dictated by nanoparticle surface chemistry. "Little organic molecules called ligands bind to the surface of our inorganic particles, and they control pretty much everything I care about," Jones said.

Recently, the Jones lab has investigated the influence of surface chemistry on the mechanical properties of a thin, plate-like nanoparticle. They have found that changing the ligands bound to the surface of the nanoparticle can control the stiffness

Below: A transmission electron microscope image at left and a color map version at right highlights deformations in silver nanosheets laid over iron oxide nanospheres. Researchers in the Jones lab determined that van der Waals forces between the spheres are sufficient to distort the silver, opening defects in their crystalline lattices that could be used in optics or catalysis.





Above: A transmission electron microscope image shows a silver nanoplate deformed by a particle, forming flower-shaped stress contours in the material that indicate a bump. Changing the shape of the material changes its electromagnetic properties, making it suitable for catalysis or optical applications.

> “Everyone in the field seems to acknowledge that what the ligands are doing is really important, and everyone seems to acknowledge that we don’t have good ways of figuring it out.”

of the material and even exert forces to reshape the particles. On a macroscopic-length scale, this would be impossible. The unique dimensions of nanoparticles, however, dramatically enhance the impact of surface effects.

“Picture an inorganic nanoparticle, and it has some atoms on the surface, and some atoms inside. The atoms on the surface have fewer neighbors; they’re bound to fewer other atoms, so they have a slightly different mechanical response than the atoms that are interior to the particle that have all of their nearest neighbors,” Jones explained. “The mechanism is still not totally clear, but somehow, when you have a ligand that binds to the surface, if it binds really strongly, it’s rigidifying all of those surface atoms, making them less likely to elastically deform.” Decreasing the size of a particle increases the surface-area-to-volume ratio, thus increasing the ratio of surface atoms to interior atoms. “That’s why these surface effects start to play a big role only when the particle is nanometers in size, because it’s only then that you have a significant fraction of the atoms in the material that can show this surface effect,” Jones elaborated.

Researchers in the Jones lab can only measure these surface effects indirectly. Previously, they discovered that if they drape a thin, plate-shaped silver nanoparticle over a spherical template particle on a surface, van der Waals attractions between the nanoplate and the surface will bend the nanoplate around the spherical template to create a bump, or dome. To assess the relative stiffness of nanoparticles with different surface ligands, they bend the particles around spherical templates, image the domes, and compare their sizes. “If the dome is really big, the particle is stiff, and if the dome is small, the particle is flexible,” said Jones.

They capture these pictures using transmission electron microscopy (TEM), a technique that images objects through diffraction of electrons instead of light. With a light microscope, scientists cannot directly see anything smaller than the wavelength of light they use. Electrons have a much shorter wavelength than light, and electron microscopy can resolve objects as small as single atoms. In TEM, electrons pass through the sample and scatter off of it. Dark areas in TEM images represent places where few electrons reached the detector on the other side of the sample, Jones said, “and that tells you where your particle is.” The metal nanoparticles the Jones group investigates have a high electron density, meaning that they scatter electrons very effectively, “so TEM is great for characterizing the inorganic core of our particles,” he explained.

Unfortunately, smaller atoms like carbon, nitrogen and oxygen that make up the organic ligands on the surface of their nanoparticles do not scatter electrons effectively, and it is often precisely those molecules that Jones lab researchers are most interested in. “Everyone in the field seems to acknowledge that what the ligands are doing is really important, and everyone seems to acknowledge that we don’t have good ways of figuring it out,” Jones said.

For this reason, members of the Jones group are devising clever new ways to visualize the surface-bound organic molecules. The traditional method has been to image the inorganic core and infer the effects of the ligands based on that information, much as they have done in their study of surface-based changes in mechanical properties. In a new method they are developing, they tag the ligands with an electron-dense material, such as another nanoparticle much smaller than the core nanoparticle. That way, they can track the tag and glean information about ligand dynamics.

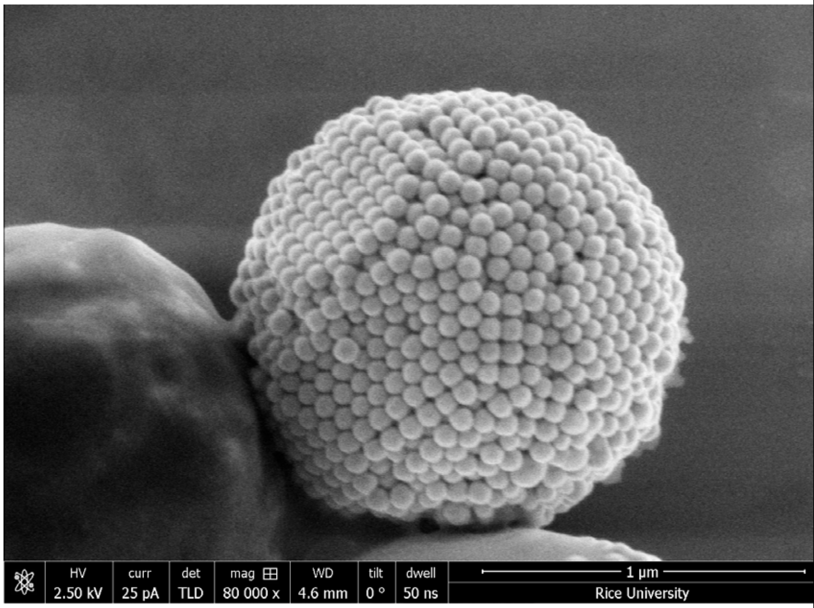
Besides imaging surface ligands, another major challenge the field of nanocrystal research faces is the nonuniformity of nanoparticles. “When an organic chemist makes a solution of a molecule, every single one is exactly the same, but that’s not true in nanoscience,” Jones said. “There is always a distribution of different particle sizes, and nanoparticles are not precisely defined on the atomic level. The whole premise of nanoscience is that a structure’s size determines its properties, so if there’s a distribution of sizes, there’s a distribution of properties.” Furthermore, in many cases, the nonuniformity of particles creates a disconnect between cutting-edge research and consumer reality. “For example, when nanostructures are used for drug delivery or some kind of biomedical application, the FDA is going to be rightly skeptical if you can’t tell them exactly what structure you put into someone’s body,” he stated. “Size matters! Different particle sizes may have different clearance pathways; one size may get through the kidneys, and one may not."

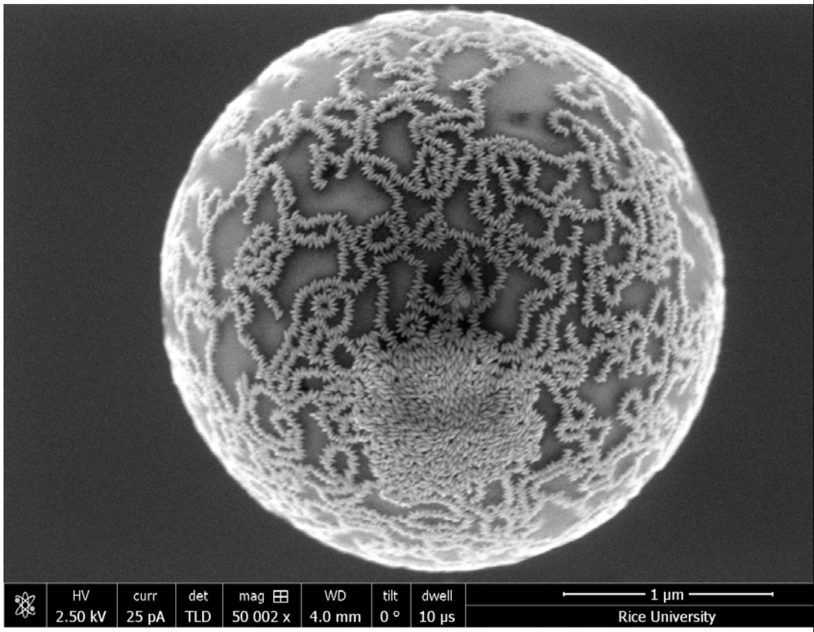
To overcome this hurdle, Jones lab researchers are investigating a class of particles called nanoclusters. Nanoclusters are larger than most molecules but smaller than nanoparticles, with behavior somewhere in between. "For example, we've discovered a new cluster in my lab called gold 32. It has 32 gold atoms in the core, along with eight ligands of one type and 12 ligands of another type," Jones illustrated. "Like a nanoparticle, it has an inorganic core and an organic ligand shell, but like a molecule, it's atomically precise." Certain combinations of metal atoms can arrange themselves symmetrically and have a high stability. Adding or removing just one atom results in an unstable cluster that cannot arrange symmetrically, and more stable clusters form preferentially and uniformly. In the larger nanoparticle regime, on the other hand, "The energy is just a smooth varying function. If I have a particle with 10,000 atoms, and I add one more, it's virtually just as stable as the one before it. As a fraction of the total number of atoms, adding one is such a tiny influence that it doesn't affect the stability of the system that much," Jones explained.

The Jones lab aims to extend that uniformity of nanoclusters into larger structures. They may, for example, employ nanoclusters as "seeds" to start the growth of larger nanoparticles. "We hope that if you start with atomically perfect seeds and then grow them out, maybe you can make atomically perfect nanoparticles," said Jones. They also might assemble nanoclusters as building blocks for a larger material. He added, "When the building blocks are all perfect, your precision in defining how they connect and build into a larger structure is much higher."

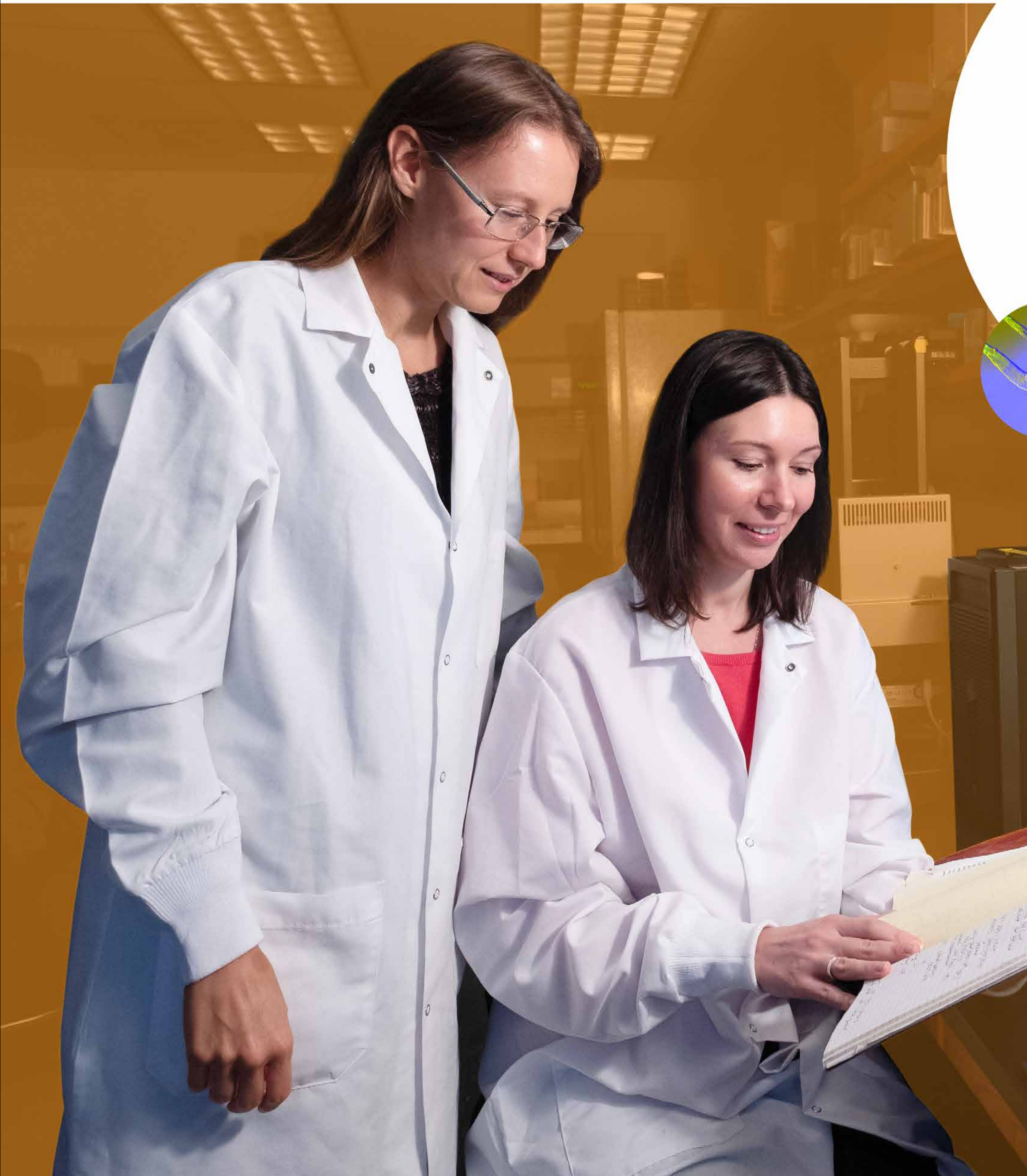
Long viewed as a technology of the future, nanoparticles have now finally started trickling into consumer products. For instance, Samsung produces a television where the backlight consists of an array of quantum dots, or light-emitting nanocrystals made from semiconductor materials. Before nanotechnology can realize its full potential in renewable energy, optics, medicine and a host of other applications, however, we have to understand the fundamental science behind it. For new applications, we need new nanomaterials, and to build new nanomaterials, "we have to understand mechanistically how nanoparticles grow and how to connect them," said Jones. Through their fundamental research, scientists in the Jones lab are building the building blocks of the future. ■

Spherical gold nanoparticles are packed into an ordered superstructure, forming a nearly spherical shape with an ordered arrangement of nanoparticles. Image credit: Zhihua Cheng



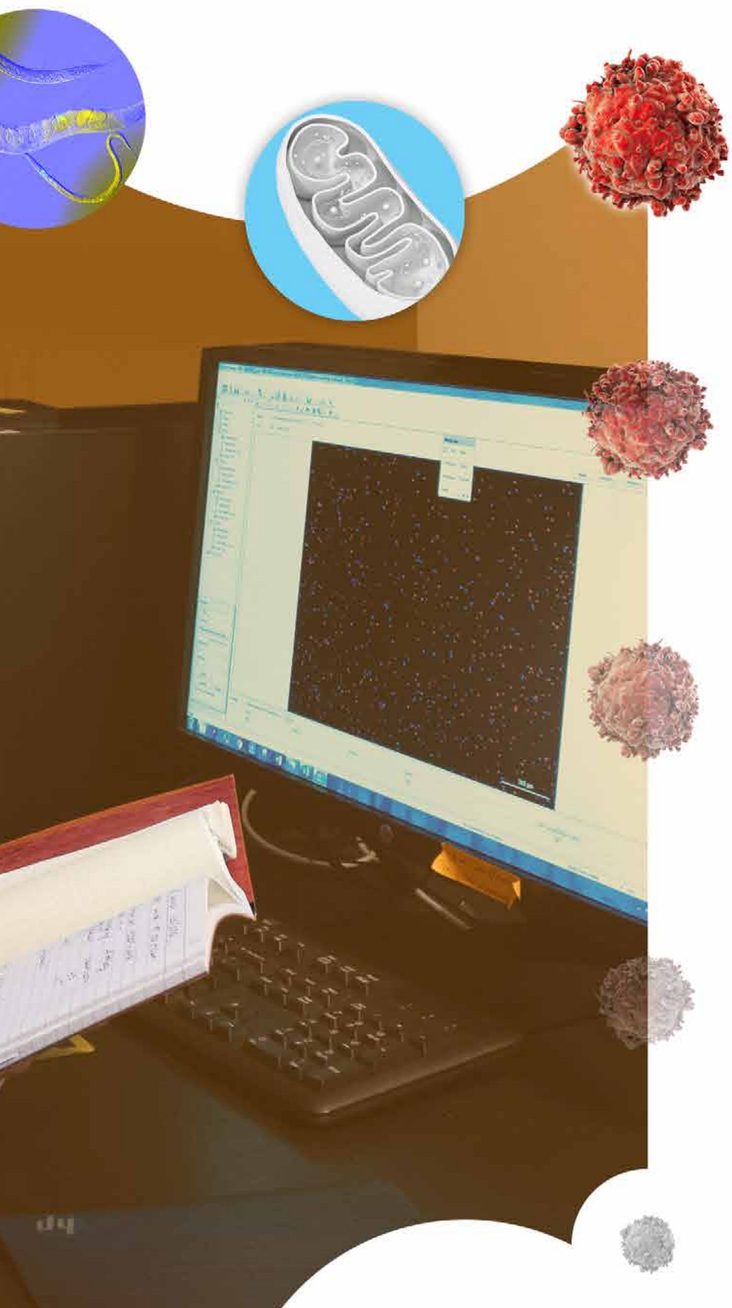


One promising way of packing nanoparticles into unique structures is using surface tension, which is strong enough to hold nano-objects and affect their packing behaviors. Here, gold nanorice particles are packed onto a spherical surface. First, the particles self-assemble into curved chainlike structures on the spherical surface. Then, those chainlike structures aggregate to form a small patch with ordered structures. Image credit: Zhihua Cheng



Mitochondrial Mechanisms May Power Down Cancer

BY GRACE BEILSTEIN



Did you ever think worms could be the key to revolutionizing cancer treatments?

Natasha Kirienko, an associate professor of biosciences at Rice, has been working with *Caenorhabditis elegans*, small nematodes used as model organisms, to better understand the mitochondria in cancer cells and find novel treatments for antimicrobial-resistant bacteria. Kirienko joined the Rice faculty in 2015 as a Cancer Prevention and Research Institute of Texas (CPRIT) scholar and now oversees the work of five graduate students, three postdoctoral scientists and leagues of undergraduates as a mentor known for spotting true passion for science at any educational level.

In her own education as a graduate student at the Institute of Protein Research (Russian Academy of Natural Sciences), Kirienko began her work with bacteria. In her Ph.D. work at the University of Wyoming, she started to work with *C. elegans*, a worm that she "became fascinated with for its versatility and usefulness across disciplines." There she used *C. elegans* to study stress and cancer models, laying the groundwork to shift her research focus to infectious diseases as a postdoctoral researcher.

Though mitochondria are well-known for their ability to produce ATP as the "powerhouse of the cell" (thank you, middle school biology), their molecular pathways also play a significant role in various immune responses. Kirienko stresses the importance of understanding the pathways within mitochondria and how infectious diseases impair them.

Given how much energy is required for the body to destroy damaged mitochondria, there are several pathways that work to repair these mitochondria before they continue to degrade and become unsalvageable. In 2017, Kirienko's Rice lab discovered a novel role for a pathway called the Ethanol and Stress Response Element (ESRE) network, which they have incorporated into their study of two previously known genetic mitochondrial pathways and how the three interact with each other. Preliminary research indicates that the ESRE pathway appears to be triggered by the presence of reactive oxygen species (ROS), though it is the least understood of the three known pathways: the key to harnessing the ESRE pathway for treatment will be understanding how it contributes to mitochondrial homeostasis.

Using their knowledge of these pathways, Kirienko's lab focuses on the role of mitophagy — the targeted consumption of mitochondria by the cell's recycling machinery — in inhibiting tumor growth and as a potential cancer treatment. This is particularly exciting for its promise in developing treatments for even "treatment-resistant" cancers, those that don't tend to respond to cocktails triggering normal programmed cell death. Harnessing the knowledge of how pathogens damage mitochondria and cause cell death could be the key to combatting even the most aggressive types of cancer.

Natasha Kirienko, left, and Svetlana Panina found that a cocktail of cancer-fighting mitocan molecules and a glycolytic inhibitor is effective at fighting acute myeloid leukemia. The discovery could lead to better personalized treatment of the disease.

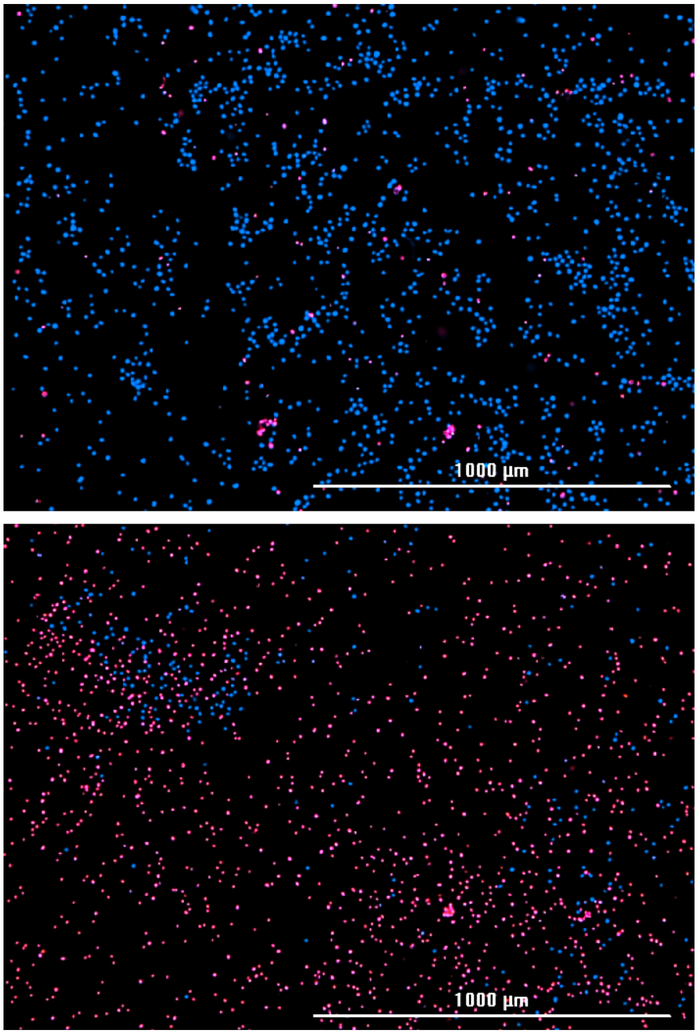
Building on her initial work with *C. elegans*, Kirienko has progressed to using mammalian cells and samples from cancer patients, analyzing more than sixty cancer cell lines from nine different cancer types in an effort to pinpoint cancer types that are particularly sensitive to mitochondrial damage. Inflicting additional damage to mitochondria causes mitophagy and can activate programmed cell death. This inquiry singled out leukemias as sensitive to this approach due to the rate at which the aberrant mitochondria can produce ATP from oxygen intake.

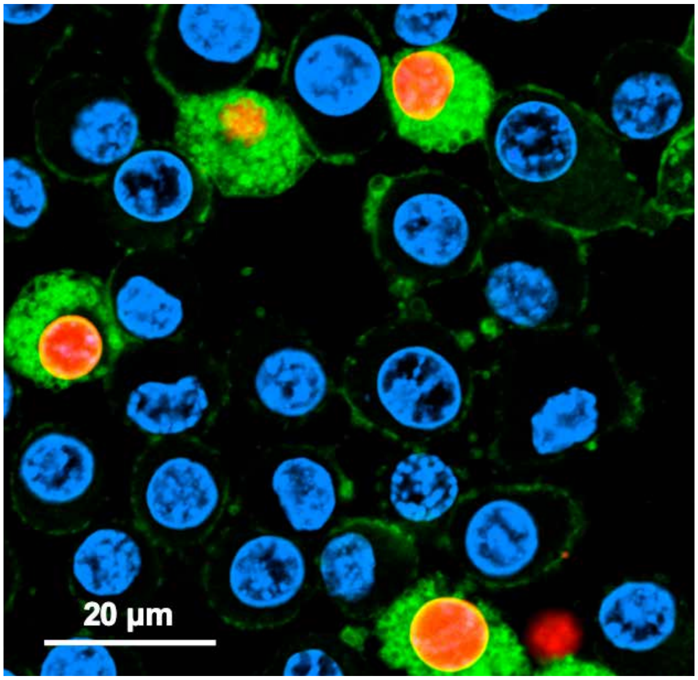
This informed some of the lab's most recent work analyzing what makes leukemias particularly responsive to mitochondrial damage and identifying drug combinations that capitalize on this weakness. Often combinations of drugs that both directly target mitochondria and target other parts of the cell prove to be the most effective. Kirienko has proven adept at developing effective cocktails that capitalize on mitochondrial weakness.

Svetlana Panina, a former postdoctoral researcher in the Kirienko group, worked on combining mitocans (existent mitochondria-targeting cancer drugs) with drugs that use other mechanisms of action (e.g., glycolytic inhibitors). These novel cancer treatments stand out for their ability to leave the majority of normal blood cells healthy — addressing a current major drawback of aggressive cancer treatments like radiation and chemotherapy that also damage healthy cells and tissues, making recovery more challenging.

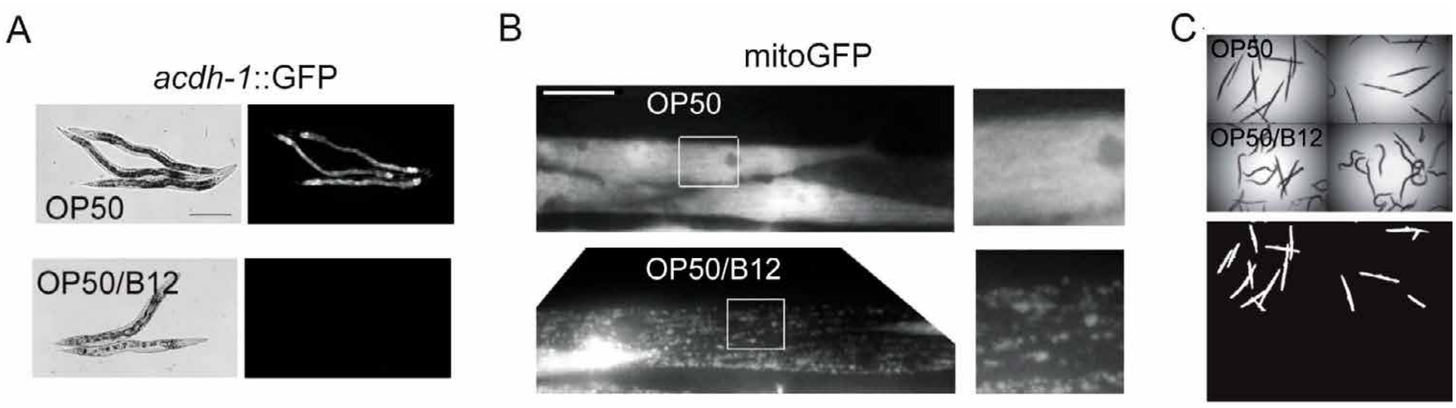
Cancer cells are less likely to replace dysfunctional mitochondria than healthy cells, enabling drug combinations like those being tested in the Kirienko lab to exploit that weakness to trigger cell death. Meanwhile, healthy cells trigger mitochondrial repair pathways, allowing them to survive. This is a major reason that drug treatments targeting the mitochondrial pathways are able to have such high selectivity and spare most healthy cells with functional mitochondria.

Microscope images show acute myeloid leukemia cells before (top) and after (bottom) treatment with a combination of a mitocan cancer drug and a glycolytic inhibitor at concentrations lower than what was necessary to kill healthy cells. Two dyes were used to stain the cells: Blue dye stained all of the cancer cells while a red dye stained only dead cells, which show up as purple in the bottom image.





Above: A confocal micrograph shows prelabeled membrane vesicles from *P. aeruginosa* (green) internalized into macrophages, resulting in cell death (dead cell nuclei labeled red). This work is helping to elucidate how bacteria can evade immune responses during infection. Image credit: Alex Kang



Researchers in the Kirienko lab found vitamin B12 promotes survival during infection by improving mitochondrial health. The expression of a fluorescent protein (top left) reflects buildup of a toxic metabolic product, propionate, in mitochondria on diets low in B12, as compared (bottom left) to those receiving sufficient B12. Mitochondrially targeted fluorescent protein (center) reveals fragmentation of mitochondria when B12 is low, and dead worms stained with fluorescent dye (bottom right) demonstrate the decreased survival rate of worms infected by the pathogen *P. aeruginosa*.

"In this case, we are working to improve mitochondrial health to help fight infections. For the cancer work, we're trying to do the opposite. We want to damage mitochondria in cancer cells to kill them. So, actually, now that we know this is important, it gives us another potential target in cancer cells."

Kirienko remarked that recent drug combinations tested in her lab have killed over 90% of targeted cancer cells, while negatively affecting only 5%-6% of healthy cells. She beamed at the mention of this highly sought-after selectivity, which represents a tremendous stride toward inflicting just enough damage to allow healthy cells to recover while wiping out aberrant ones.

While Kirienko's work offers exciting developments to the field of cancer treatment, she is inspired by what she calls the "translatability of fundamental biological processes." Her newfound understanding of the pathways within mitochondria has also branched off into work with bacterial infections and pathogenesis. Her lab is studying the damage that the bacteria *Pseudomonas aeruginosa* inflict on mitochondria and how stimulation of the natural immune response can improve the chances of host cell survival.

Kirienko and Alexey Revtovich, a post-baccalaureate student initially hired as a technician in her lab, focused on how vitamin B12 levels can increase the survival rate of host cells affected by pathogens. With an estimated 10%-40% of aging U.S. adults deficient in B12, their research could be the key to reducing elderly patients' susceptibility to infection with only a vitamin supplement.

Like humans, *C. elegans* does not produce B12 for itself, but absorbs it through its diet. The team found that without sufficient B12, *C. elegans* is unable to properly metabolize branched chain amino acids, leading to a toxic buildup of byproducts that damage mitochondrial health. Sufficient levels of B12 increase stress tolerance and resistance to pathogens, like *P. aeruginosa*, a potentially deadly disease in worms and humans.

"In this case, we are working to improve mitochondrial health to help fight infections," said Kirienko. "For the cancer work, we're trying to do the opposite. We want to damage mitochondria in cancer cells to kill them. So, actually, now that we know this is important, it gives us another potential target in cancer cells."

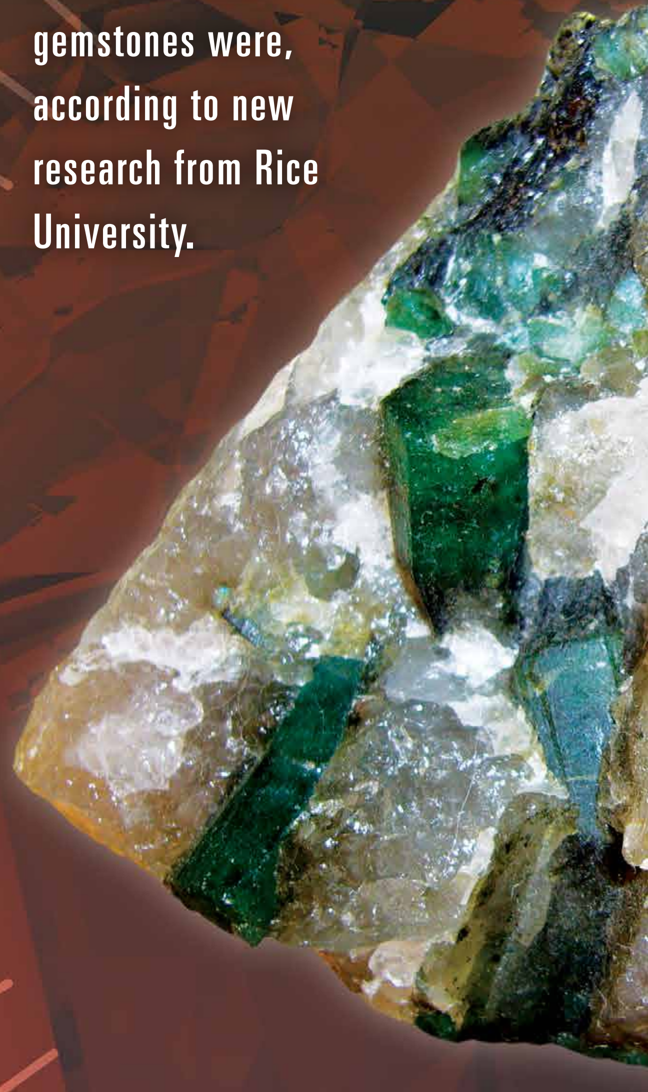
Kirienko's group continues to ask questions that researchers in the field have yet to fully address. "Do the toxins affect mitochondria directly," she asked, "or do they just trigger inflammation and damage mitochondria in a secondary way?"

Developing a complete understanding of mitochondrial pathways and the role they play in the development of disease may be the key to boosting the immune response with medical intervention in novel ways. Backed by decades of studies showing that boosting the innate immune response soon after infection often results in the best outcome for the patient, this can also help to curtail the alarming rate of antibiotic overprescription that has led to deadly antibiotic-resistant bacterial strains.

Interweaving her expertise with *C. elegans* and cancer models with the mitochondrial role in infectious disease, Kirienko continues to inspire each Rice student who enters her lab to see the promise that starts with rethinking the mitochondria, which — harnessed correctly — just might be powerful enough to conquer cancer. ■

EARTH GROWS *Fine Gems* IN MINUTES

Rome wasn't built in a day, but some of Earth's finest gemstones were, according to new research from Rice University.



BY JADE BOYD

Aquamarine, emerald, garnet, zircon and topaz are but a few of the crystalline minerals found mostly in pegmatites, veinlike formations that commonly contain both large crystals and hard-to-find elements like tantalum and niobium. Another common find is lithium, a vital component of electric car batteries.

"This is one step toward understanding how Earth concentrates lithium in certain places and minerals," said Rice graduate student Patrick Phelps. "If we can understand the basics of pegmatite growth rates, it's one step in the direction of understanding the whole picture of how and where they form."

Pegmatites are formed when rising magma cools inside Earth, and they feature some of Earth's largest crystals. South Dakota's Etta mine, for example, features log-sized crystals of lithium-rich spodumene, including one 42 feet in length and weighing an estimated 37 tons. The research by Phelps, Rice's Cin-Ty Lee and Southern California geologist Douglas Morton attempts to answer a question that has long vexed mineralogists: How can such large crystals be in pegmatites?

"In magmatic minerals, crystal size is traditionally linked to cooling time," said Lee, Rice's Harry Carothers Wiess Professor of Geology. "The idea is that large crystals take time to grow."

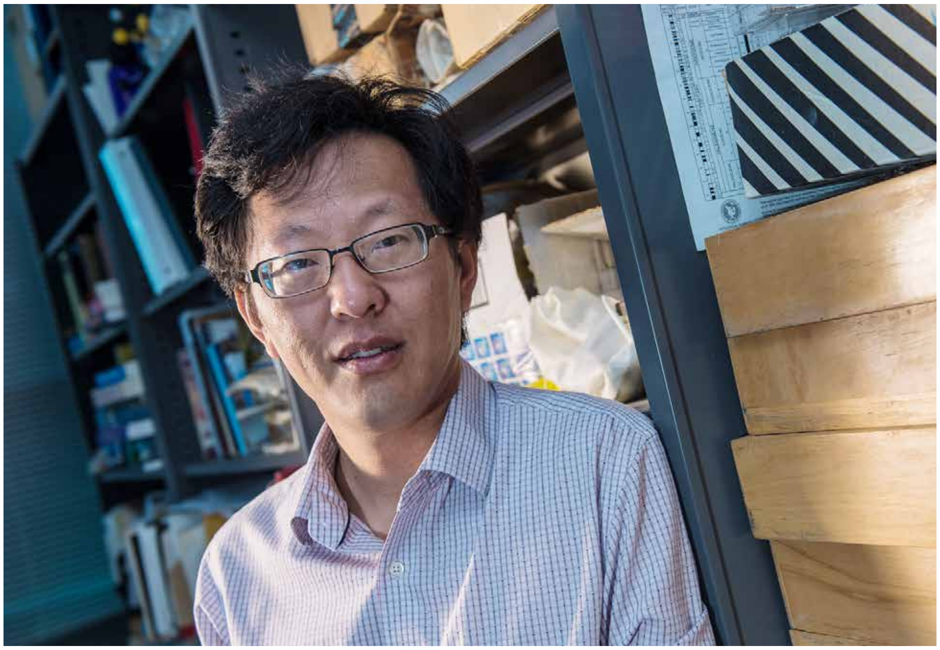
Magma that cools rapidly, like rock in erupted lavas, contains microscopic crystals, for example. But the same magma, if cooled over tens of thousands of years, might feature centimeter-sized crystals, Lee said.

"Pegmatites cool relatively quickly, sometimes in just a few years, and yet they feature some of the largest crystals on Earth," he said. "The big question is really, 'How can that be?'"

When Phelps began the research, his most immediate questions were about how to formulate a set of measurements that would allow him, Lee and Morton to answer the big question.

"It was more a question of, 'Can we figure out how fast they actually grow?'" Phelps said. "Can we use trace elements — elements that don't belong in quartz crystals — to figure out the growth rate?"

It took more than three years, a field trip to gather sample crystals from a pegmatite mine in Southern California, hundreds of lab measurements to precisely map the chemical composition of the samples and a deep dive into some 50-year-old mate-



Cin-Ty Lee

Brazilian emeralds in a quartz-pegmatite matrix. Photo courtesy of Madereugeneandrew/Wikimedia Commons rials science papers to create a mathematical model that could transform the chemical profiles into crystal growth rates.

"We examined crystals that were half an inch wide and over an inch long," Phelps said. "We showed those grew in a matter of hours, and there is nothing to suggest the physics would be different in larger crystals that measure a meter or more in length. Based on what we found, larger crystals like that could grow in a matter of days."

Pegmatites form where pieces of Earth's crust are drawn down and recycled in the planet's molten mantle. Any water that's trapped in the crust becomes part of the melt, and as the melt rises and cools, it gives rise to many kinds of minerals. Each forms and precipitates out of the melt at a characteristic temperature and pressure. But the water remains, making up a progressively higher percentage of the cooling melt.

Rice University graduate student Patrick Phelps used cathodoluminescence microscopy to measure the chemical composition of sample crystals. Image credit: Linda Welzenbach

Black tourmaline going to pink tourmaline within a quartz pegmatite at California's Stewart Lithia mine. Image credit: Patrick Phelps

"Eventually, you get so much water left over that it becomes more of a water-dominated fluid than a melt-dominated fluid," Phelps said. "The leftover elements in this watery mixture can now move around a lot faster. Chemical diffusion rates are much faster in fluids, and the fluids tend to flow more quickly. So when a crystal starts forming, elements can get to it faster, which means it can grow faster."

Crystals are ordered arrangement of atoms. They form when atoms naturally fall into that arranged pattern based on their chemical properties and energy levels. For example, in the mine where Phelps collected his quartz samples, many crystals had formed in what appeared to be cracks that had opened while the pegmatite was still forming.

"You see these pop up and go through the layers of pegmatite itself, almost like veins within veins," Phelps said. "When those cracks opened, that lowered the pressure quickly. So the fluid rushed in, because everything's expanding, and the pressure dropped dramatically. All of a sudden, all the elements in the melt are now confused. They don't want to be in that physical state anymore, and they rapidly start coming together in crystals."

To decipher how quickly the sample crystals grew, Phelps used both cathodoluminescence microscopy and laser ablation with mass spectrometry to measure the precise amount of trace elements that had been incorporated into the crystal matrix at dozens of points during growth. From experimental work done by materials scientists in the mid-20th century, Phelps was able to decipher the growth rates from these profiles.

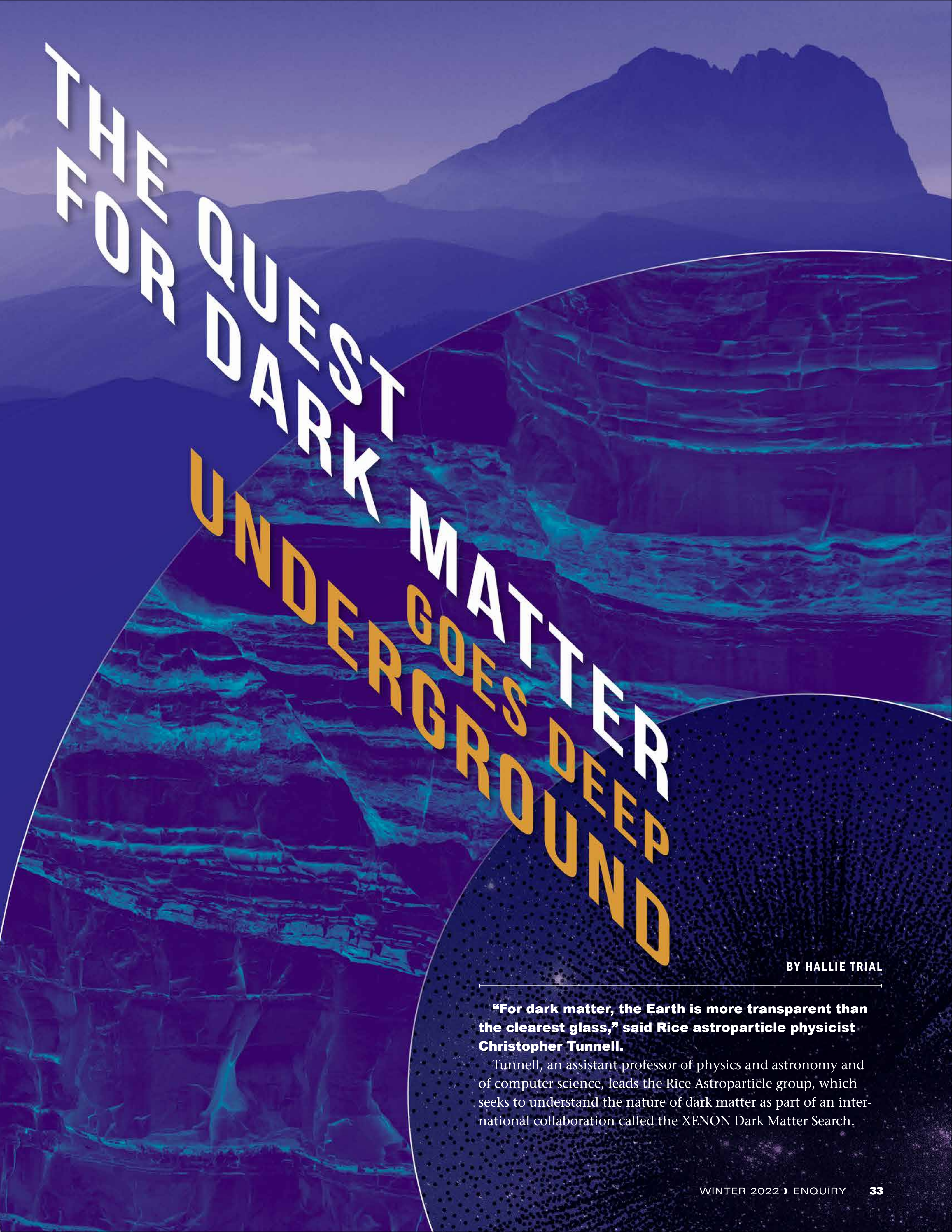
"There are three variables," he said. "There's the likelihood of things getting brought in. That's the partition coefficient. There's how fast the crystal is growing, the growth rate. And then there's the diffusivity, so how quickly elemental nutrients are brought to the crystal."

Phelps said the fast growth rates were quite a surprise.

"Pegmatites are pretty short-lived, so we knew they had to grow relatively fast," he said. "But we were showing it was a few orders of magnitude faster than anyone had predicted.

"When I finally got one of these numbers, I remember going into Cin-Ty's office and saying, 'Is this feasible? I don't think this is right.'" Phelps recalled. "Because in my head, I was still kind of thinking about a thousand-year time scale. And these numbers were meaning days or hours.

"And Cin-Ty said, 'Well, why not? Why can't it be right?'" Phelps said. "Because we'd done the math and the physics. That part was sound. While we didn't expect it to be that fast, we couldn't come up with a reason why it wasn't plausible." ■



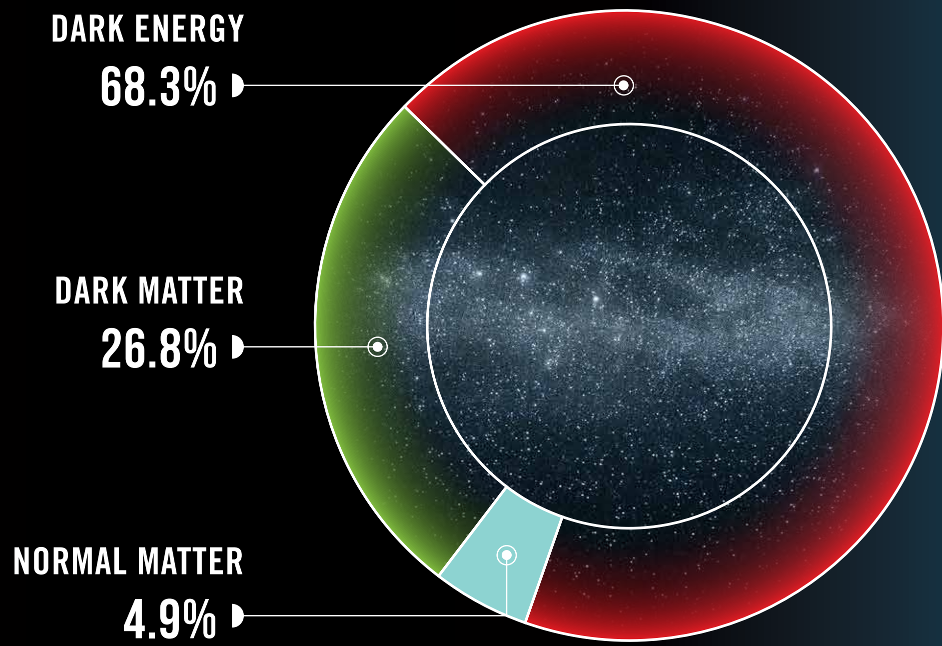
THE QUEST FOR DARK MATTER GOES DEEP UNDERGROUND

BY HALLIE TRIAL

"For dark matter, the Earth is more transparent than the clearest glass," said Rice astroparticle physicist Christopher Tunnell.

Tunnell, an assistant professor of physics and astronomy and of computer science, leads the Rice Astroparticle group, which seeks to understand the nature of dark matter as part of an international collaboration called the XENON Dark Matter Search.

Most of our universe is made up of stuff we can't see. Matter as we know it — all of the planets, stars and galaxies that can be seen — makes up less than 5% of the universe. The rest of the universe is made up of dark energy, an unknown force that causes the accelerating expansion of the universe, and dark matter, which interacts with normal matter only through its gravity. Although we cannot directly observe dark matter, astronomers can observe the gravity of massive galaxy clusters — and their dark matter — bending and distorting the light from distant galaxies located behind them. This phenomenon is called gravitational lensing.



"Dark matter is 'stuff' that only interacts, as far as we have observed so far, gravitationally. So we can't see it; it doesn't interact with light," explained Sophia Farrell, a graduate student in the research group. How do we know it exists, then? Astronomers observe "normal" matter responding to a gravitational pull that can't be explained by matter we can detect, "so we know there's something else out there," said Farrell.

And whatever that something is, there's a lot of it. "There appears to be five times more of this other matter, which we call dark matter, than normal so-called baryonic matter. So the next question is, well, if our whole galaxy is mostly dark matter, what can we say about it?" said Tunnell.

Astronomy is full of "dark" examples of objects being detected initially gravitationally, before follow-up studies understood the objects more. For instance, the planet Neptune was right where French mathematician Urban Le Verrier predicted it would be when German astronomer Johaan Gottfried Galle looked for it. For something we cannot observe directly, dark matter is similarly understood through gravity. Tunnell said, "On the astronomy side, we similarly know how it influenced the early universe and the Big Bang, how it influenced the structure of the universe, and we understand how it influences current observations. What we don't know is what it is."

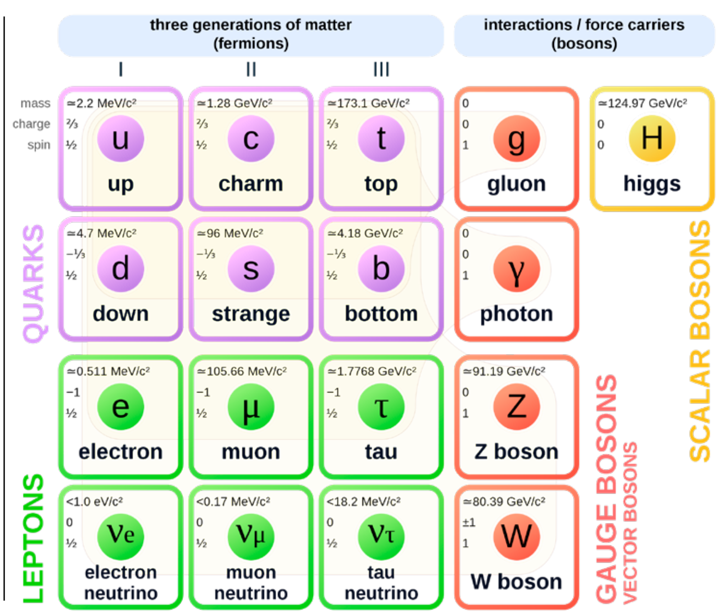
We do know what it isn't: Dark matter does not consist of any of the fundamental particles physicists have discovered. "The periodic table is a catalog of all the elements that we know about. There's an equivalent for particles. Since the '50s, particle physicists have been trying to make an inventory of all the particles we know." The miniscule, chargeless neutrinos might have seemed like good candidates for dark matter particles because of their weak interactions with other matter, but "if dark matter were neutrinos, you wouldn't be able to fit enough in a galaxy to account for the observed mass," said Tunnell.

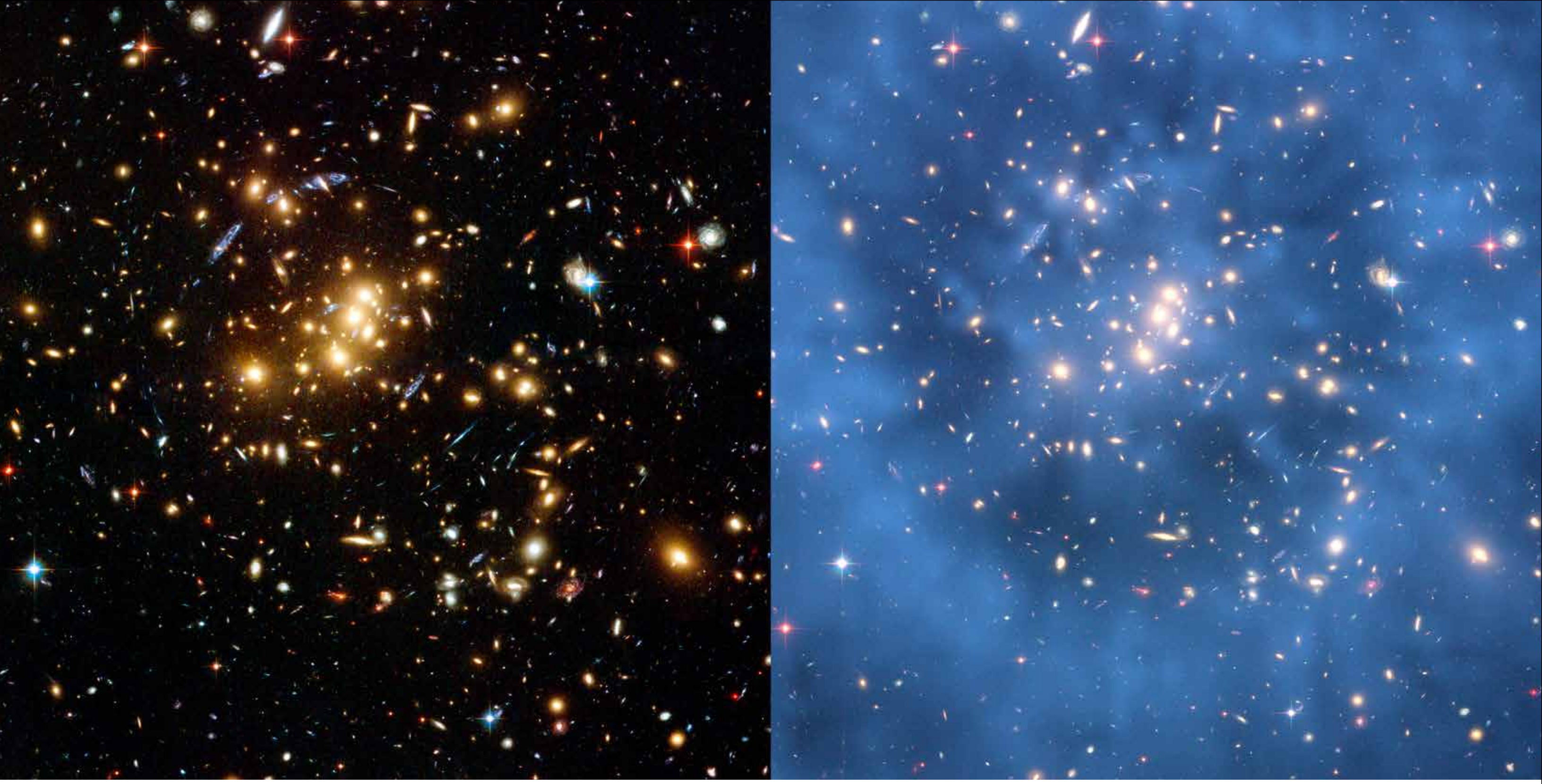
Theoretical physicists have speculated that an as-yet unobserved particle called a Weakly-Interacting Massive Particle, or WIMP, might serve as the building block for dark matter.

"For various theoretical reasons, it would work out really great if this WIMP,

Standard Model of Elementary Particles

The Standard Model of fundamental particles, or the "physicist's periodic table." Elementary particles that we currently know are shown grouped into fermions and bosons. The corresponding antiparticles are not shown here but have the same mass but opposite charge.





Two views from Hubble of the massive galaxy cluster Cl 0024+17 (ZwCl 0024+1652) are shown. To the left is the view in visible light with odd-looking blue arcs appearing among the yellowish galaxies. These are the magnified and distorted images of galaxies located far behind the cluster. Their light is bent and amplified by the immense gravity of the cluster in a process called gravitational lensing. To the right, a blue shading has been added to indicate the location of invisible material called dark matter that is mathematically required to account for the nature and placement of the gravitationally lensed galaxies that are seen. Credits: NASA, ESA, M.J. Jee and H. Ford (Johns Hopkins University)

with a mass of roughly 100 times the mass of a hydrogen atom, existed. It would solve a lot of cosmological mysteries," Farrell said. "Unfortunately, finding it is really difficult because if it interacted with matter strongly, or even kind of strongly, we would have seen it by now, in space and in detector experiments."

Scientists believe, however, that if dark matter particles exist in the way that we understand them, they should be detectable. "Something made dark matter in the early universe, which means that at some point, there was some interaction between dark matter and everything else," said Tunnell. "If dark matter interacted at some point with normal matter, maybe it could do so again. And the reason why we haven't seen this is because it's such a faint signal, such a subtle effect, that only the most sensitive experiments that humankind has ever built could ever observe such an interaction."

Researchers working with the XENON Dark Matter Search have set out to build such sensitive detectors. The series of detectors they have constructed consist of huge vats of liquid xenon buried under a mountain in Italy.

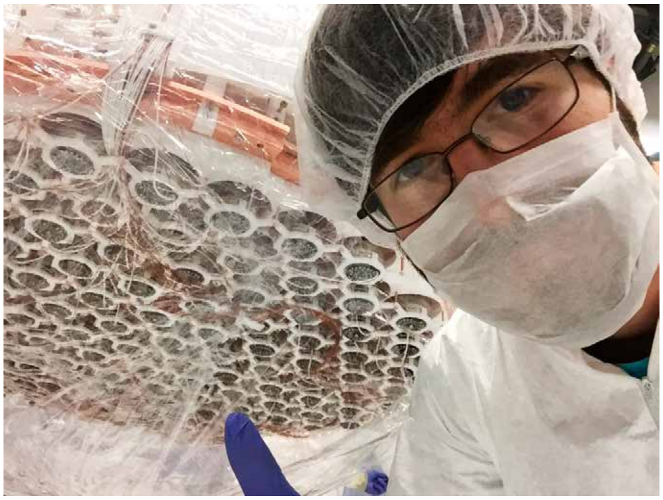
"If you're looking for a very rare signal, you can't have anything else happening in your detector that could be a background," said Tunnell. Signals from processes such as decay of naturally occurring radioactive isotopes and cosmic rays produced in the upper atmosphere would overwhelm the detector and drown out the signs of dark matter interaction. "Just the natural radioactivity within you and me would swamp a lot of these detectors," Tunnell explained.

"If you go underground under a mountain, you reduce the background noise by a factor of a thousand; if you put a water tank around the detector, you get nine orders of magnitude less," Tunnell said. "And then a lot of our experimental design is how we get rid of these last few orders of magnitude." There's a limit to how much radiation the scientists can block, though, because low levels of radioactive decay occur within the walls of the tank holding the xenon.

Scientists chose xenon very deliberately as the material to fill these tanks. "Xenon is self-shielding. Because liquid xenon is very dense, it can stop anything else from penetrating," said Tunnell. This means that the xenon at the edges of the container protect the material at the center from radioactive noise coming from outside the detector. Tunnell continued, "Because xenon is a noble element, you can also purify it quite well." If they chose a less chemically stable element, it could react to form contaminant molecules even after extensive purification.

Xenon also proves ideal for producing the signals that the detectors measure. "What we want to do is measure a particle coming into the center, scattering with a nucleus and then leaving," Tunnell stated. "This nucleus moves and stops, and as it stops, it gives off heat, it creates light, and it generates electrons. As the nucleus is stopping, it's ionizing things in the medium." We call the process that gives off light scintillation, and xenon scintillates very effectively.

The detector has a collection of photomultiplier tubes (248 in the last detector, XENON 1 ton) at the top and bottom of the tank. These tubes can detect single photons of light produced when a nucleus stops moving after a collision. A strong electric field is applied across the tank so that electrons freed during the ionization process move to the top of the tank to produce a second signal detected later.



Christopher Tunnell at the XENON1T experiment in Italy

"You can think of it like a scuba diver with a flashlight," Tunnel said. "The scuba diver is underwater, and they're turning on a flashlight, and simultaneously there are bubbles coming out of their suit. So this light will go more or less instantly through the water, and if you are on top trying to figure out what the scuba diver is doing, you'll see immediately that light, and then shortly after the bubbles will rise to the top."

The XENON detectors work using the same principle. "This type of mechanism where you have two different signals is what we call a time projection chamber," he explained. In the same way that an observer at the water's surface can figure out how deep the scuba diver was based on the time difference between the arrival of the light and the bubbles, physicists can discover where a signal was produced in the chamber by the time difference in the arrival of photons and electrons. Determining the position serves a vital purpose in analyzing the data because signals from the edges of the container are almost certainly noise.

The extreme sensitivity of these detectors has empowered physicists to rule out many theoretical possibilities about dark matter. While they have yet to find definitive evidence of a dark matter particle, this is a discovery in its own right. Each new generation of detector is more sensitive than the last, and when the detector sees no scattering of dark matter particles, this places a new upper limit on the possible strength of interaction between "normal" and dark matter. "We don't get a binary answer of whether there is dark matter or not; the concept of what dark matter is is slowly changing," said Tunnell. "We're really getting to the level of sensitivity now that in the next few years, we're either going to discover dark matter or really require theorists to think long and hard about how to explain observations with some serious revisions to the model."

For example, a concept called supersymmetry seeks to explain the relationship between fermions (matter particles) and bosons (force-carrying particles). Supersymmetry suggests that each particle in the fermion class has a "superpartner" in the boson class whose spin differs from the fermion spin by a half-integer.

"Supersymmetry would have offered various new particle candidates that could have been dark matter," Tunnell said. "Supersymmetry was people's leading idea on how to solve a lot of these big questions in physics, and between CERN and XENON, we've more or less shown that this theory that people were talking about doesn't actually answer the questions as well as we were hoping it would."

While XENON was constructed to search for dark matter particles, its general capacity to pick up weak signals from rare interactions also elucidates many other processes. In spring 2019, the Rice Astroparticle group helped discover the decay of a xenon isotope whose half-life is many orders of magnitude longer than the lifetime of the universe; in other words, observing a decay phenomenon is astronomically improbable under normal circumstances. This isotope, xenon 124, decays by a process known as double electron capture and represents the first known example of this type of nuclear reaction.

Sorting through the data to draw these conclusions "is a needle in a haystack problem, but there's one needle in a haystack the size of Texas," said Tunnell. "This data is coming at you at 500 megabytes per second. We try to do very sophisticated live decisions on the streaming data to determine what we keep and what we throw away. This will get you already down to a much smaller data rate, but you're still at like a petabyte a year." That's 10^15 bytes. You can buy an iPhone 12 with 256 GB of data, and it would take a 30-meter stack of these iPhones to store one petabyte of data.

One of the ways that Tunnell and the students in the Rice Astroparticle group are trying to understand this data is through machine learning. Their task differs from typical applications of machine learning in several ways. "We've done science for a long time, so we typically have pretty good ideas initially of what should be happening in the detector that we can use to inform the data analysis," Tunnell explained. "Whereas if you're analyzing input from a self-driving car, you can't write down a mathematical expression for

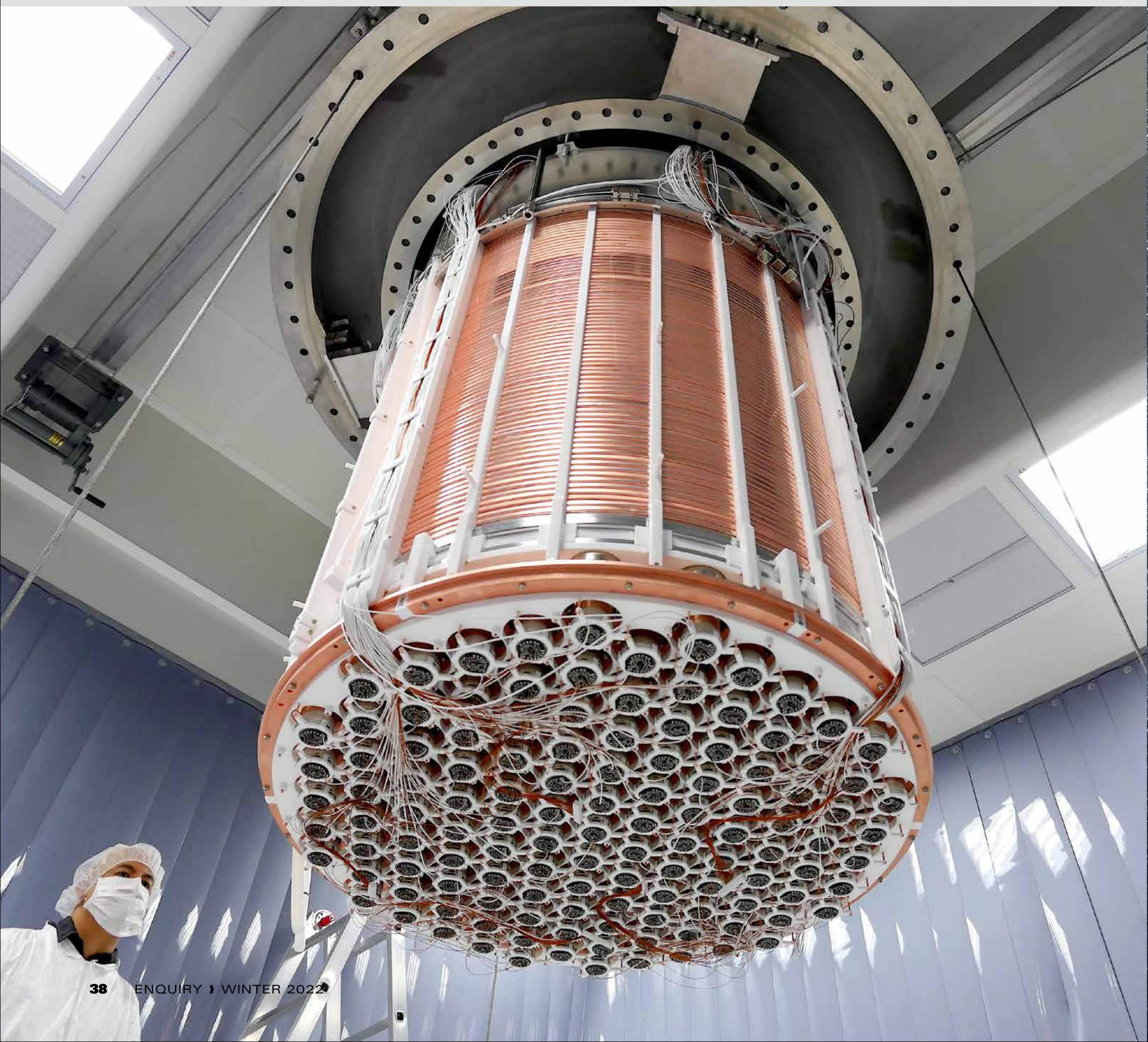
The XENON Experiment underground. On the left is the water tank with a poster showing what is inside. On the right is the three-story service building.

what a stop sign looks like. The machine learning algorithms will learn what a stop sign looks like, whereas we want the algorithms to know beforehand a formula for the theory of stop signs."

Physicists working on the XENON project also deal with miniscule signal-to-noise ratios. "If you have a picture that you're trying to find a stop sign in, it's pretty clear there's a big red stop sign in the middle and then some junk around it. The size of the signal is quite large compared to the size of the background. We're looking for tiny signals buried in a ton of noise instead of signal and noise being comparable," said Tunnell. "If you're actually trying to do something with that, you don't want to be spending all of your time rummaging around this giant haystack; you want to use prior knowledge to help guide you through the search." Tunnell and his students are currently investigating how to effectively encode established physics knowledge into machine learning algorithms.

In doing so, they address sweeping questions with implications far beyond dark matter. Tunnell explained, "We're really having to rethink what measurement means in the computational age. How do we make computational techniques, not just for this dark matter experiment, but for the next century of experiments — experiments in physics, chemistry, biology and other sciences? How do we realize the full impact of machine learning in the physical sciences?" ■

The heart of the XENON1T detector, showing the bottom array of photomultiplier tubes and the copper structure that creates the electric drift field



Tracking Nerve Cells in the Gut Through Development and Disease

The enteric nervous system (ENS) consists of a diversity of neuron subtypes that reside within the walls of every vertebrate organisms' gut. For this reason — and for its ability to operate autonomously in regulating our digestive systems — it has been called both the gut brain and our second brain. Whenever you feel hungry or have a stomachache, it is the ENS that relays that message to the brain.

When compared to our knowledge of the central nervous system, not much is known about the ENS, due in part to the impossibility of monitoring its development in human embryos. As a solution, researchers in the lab of Rosa Uribe, assistant professor of biosciences, have been developing the zebrafish as a model organism for studying the ENS.

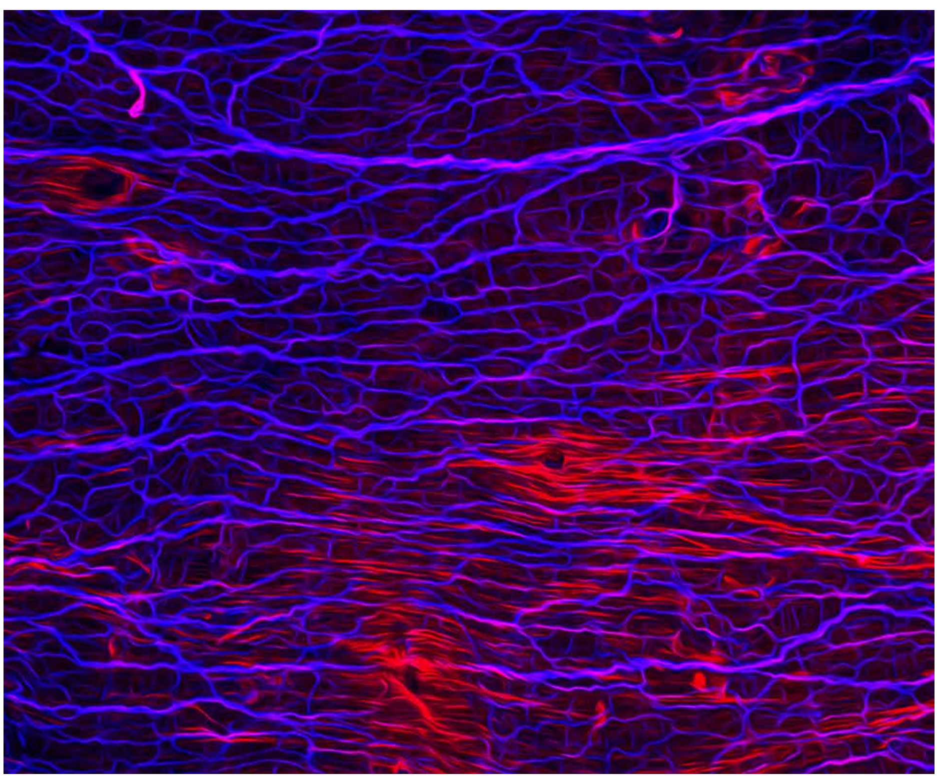
Graduate student Phillip Baker studies the formation of the ENS in zebrafish embryos, something that hasn't been done in an intact, living specimen. "We want to bridge the gap between human and zebrafish enteric nervous systems," he said.

Because they are vertebrates that develop in transparent eggs after fertilization, Baker can use microscopes, computers and cameras to watch as a population of neural stem cells migrates into the gut to form the ENS. Ultimately, he hopes to understand how stem cells proliferate as they differentiate into the cells of the ENS. "I want to know how many times does one cell divide and how does it change as it becomes an immature neuron," he said. Using fluorescent proteins that mark specific cell types, he follows their movements under a microscope and recovers those cells later to see what genes they are expressing.

Recently, the Uribe lab elucidated the presence and organization of glial cells, a nonneuronal cell that provides support and protection for neurons within the context of the gut. By tagging proteins associated with either glia or neurons with fluorescing proteins, they were able to directly view the multicellular structures these ENS cells formed with traditional microscopes and electron microscopy. They found that glial cells associate near neurons in a manner similar to how insulators protect the wires of any electronic appliance: They wrap themselves around and insulate axons, analogous to wires, to allow their electric signals to propagate.

This was not previously known to happen in zebrafish, and proving that this phenomenon was occurring strengthens its case as a model organism. Establishing organisms to easily study previously inaccessible systems is the first step to translate such findings into therapeutic applications. "We are trying to study development and how stem cells are able to form complex neural networks and understand how this goes wrong in disease," Baker said. "Then we can apply that understanding to the treatment of disease and the future of regenerative medicine." ■

— JACOB GOELL



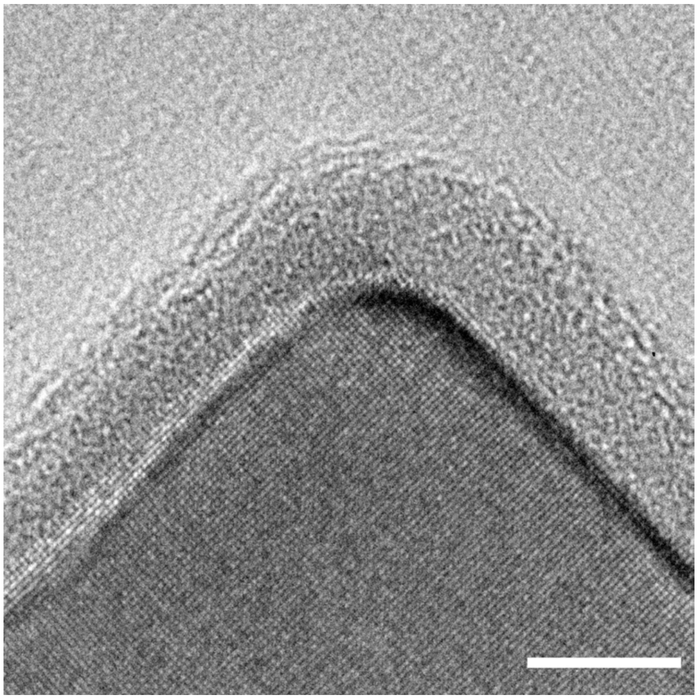
This image of a zebrafish intestine shows neuron (blue) and glial (red) projections labeled with anti-acetylated tubulin and anti-GFAP antibodies. Image credit: Phillip Baker

"We are trying to study development and how stem cells are able to form complex neural networks and understand how this goes wrong in disease."

Enabling Advances in Aluminum Nanoparticle Applications

The first large-scale process for separating aluminum from its ore was so expensive that Emperor Napoleon III is said to have thrown banquets at which only the most important guests had the honor of eating with aluminum cutlery, while others had to make do with silver and gold. Only as aluminum became more affordable could its full potential be realized in applications from aerospace engineering to food packaging.

We may soon experience a similar shift in plasmonic nanoparticle technology, through the efforts of researchers like Benjamin Clark '20, a former chemistry graduate student in the lab of Naomi Halas, the Stanley C. Moore Professor of Electrical and Computer Engineering and professor of chemistry, of bioengineering, of physics and astronomy, and of materials science and nanoengineering.



Through the decomposition of AIH3 with Tebbe's reagent in tetrahydrofuran, members of the Halas lab demonstrated the shape-controlled synthesis of aluminum nanocubes with sharp corners for cost-effective plasmonics. This image depicts the atomic lattice of an aluminum nanocube corner protected by the native aluminum oxide shell. The scale bar is 5 nm. Image credit: Benjamin Clark

Plasmonic nanoparticles exhibit a collective oscillation of their conduction electrons through interaction with the electromagnetic field of light. "This results in strong absorption or light scattering at particular frequencies when there's an oscillation in the electron cloud that matches up with the oscillation of the electric field of the light wave," Clark explained, "and that's called a localized surface plasmon resonance." Because the nanoparticles absorb specific frequencies of light in the visible range, they appear colored. Additionally, the oscillation causes heating on the surface of the nanoparticle.

"If this is supposed to be revolutionary technology, we can't be making it out of super precious, expensive elements."

These unique properties lead to applications as diverse as those of bulk aluminum metal. Medical professionals can inject nanoparticles into a tumor and then excite them with light to kill the tumor cells by heating, while the vibrant colors and optical properties of nanoparticles make them useful for paints, electronic screens and new glass materials.

The problem? "If this is supposed to be revolutionary technology, we can't be making it out of super precious, expensive elements," said Clark. Most nanoparticles are made from silver and gold because of the ease of synthesis. Scientists use aluminum hydrides as the precursors for aluminum nanoparticles, and the air and water sensitivity of these hydrides complicate the production process. "That made it an underexplored research area with lots of opportunities," Clark said.

"Aluminum hydride precursors can thermally decompose into aluminum and hydrogen gas to make nanoparticles, and you can use a catalyst to promote the process," Clark explained. By combining various precursors with different catalysts (or none at all), Clark made aluminum nanoparticles of many different shapes, such as large nanorods, nanocubes and branched nanowires. "If you can control that with chemistry and make particles that have different sizes and shapes, then they have different optical responses," he said, which makes the particles useful for different applications.

Now, Clark works with the company nanoComposix, seeking to industrialize the production of nanoparticles and shift them from the research lab into everyday life. ■

— HALLIE TRIAL

Wave Function-Based Models for Strongly Correlated Electrons

In the context of chemistry, the word “orbital” conjures mental images of the lobes of electrons drawn like clusters of party balloons in introductory chemistry texts. Theoretical chemists and physicists built these orbitals we know and love from mathematical treatments of single electrons that considered the particle and wavelike properties of the system.

Most modern investigations of electronic structure rely on these single electron orbitals as building blocks, combining them into multielectron building blocks called Slater determinants and using these in turn to construct complex molecular orbital wave functions. Traditionally, the set of Slater determinants is generated from a “reference” Slater determinant, which can be considered the zeroth-order description of the system. These models work for most situations, but in systems scientists call strongly correlated, “the results produced by molecular orbital building blocks are not even qualitatively correct,” said chemistry graduate student Rishab Dutta. This is because in order to simplify the computations used to develop molecular orbital theory, theoretical chemists did not explicitly include interactions between individual electrons in the reference Slater determinant. Strong correlation, a phenomenon in which electron-electron interactions are too strong to ignore, occurs in many common chemistry problems like transition metal complexes and breaking of multiple bonds.

Working in the group of Gustavo Scuseria, the Robert A. Welch Professor of Chemistry and professor of physics and astronomy and of materials science and nanoengineering, Dutta focuses on developing building blocks for molecular wave functions that take into account interelectronic interactions: geminal wave functions. “Geminals are building blocks made of two electrons,” explained Dutta. “Pairing interactions become important for strongly correlated systems, so geminal wave functions give us a way of incorporating electron-electron interactions into the building blocks themselves.” Geminal wave functions can be combined into larger building blocks, the simplest of which is called antisymmetric geminal power (AGP) wave functions. As with Slater determinants, more accurate wave functions can be easily built starting from one reference AGP wave function.

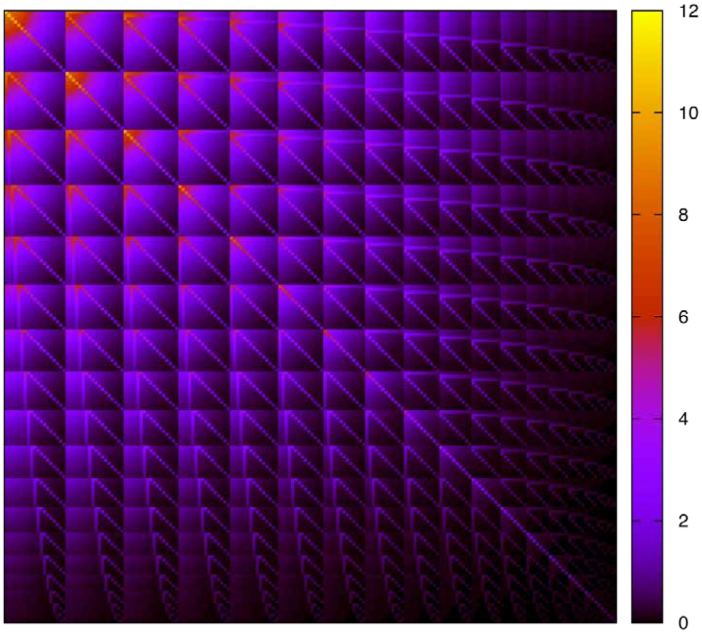
In addition to capturing the physics of strongly correlated systems more accurately, AGP-based wave functions have another advantage over traditional molecular orbital treatments. Unlike molecular orbital wave functions, AGP wave functions overlap with themselves, and the degree of overlap for different parts of the system “naturally describes which orbitals are more important than others,” said Dutta.

Theoretical chemists have explored this concept in the past, but geminal wave functions fell out of vogue because of their computational and algebraic complexity. Specifically, studying these wave functions involves noncommutative algebra, which is algebra in which the commutative property of multiplication does not hold, i.e., a x b is not the same as b x a. Members of the Scuseria group developed an automated noncommutative algebraic system that has facilitated Dutta’s work on geminal wave functions.

“Our work is at the interface of chemistry (systems of interest), physics (quantum mechanics), applied maths (algorithms) and computer science (efficient codes),” said Dutta. In this active interdisciplinary space, even models as firmly entrenched as molecular orbital theory can be rebuilt from the ground up. ■

— HALLIE TRIAL

“Geminals are building blocks made of two electrons. Pairing interactions become important for strongly correlated systems, so geminal wave functions give us a way of incorporating electron-electron interactions into the building blocks themselves.”



A matrix plot of the metric of a correlated wave function based on a geminal-based mean-field reference called AGP (antisymmetric geminal power). Configurations based on this metric have shown good accuracy in describing the important parts of the Hilbert space of a strongly correlated fermionic system with pairing interactions. Image credit: Rishab Dutta

Even 'Goldilocks' Exoplanets Need a Well-Behaved Star

An exoplanet may seem like the perfect spot to set up housekeeping, but before you go there, take a closer look at its star.

Rice University astrophysicists are doing just that — building a computer model to help judge how a star's own atmosphere impacts its planets, for better or worse. By narrowing the conditions for habitability, they hope to refine the search for potentially habitable planets.

Former graduate student Alison Farrish '21 and her research adviser, solar physicist and Rice professor of physics and astronomy David Alexander, led their group's first study to characterize the "space weather" environment of stars other than our own to see how it would affect the magnetic activity around an exoplanet.

"It's impossible with current technology to determine whether an exoplanet has a protective magnetic field or not, so this paper focuses on what is known as the asterospheric magnetic field," Farrish said. "This is the interplanetary extension of the stellar magnetic field with which the exoplanet would interact."

In the study, the researchers expand a magnetic field model that combines what is known about solar magnetic flux transport — the movement of magnetic fields around, through and emanating from the surface of the sun — to a wide range of stars with different levels of magnetic activity. The model is then used to create a simulation of the interplanetary magnetic field surrounding these simulated stars, which can be used to hypothesize the potential environment experienced by exoplanet systems.

"To most people, a 'habitable zone' planet traditionally means it has just the right temperature for liquid water," Farrish said. "But in these specific systems, the planets are so close to their stars that there are other considerations. In particular, the magnetic interaction becomes very important."

These "Goldilocks" planets may enjoy temperatures and atmospheric pressures that allow life-giving water to exist, but they likely orbit too close to their stars to escape the effects of the star's strong magnetic fields and the associated radiation.

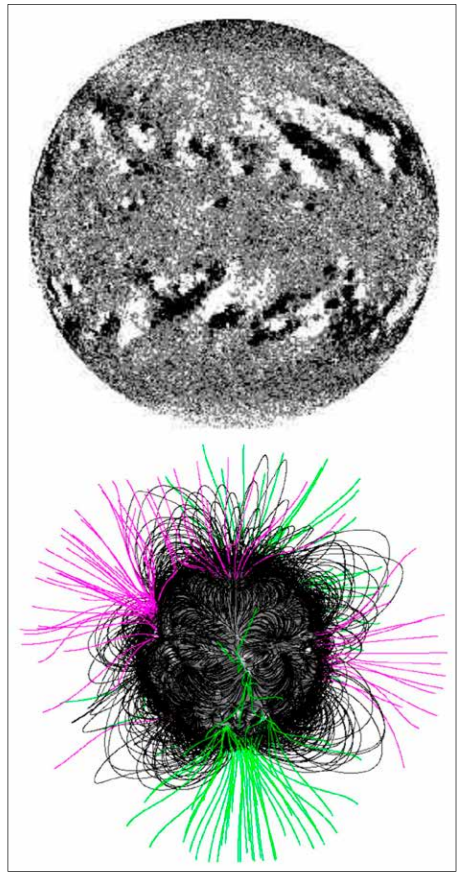
The key parameters in the model are the stellar Rossby number, which defines how active the star is, and the Alfvén surface, which determines where the asterospheric magnetic field effectively decouples from the star.

"All of the planetary systems that people are currently paying a lot of attention to — Ross, Proxima and TRAPPIST — are catching interest because they have planets in their habitable zones, but, based on our calculations, most of them fall within the mean Alfvén surface," Farrish said. "This creates the potential for a direct magnetic connection between the star and the planet which would more strongly drive the loss of the planet's atmosphere."

Farrish and Alexander note that the team found one exceptional system in GJ 3323, an M-dwarf star that contains two "super Earths" discovered in 2017. One, GJ 3323 b, lies within the star's habitable zone but also well within the Alfvén surface. The other, GJ 3323 c, orbits outside the Alfvén surface but unfortunately well outside the habitable zone.

"I'm being cautious to not say there's one system we're all excited about, but having two similar size planets of the same age on either side of the Alfvén surface could prove useful, when observations improve, in exploring how magnetic fields form in exoplanets," Alexander said. ■

— MIKE WILLIAMS



A stellar transport simulation, top, shows positive (white) and negative (black) magnetic polarity on the surface of a star. At bottom, associated coronal magnetic field lines show outward (magenta) and inward (green) lines that extend into interplanetary space, forming the magnetic field of the inner asterosphere, while those in black represent closed lines with ends rooted in the stellar photosphere. Image credit: Alison Farrish

Magnets Delay the Escape of Laser-Cooled Plasma

Graduate students Grant Gorman and MacKenzie Warrens find their work *cool*. Incidentally, cool is also an apt description of their research in the lab of Tom Killian, Rice's E. Dell Butcher Professor of Physics and Astronomy and dean of the Wiess School of Natural Sciences, where they study ultracold systems — those with temperatures about a degree above absolute zero.

Plasma — a state of matter where ionized atoms coexist with their ejected electrons — is traditionally thought of as *hot*, but it is possible to create plasma without going to substantial temperatures and, even better, to generate plasmas at ultracold temperatures.

"To create our plasmas, we use one set of laser beams to cool a cloud of neutral atoms to a few thousandths of a degree above absolute zero. Then a very intense, 10-nanosecond pulse from a different laser knocks an electron off each atom to make an ionized gas. The ions only heat slightly during this process, and the plasmas that we create are extraordinarily cold compared to most plasmas throughout the universe," said Gorman.

At the high temperatures of normal plasmas, positive ions move very quickly and aren't strongly affected by passing near other ions. At ultracold temperature, charged ions in the plasma slow down, allowing for conditions where the Coulomb interaction of neighboring ions is the dominant effect instead of kinetic energy. Understanding the behavior of plasmas in this so-called *strong* coupling regime has long been a focus of the Killian research group.

"Plasmas can be characterized by the degree of Coulomb coupling, which depends on the ratio of the Coulomb energy between neighboring ions and the average thermal energy. Strongly coupled plasmas are found in white dwarf stars or in plasmas created by the interaction of very powerful lasers with solid materials, which are both challenging environments to study. Since we make our plasmas really cold, it allows us to achieve strong coupling despite relatively low densities," said Warrens. At lower densities, the dynamical time scale of phenomena of interest, like wave propagation or equilibration, is longer, making experiments easier.

Recently, the team began studying the effect of magnetic fields on an ultracold neutral plasma (UCNP). Charged particles are deflected when they move through a magnetic field, and this simple phenomenon makes magnetized plasmas much more complicated than unmagnetized ones. "There is a lot we don't understand about how strongly coupled plasmas behave in magnetic fields, and that is what we are studying," said Gorman. "We had to overcome some challenges first, though. We observe the plasma by taking pictures of the ions using laser-induced fluorescence. The presence of spatially varying magnetic fields greatly complicated our use of this probe, and it took more than a year to develop the tools to decouple the effects of the fields from our measurements."

They found that appropriately designed magnetic fields can confine the UCNP for around 0.5 milliseconds, while unmagnetized plasma escapes in a few tens of microseconds. This doesn't sound like much, but that extra delay is very helpful for studying dynamics inside the plasma.

"The nice thing about our system is that we can confine these plasmas in a nice clean lab setting and study the plasmas as they cross field lines," said Warrens. "Now we can observe the fundamental plasma dynamics and test theories that are developed for more complex environments, like plasmas in space." ■

— RISHAB DUTTA

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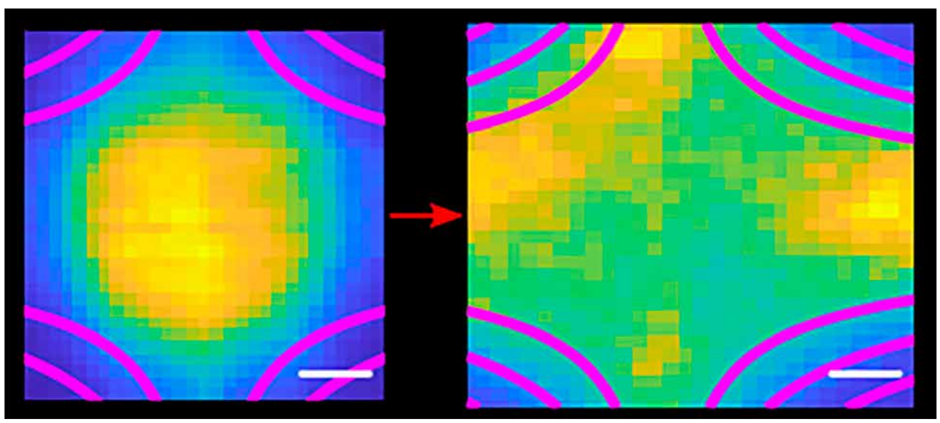


Images produced by laser-induced fluorescence show how a rapidly expanding cloud of ultracold plasma (yellow and gold) behaves when confined by a quadrupole magnet. Ultracold plasmas are created in the center of the chamber (left) and expand rapidly, typically dissipating in a few thousandths of a second. Using strong magnetic fields (pink), Rice University physicists trapped and held ultracold plasmas for several hundredths of a second. Image credit: Killian research group

Coral-Eating Predators May Boost Reef Health by Moving Helper Algae

Graduate students Lauren Howe-Kerr's and Carsten Grupstra's research hours are split between the coral reefs of the French Polynesian island of Mo'orea and the Rice lab of Adrienne Correa, assistant professor of biosciences. Twice each year they travel to Mo'orea to gather samples from coral reefs in order to monitor how reef health has changed over time.

Corals and single-celled algae have a symbiotic relationship. Corals give these symbionts a place to live, and in exchange, symbionts provide corals with nutrients created via photosynthesis. A single coral colony can sometimes be home to several species of symbionts, and coral-symbiont interactions are essential for healthy reef systems. Warming ocean waters cause corals to expel their symbionts, turning them deathly white in coral bleaching events.

In earlier work at the Australian Institute of Marine Science, Howe-Kerr was part of a team that used water tanks to simulate coral environments under stress from rising water temperature, increased acidity and exposure to bacteria. Looking at the community of symbionts in each coral, researchers found that corals with more similar groups of symbionts were more resilient to stress. "In the best-performing corals, we saw a more constrained community that changed very little, no matter which stress they experienced," Howe-Kerr said. "In contrast, the colonies that performed poorly under stress had community characteristics that varied."

This finding is now being tested at a large scale as the team examines French Polynesian corals that survived a 2019 bleaching event. "We are investigating whether the corals that survived the bleaching have similar algal symbiont communities," said Howe-Kerr. Certain types — or combinations — of symbionts may help reefs survive stressors.

In thinking about ways that algae might be distributed on reefs, the team focused on a surprising candidate: coral predators. "Most of them take small bites of adult corals and don't kill the colonies they're eating," said Grupstra. As butterflies and bees move pollen from flower to flower, predator fish eat healthy corals — and their symbionts — and excrete them as they swim over the reef, potentially delivering a dose of algae "medicine" to stressed corals.

To examine the role of coral predators in dispersing symbionts, Grupstra and Howe-Kerr collected fecal samples from seven fish species that eat different amounts of live coral tissue. High concentrations of live coral symbionts were present in feces collected from this diverse group of predator fish — even after passing through their digestive tracts. In fact, the team estimates that, in 100 square meters of reef, some fish species excrete around 1 billion live symbionts daily, supporting the idea that predator fish may play an important role in spreading beneficial algal symbionts across reef systems.

As bleaching events become more common, innovative solutions may help corals become more resistant to the effects of climate change. "We don't really know all of the interactions that are happening on coral reefs," Grupstra said. "Some species may be important for coral reef conservation in ways that we haven't imagined." ■

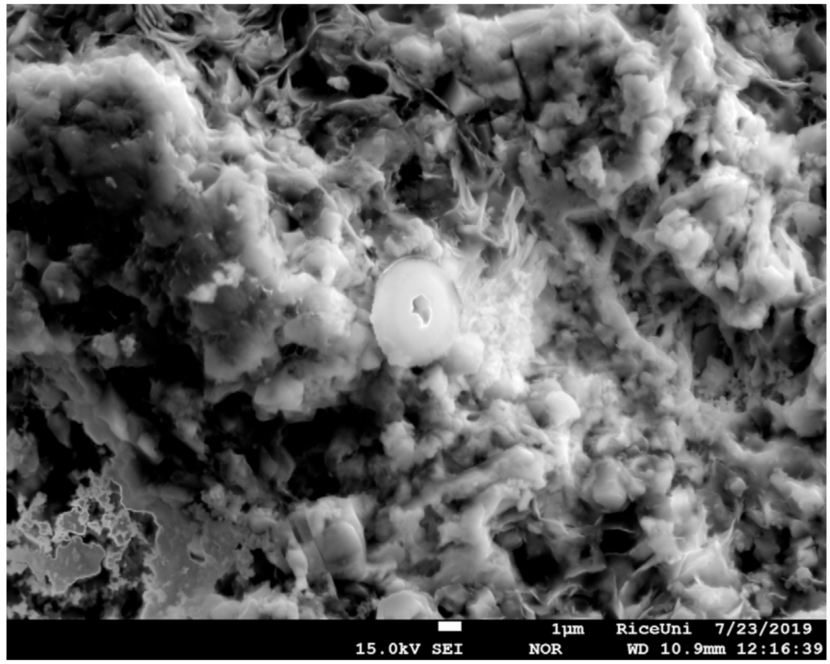
—HENRY BARING

Coral-eating fish such as the Pacific double-saddled butterflyfish (pictured) may help corals recover from coral bleaching. Members of the Correa group characterized for the first time the diversity and overall number of microalgae that are being defecated by butterflyfish directly onto bleached corals, providing insight into the role that reacquiring microalgae plays in coral recovery from bleaching. Image credit: Carsten Grupstra

Getting a Closer Look at the Ocean Floor

Have you ever wondered how we can know what the climate of our planet has looked like throughout history? Paleoceanographers like Debadrita Jana, a graduate student in the lab of Mark Torres, an assistant professor of Earth, environmental and planetary sciences, use ocean floor sediments, lake floor sediments and coral reefs as proxies to help inform our understanding of past climates. Specifically, researchers examine the ratios of stable elemental isotopes in sediment samples to understand historical variations in temperatures and other large-scale events.

Recently, Jana undertook a research project focused on using ocean floor sediments to infer past climate conditions and to determine whether measurements of bulk sediment are appropriate — or if a closer look is necessary for a complete understanding of what the ocean floors can tell us about the climate of the past.



A scanning electron microscope photomicrograph shows a coccolithophorid exoskeleton nannofossil found in shallow marine sediment. This small exoskeleton contains specific isotopic information about the climate in the region at the time the organism was alive. Image credit: Debadrita Jana

Foraminifera are microscopic organisms that live at the surface of the ocean, within the water column or at the ocean floor. They possess carbonate exoskeletons, or tests, which deposit on the ocean floor once the organism dies. These tests store a record of the ratios of stable oxygen and carbon isotopes that existed in the ocean during the plankton's life.

Recovering these old exoskeletons through ocean drilling expeditions and measuring their oxygen isotopic ratios can be done to inform the temperature at the time of deposition. Typically, higher ratios of the heavier to the lighter isotope of oxygen indicates colder temperatures. Changes in the isotopic ratios of carbon indicate a change in the global carbon cycle, which is typically related to some significant change in climate.

Many scientists have relied on measurements of multiple individuals to make interpretations about past climate and oceanographic conditions. Jana is primarily interested in the questions that examine how the final measurement is influenced by variations within each individual's test. "What does the number that we get by measuring a batch of foraminifera mean?" she asked. "Is it an appropriate proxy? Do the individual foraminifera tell a more detailed story?

"For example, the isotope signal can be influenced by variable transport and alteration of individual shells," she explained, "but by considering individuals on their own, we can account for variations — or at least be aware of the possible complications that go hand in hand with interpreting these kinds of data."

Even more exciting, perhaps, is the answer to the question, "How do these relationships correlate between different regions and different times?" Each sample can be placed according to its time of deposition through knowledge of the samples' depth and various time-specific events observed in nearby sediment, including fossil records and records of the magnetic poles flipping. Combining these analyses for each sample allows a more complete picture of how the different regions of the ocean and the climate have changed throughout the history of our planet.

As Jana said, "Geologists believe that the present is the key to the past. But the past is also the key to the present." And as we begin to understand more about the ocean and how ocean life is changing, she said, "I have my small part of the story to add." ■

— **DOUGLAS WALKER**

Knowledge of a Knot

In mathematics, there is a long-standing joke that topologists cannot differentiate between a donut and a coffee mug. At first glance, the two objects look strikingly different. But, if a coffee mug is made out of material that can stretch, it can be deformed until it is a donut. For topologists who study fundamental characteristics not altered by stretching, pulling or twisting, it makes sense that these two objects would resemble each other.

Topology and knot theory, which is the fundamental question of topologically unique knots, are central ideas behind the research of Allison Miller, previously a G.C. Evans Instructor in Rice's Department of Mathematics. Miller, now an assistant professor at Swarthmore College, first began her journey with knot theory as an undergraduate and became involved in topology research in graduate school.

According to Miller, a foundational question of knot theory is: "If you are given the picture of two knots, can you tell if they are the same? If they are the same, hopefully you can wiggle one around until it becomes the other one. If they aren't the same, then you will never be able to create the other one. You want to prove that the two are different."

3D knots are created by taking a string, creating crossings and then fusing the ends together to form a closed loop. The simplest 3D knot is the "unknot," a closed loop without a knot tied in it that is the boundary of a disk in 3D space. 3D knots that are boundaries of a disk in 4D space are called 4D trivial. Miller uses knot theory to build mathematical tools to investigate the 4D topology of specific knots.

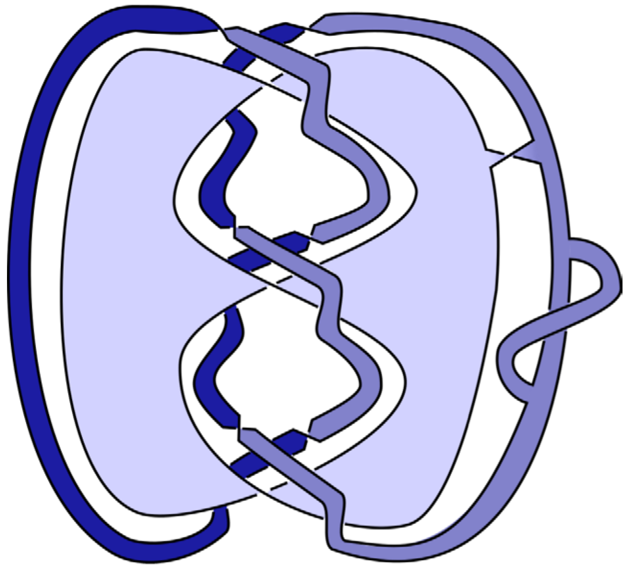
She is working on understanding the behavior of knots under the satellite operation, which is a way of combining two knots to get a third knot. She is studying a knotted surface in 3D space whose boundary is the satellite knot obtained by combining the unknot and the left-handed trefoil knot — the simplest knot that can't be untied to the unknot without cutting it.

The 4D properties of this knot are currently not well understood, but Miller has found some characteristics of the left-handed trefoil knot that have carried over to this satellite knot. However, the characteristics of the trefoil knot aren't concrete enough in this knotted surface to confidently classify it as a left-handed trefoil knot. Miller says that she'll continue to work on this knot as new mathematical tools arise, which could potentially help her further dissect this knot and understand its 4D characteristics.

While the applications of Miller's research are unknown right now, research in mathematics often finds unexpected uses in the future. As she said, "Mathematics has this philosophy that current research eventually will yield applications and directly impact people's lives in ways we can't foresee at the moment." ■

— AKSHAYA VENKATESH

"If you are given the picture of two knots, can you tell if they are the same? If they are the same, hopefully you can wiggle one around until it becomes the other one. If they aren't the same, then you will never be able to create the other one. You want to prove that the two are different."



This image depicts a knotted surface in 3D space whose boundary is the satellite knot obtained by combining a pattern with the left-handed trefoil knot. The 4D properties of this knot are currently not well understood. Image credit: Allison Miller

Characterizing Oak Gall Communities

"I'm just that guy who likes bugs," said Charles Davis '20. "By far, my favorite class was insect biology. I still have my insect collection from that class, and that's one of the things that will definitely remind me of my time at Rice."

Naturally, Davis' senior undergraduate research project also focused on insects that can be found on campus: gall wasps. Working in the lab of Scott Egan, associate professor of ecology and evolutionary biology, Davis studied wasp-induced galls found on live oak trees and the hyperdiverse insect communities that live within them.

Galls are benign, tumorlike growths on plants caused by many types of organisms, including gall wasps. The gall offers a cozy home for the gall formers, providing nutrients and protection to wasp larvae as they develop within. Gall wasps may trigger gall development, but many other insects also take advantage of the gall's protective environment. "Galls support a wide array of different organisms and create this very diverse ecosystem that you wouldn't really expect to see at first glance," said Davis.

Compared to many other types of galls, those formed by gall wasps are more complex structurally. Each species of gall wasp induces a unique gall structure that may consist of a single chamber or multiple chambers. Davis wanted to know how differences in gall structure impact the communities of organisms living within. "For example, large, multichambered galls have a lot of material available for consumption," he said. "They may house a large number of organisms."

Eight gall wasp species can be found on two live oak species across the southeastern United States, but it is unclear how the communities found within their galls overlap. Davis chose to focus his study on two types of live oak galls — the multichambered woody branch galls (*Callirhytis quercusbatatoides*) and the single-chambered fuzzy leaf galls (*Andricus quercusfoliatus*) — using morphology and genetic sequencing to describe the communities of organisms found within each. "Characterizing the natural enemy communities for each species will provide insight into the complex food webs associated with these wasps," Davis explained.

In order to describe the communities, Davis analyzed 2,497 insects reared in both types of galls, using morphology and genetic markers to draw species distinctions. The work to distinguish species can be complex and time-consuming. Individuals within a single species can exhibit widely varying morphologies, and different sexes within a species can differ so greatly in appearance that they seem to be different species. Genetic analysis can be used to group different morphospecies together as a single species.

Davis identified 64 species within the gall study systems, some of which had never been described before. "Based on morphology, we found 64 species — 31 from the fuzzy leaf galls and a little more than 33 from the woody branch galls — with eight species potentially shared across both types of galls," said Davis. "There was not as much overlap between the species found in the two types of galls as I expected, but the most abundant genera are shared between both galls."

Davis' senior thesis research contributes to ongoing efforts in the Egan lab to understand the arthropod communities associated with different galls on live oaks. With a more complete picture of all the members in the live oak gall community, these biologists aim to reveal the ecological and evolutionary processes that make the gall system so diverse. ■

— **LAUREN KAPCHA**

Davis is now attending graduate school at Penn State University, working toward a Ph.D. in entomology.

Charles Davis '20

Envisioning an Effective Therapy Future for Eye Diseases

Megan Shen ’20

Every year, about 28,000 babies are born prematurely in the United States, approximately half of whom have some degree of the eye disorder retinopathy of prematurity (ROP). Many of these infants with ROP spontaneously recover on their own, but others develop complications, including lifelong vision impairment and blindness, with 400–600 of these infants becoming legally blind due to their ROP.

Existing treatments, which include laser therapy and cryotherapy, may reverse or slow the development of abnormal growth of the blood vessels associated with ROP. Yet in the process, they can destroy healthy retinas, leading to some vision loss in the areas treated. It was the desire to address these adverse effects that led Rice undergraduate Megan Shen ’20 to join Yingbin Fu’s lab in the Department of Ophthalmology at Baylor College of Medicine, which specializes in retinal degenerative diseases.

Shen joined the lab as a freshman, and throughout her time in the lab, she worked with mouse models that replicate diseases, tested different possible treatments, and investigated the mechanisms and signaling for different pathologies, especially ROP.

Shen explained that ROP manifests in premature infants as their immature retinas suffer damage to their vessels when exposed to relatively higher oxygen conditions. Subsequently, there is a lack of vessel growth throughout the retina, which the body attempts to compensate for by secreting growth factors. “This overdose of growth factors can cause new vessels to grow too quickly,” Shen said. “When the vessels grow too fast, they become leaky and grow into wrong places, which can cause serious problems with your vision.”

Shen used the mouse models to study these issues faced by premature infants with ROP. Mice are born with immature retinas, and when mouse pups are put into high-oxygen chambers, they experience damage similar to that of premature infants with ROPs. Staining for endothelial cells lining the surface of blood vessels allows researchers to assess damage to their vessels. In fact, by analyzing and quantifying these neovascular areas, researchers can gauge the severity of the disease phenotype.

Changes or abnormalities in the retina are especially noticeable at its center. A normal central retina is covered in blood vessels as the mouse develops, but, according to Shen, high oxygen levels in the chamber lead to vessel loss in the central regions of the retina. Further, observations of the retina flat mounts suggest that the expression of certain genes can influence the recovery process. Through these retina flat mounts, which display the severity of the disease phenotype at different time points, the research team studied how these processes or pathways might promote faster growth of healthy, normal vessels rather than pathological, leaky ones. “Modulating the activity of this gene or pathway might be a potential target to guide the development of different treatments, such as with antibody or protein injections, which will be superior to the current laser therapy and cryotherapy,” Shen said.

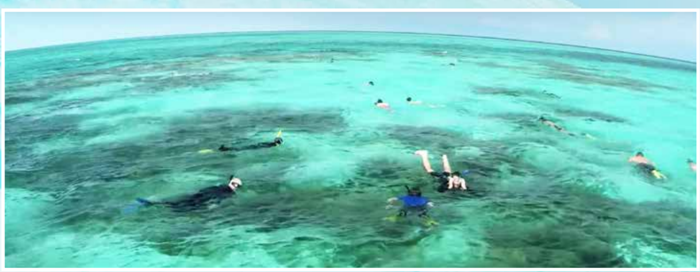
Though her journey in the lab can be described as nothing other than successful, Shen named her failures as the most rewarding part of her research experience. Excitedly she stated that it is all about “so much trial and error, trying to troubleshoot, and having to address problems you hadn’t expected.” When asked about the beautiful image of the retina she presented, featured on the front cover, Shen recalled the extensive process to isolate and then flat-mount it successfully. Recalling all of the modifications to the procedure she employed to perfect the protocol, she described the process of obtaining such an impeccable image as “one of the things I am most proud of doing in the lab.” ■

— MAGGY NINO

PATHWAYS TO DISCOVERY







The Pathways to Discovery program in the Wiess School of Natural Sciences aims to give all natural sciences undergraduate and graduate students the opportunity to develop the skills they need to become the scientific leaders and decision-makers of tomorrow. Events and resources are designed to provide students with personalized academic advising, strengthen bonds between natural sciences students and faculty, engage undergraduate students in research across all disciplines, expose students to the full range of career opportunities accessible to natural sciences graduates and connect students to the Houston community.

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IMAGE CREDIT: HENRY BARING

Campus Garden Hosts First In-Person Event in a Year

The Betty and Jacob Friedman Holistic Garden provided the perfect setting for the Wiess School of Natural Science's first in-person, near-normal event in more than a year. In May 2021, director Joe Novak, garden manager Jade Hagan and several student volunteers provided a small number of guests with tours of garden highlights — a variety of garden beds, rainwater harvesting and composting systems, an outdoor kitchen, a pollinator garden and a chicken coop.

Built in 2018, the 2.5-acre garden is a part of the Department of BioSciences at Rice University and is nearly four times larger than previous Rice gardens combined. With a mission to promote and educate, the garden serves the Houston community, including Rice students enrolled in the community garden course, student clubs, garden volunteers, the University of Texas School of Public Health, schools, nonprofits and anyone who has an interest in horticulture. ■

— LAUREN KAPCHA