

SPECTRUM

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

INSTANT OF DISCOVERY

THE BRILLIANCE OF BASIC RESEARCH

SPRING 2014



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THE MIT SPECTRUM

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BASIC RESEARCH AT MIT

What single factor mattered most in MIT's transformation from an excellent science-grounded technical training school into a leading university with global impact? I believe it was the insistence of MIT's 9th president, Karl Taylor Compton (1930-1948), that the Institute dramatically expand its fundamental scientific research. Thanks to his vision, at MIT, science and engineering are equal partners in progress.

Today, basic research serves as our foundation and inspiration. The drive for discovery is inherently valuable, of course; there may be no higher expression of human achievement than the passion for understanding how the world works. This issue of *SPECTRVM* presents an extraordinary range of research explorations, from the cosmos to the climate, from energy to oceans, from the frontiers of new materials to subjects as ancient as war. (One exciting development since Compton's time has been the growth at MIT of fundamental research outside the sciences.)

On this campus, there is no currency more precious than a striking set of research results. But we also value research as a process, as an essential aspect of how we teach our students. In President Compton's day, MIT had a few hundred graduate students. Today, our 6,700 graduate students and hundreds of post-doctoral researchers constitute a major force in our pursuit of knowledge and solutions. And, through our Undergraduate Research Opportunities Program (UROP), more than 85% of MIT undergraduates participate in frontline faculty research before they graduate. When students tackle the practical challenges of exploration, experimentation, and discovery, they engage in a powerful form of "learning by doing"—and they experience a distinctive part of what it means to be educated at MIT.

At an institution so focused on inventing the future, we also know that fundamental research is the deep source of the most important and lasting new ideas. This issue of *SPECTRVM* highlights the work of several scientists whose groundbreaking research contained the seeds of profound innovations, from GPS to drugs for fighting cancer. By turning scientific breakthroughs into job-rich companies, our graduates also serve the world.

At MIT, we advance human knowledge through basic research every day. But in an era of shrinking federal funding, the future of fundamental research is far from guaranteed. Investing in basic research is investing in our future. It is up to us who understand its value to make the case for its lasting importance to society as a whole.

Sincerely,

L. Rafael Reif



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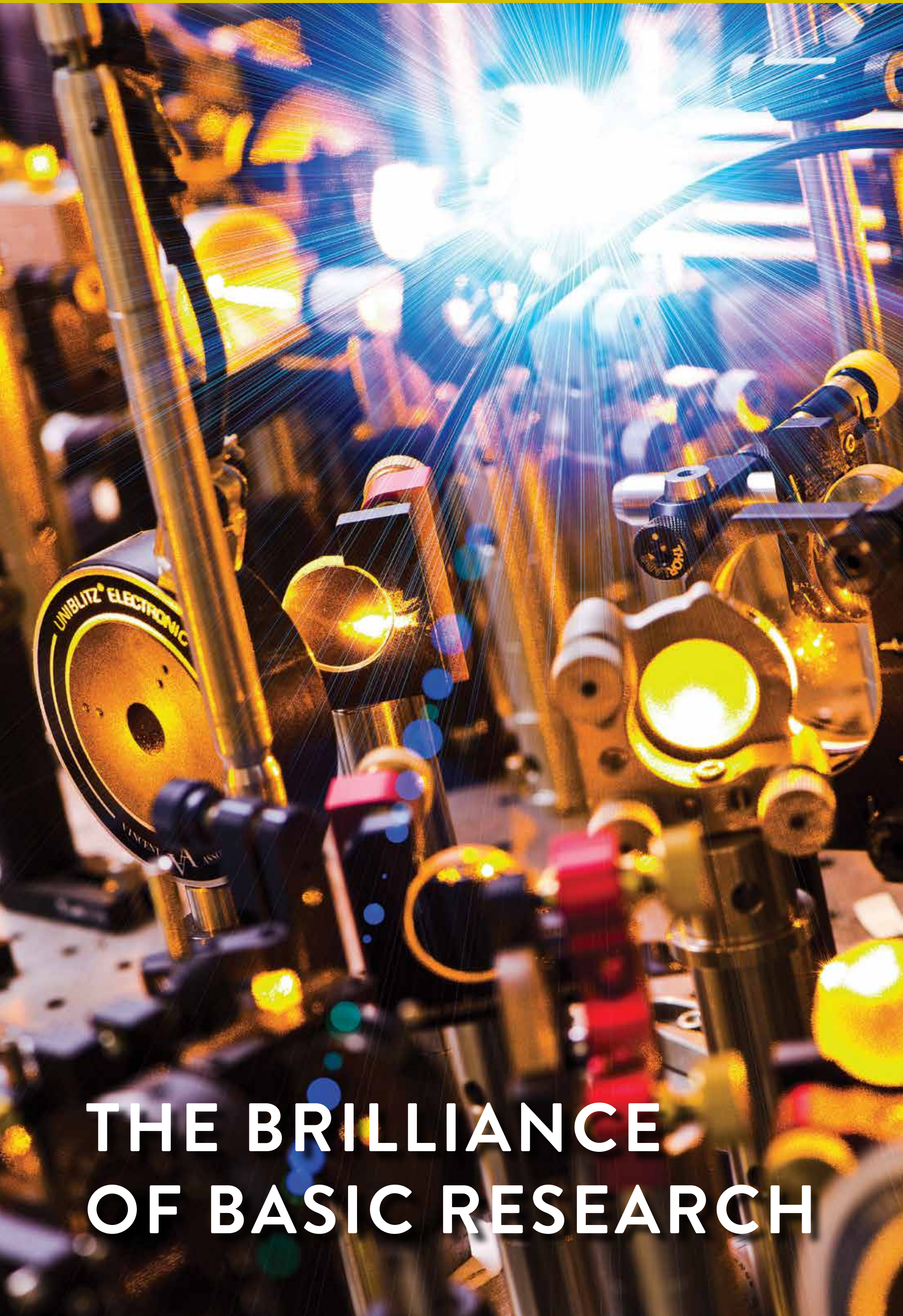
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THE BRILLIANCE OF BASIC RESEARCH

“I wasn’t dreaming of developing the GPS,” says Prof. Emeritus Dan Kleppner, who in 1960 helped invent the hydrogen maser, an atomic clock that’s now at the heart of satellite-based global positioning systems.

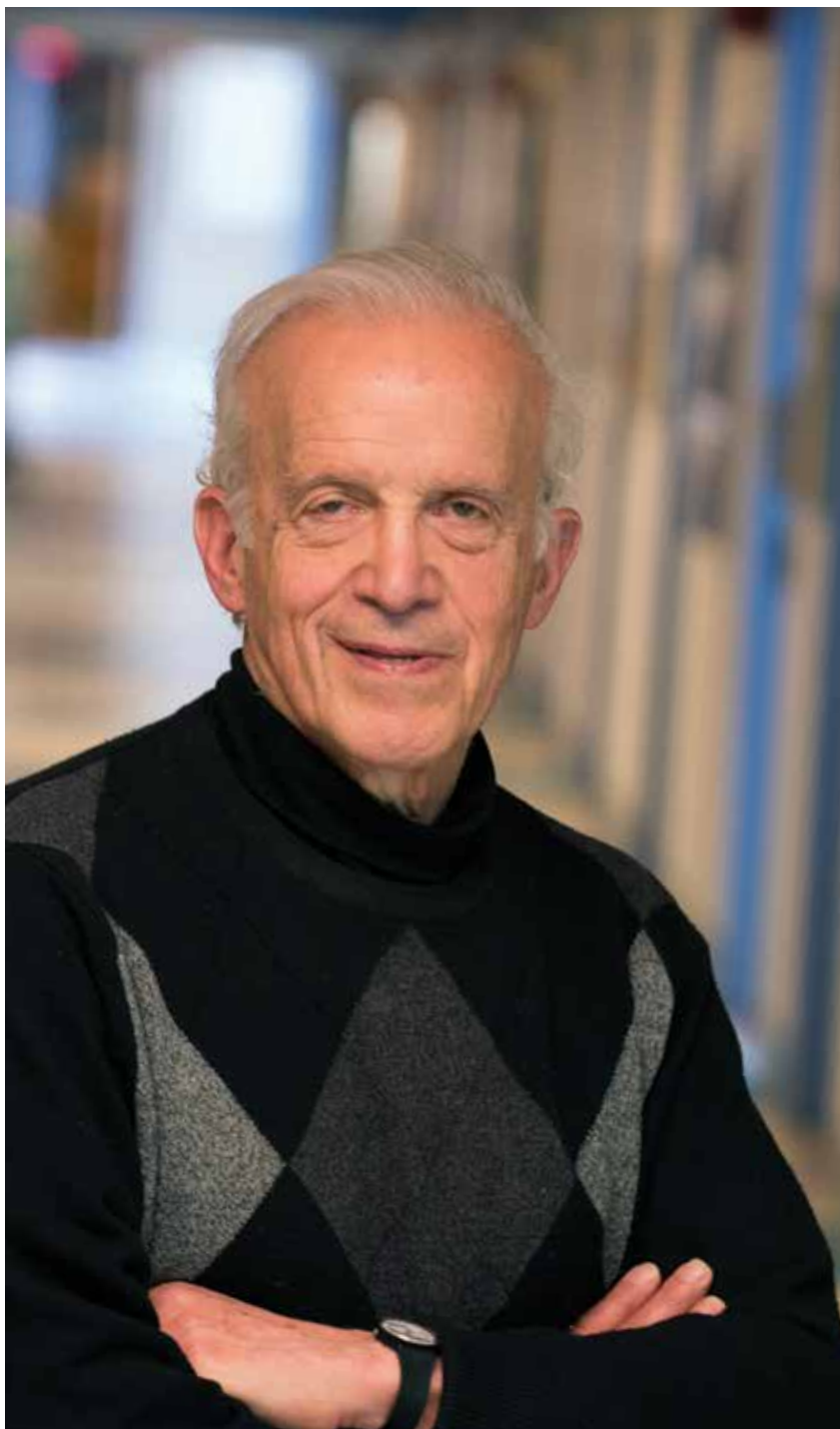
“With basic research, you don’t begin to recognize the applications until the discoveries are in hand,” he says. “In my view, basic science is the best thing that mankind pursues—not so much because it leads to new applications but because it leads to new understanding. For me, there’s no greater pleasure than the joy of discovery.”

This excitement abounds at MIT. Basic research has led to discovery of the first human cancer gene; the first experimental confirmation of the existence of the quark; the first chemical synthesis of penicillin; and the discovery of *Prochlorococcus*, the most abundant photosynthetic species on Earth.

An astonishing range of basic research is now underway. In nearly every field, MIT has experts at the frontier. Consider Nobel Laureate Bob Horvitz, who discovered that there are specific genes that determine cell death. Today this discovery is revealing new therapies to treat cancer, Alzheimer’s, and Parkinson’s disease. Or consider Janet Conrad, whose investigations of the physics of neutrinos are changing the way we understand matter. In the late 1990s, we learned that these elusive particles have mass, the most shocking surprise in particle physics in the past 40 years.

Each year, 3,500 research scientists and visiting faculty work on projects with faculty and students; thousands of graduate students conduct research to become leaders in their fields; and nine out of 10 undergraduate students participate in UROP, MIT’s flagship Undergraduate Research Opportunities Program, which matches students with faculty in research partnerships. Like faculty, students publish in scholarly journals, present at professional conferences, make policy recommendations, and release their discoveries into the world.

Basic research is the bedrock of MIT—and the foundation for tomorrow.



Dan Kleppner invented an atomic clock now at the heart of the GPS.



Ram Sasisekharan holds 85 patents and launched three biotech companies.

Why Basic Research?

Why pursue basic research simply for the sake of curiosity, discovery, knowledge, when applied research specifically tackles the world’s biggest problems—poverty, energy, disease, or building new businesses to boost the economy? Faculty say it’s because basic research is the process of creation, and without it, applications vanish.

“People think of basic and applied research as separate, but it’s an extremely important mix,” says Ram Sasisekharan, professor of biological engineering whose research on complex sugars has led to a cascade of potential medical applications that could significantly improve outcomes for patients with cancer and infectious diseases. “Often basic science fuels the applications in a much more profound way,” he says. “To have a higher probability of success in the applied arena, it’s extremely important to be well-grounded in the basic mechanism of the targets we’re after.”

Richard Schrock, the Frederick G. Keyes Professor of Chemistry who won the Nobel Prize in 2005, says: “I got here by doing basic research.” By following his curiosity, he says, he developed the catalysts for the chemical reaction now used every day for the green production of pharmaceuticals, fuels, and other synthetic chemicals.

“The value of basic research is you discover something you didn’t expect — that nobody expected. And it’s where almost everything we now expect came from,” he says. “My work had applications. I just didn’t know it at the time.”

“We came up with a great technology, but the whole MIT ecosystem is responsible for our success.”

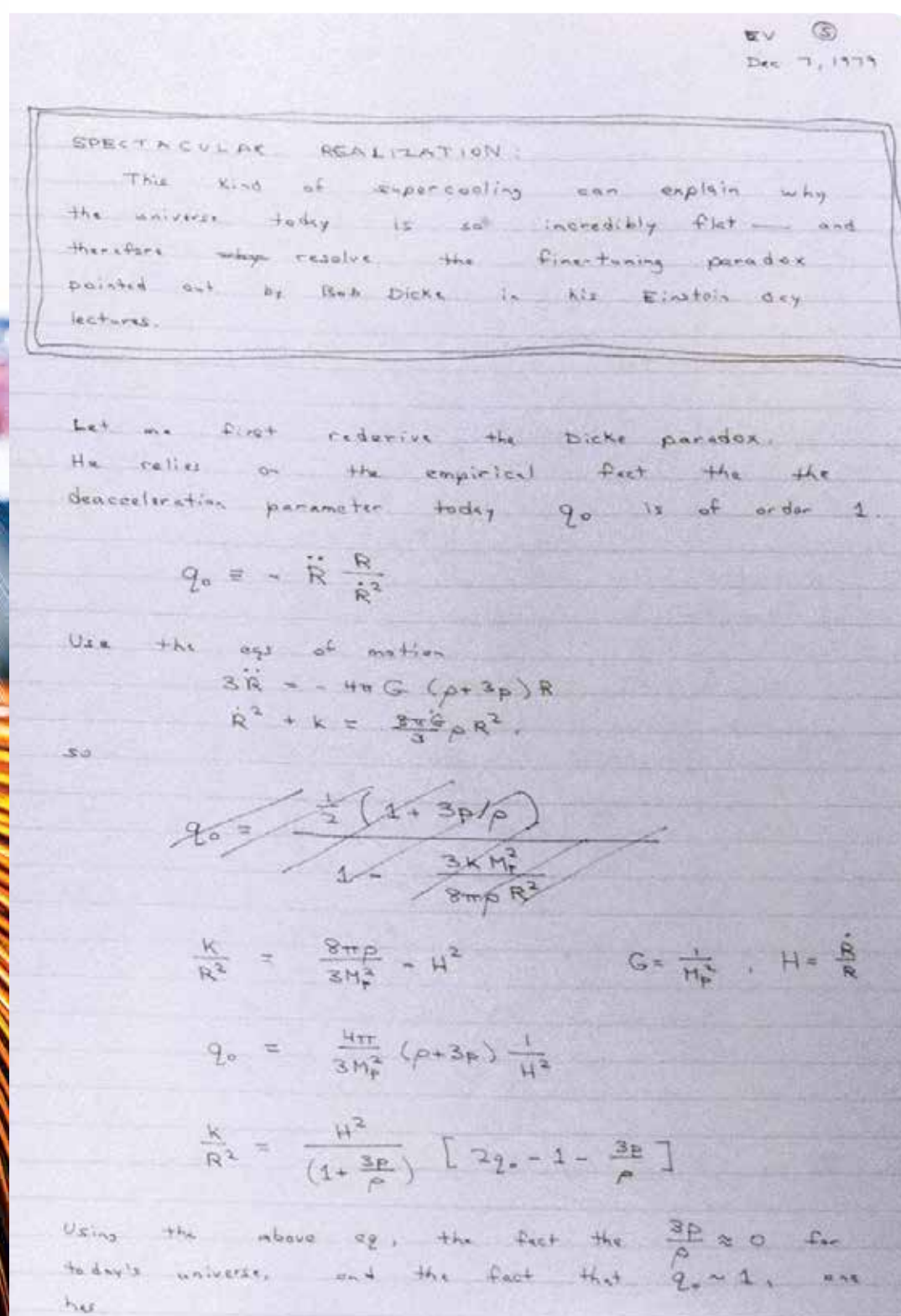
Longterm, Breakthroughs

Basic research can be breathtaking but often takes a breathtaking amount of time.

Recently, Prof. Alan Guth celebrated one of the most significant breakthroughs in the history of physics with the first direct evidence confirming his theory of what happened in the fraction of a second after the Big Bang.

His groundbreaking theory of cosmic inflation states that within that first sliver of time, the universe expanded exponentially by a factor of 10^{25} . A golf ball expanding that much would end up 500 times as big as the Milky Way galaxy. Looking back 14 billion years to that first instant of cosmic time with telescopes at the South Pole, a team of radio astronomers recently detected ripples in the fabric of space-time—gravitational waves—the mark of a universe pulling apart in the first fraction of a second after its birth.

Guth’s revolutionary work—first done in 1979—offers spectacular insights into some of humankind’s most basic questions, like, how did the universe begin? And why do we exist?



On a night in 1979, Alan Guth wrote of his insight: “spectacular realization.”

“Basic science is powerful but takes time to develop,” says Dina Katabi, professor of electrical engineering and computer science and winner of a MacArthur “genius” award. “And unless you invest early on, you cannot reap the benefit later.”

“Sometimes you need to invest at the time when it’s not clear that this development will lead to anything, say, in terms of a product. But later, even 60 years later, it becomes pretty clear that this work has become an amazing innovation.”



Kripa Varanasi: "MIT is a powerhouse."

Ideas in the Marketplace

Ram Sasisekharan, who holds 85 patents and launched three biotech companies in Kendall Square in Cambridge, says that basic science can lead to applications, companies, jobs, a stronger economy, and global competitiveness.

What sets MIT apart from other universities, he says, is that MIT's culture emerged from its history as an engineering school with deep ties to industry, making it easier for the discoveries of science to enter the marketplace than at other science institutions. In part, he says, MIT's success is because of MIT's Technology and Licensing Office, which makes patenting and licensing easier, and also because MIT values and supports collaboration, often across engineering and science.

At other universities, it may be tough, say, for a biologist to launch a company, but at MIT, biologists have helped transform Kendall Square into a biotech capital of the world. Kendall Square (the neighborhood surrounding MIT's campus) now hosts 150 high-tech companies, including some of the most celebrated technology, biotech, and pharmaceutical companies on the planet.

"MIT is a powerhouse. Its success is combining basic research with launching companies to bring those innovations to market," says Kripa Varanasi, associate professor of mechanical engineering, who has filed for more than 50 patents, and who studies hydrophobic (water-shedding) surfaces, like those found in nature. His work could solve big problems in energy, water, agriculture, or transportation, but, he says, typical of basic research, his efforts recently led in a surprising direction when he launched LiquiGlide, a company to market his nonstick, nontoxic, super-slippery coating for packaging, which aids in completely dispensing from a container various viscous liquids like ketchup, toothpaste, or jelly. The product—supported by a viral video that showed ketchup flowing easily from the bottle—was named by *TIME* magazine among the best inventions of 2012.

"We came up with a great technology, but the whole MIT ecosystem is responsible for our success. Everybody rallied—people at the Martin Trust Center for MIT Entrepreneurship, the Venture Mentoring Service, the MIT Deshpande Center for Technological Innovation. They posted our videos of ketchup sliding out of the bottle and overnight it became national news," says Varanasi, adding that MIT's entrepreneurial culture makes commercialization easy and the Institute unique.



***"Basic science is powerful
but takes time to develop
and unless you invest
early on, you cannot reap
the benefit later."***



Penny Chisholm: Decline of funding is disrupting the research process.

***“They take fewer risks.
But then, the probability of
discovering something
really new and exciting
goes down.”***



Kwanghun Chung: Colleagues are excited where his work will lead in 10, 25, 50 years.

Less Funding Slows Discovery

Basic research takes not only time but also money. Just ask Penny Chisholm, the Lee and Geraldine Martin Professor of Environmental Studies, who revolutionized our understanding of life in the world’s oceans in 1988 when she and colleagues identified *Prochlorococcus*, a form of ocean plankton that is the tiniest and most abundant photosynthetic organism in the ocean, and which plays a role in regulating climate.

Not only is it also the most abundant single species on Earth, it was completely unknown before her discovery—and Chisholm credits federal funding for the breakthrough. “For 25 years, most of my research was funded by the federal government,” she says.

In fact, MIT played a key role in the 20th century in advancing federal investment in basic research. By the start of World War II, MIT ranked among the U.S.’s top science universities.

At the end of World War II, Vannevar Bush, MIT professor, engineering dean, and science advisor to President Franklin Delano Roosevelt, wrote *Science: The Endless Frontier*, a report that became the foundation for post-WWII science policy and led to the 1950 creation of the National Science Foundation to support civilian scientific research.

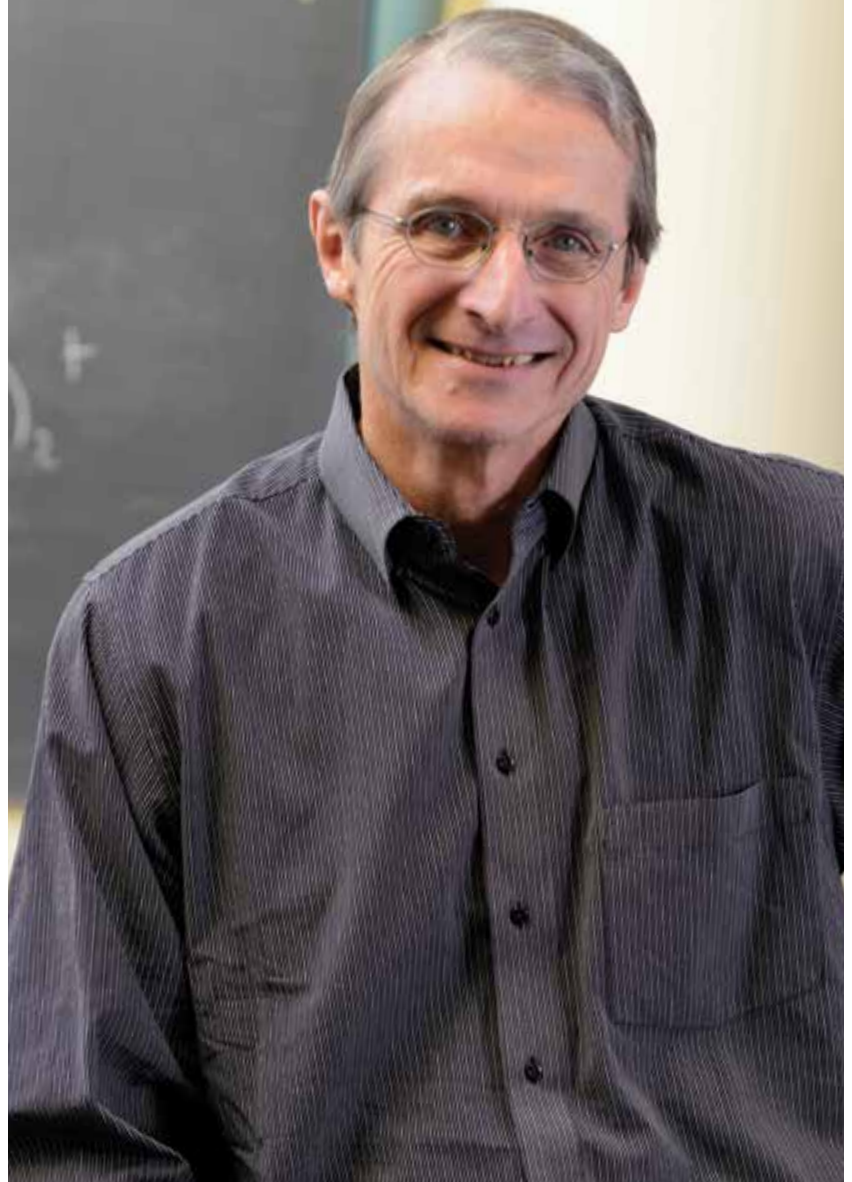
After the war, the U.S. government funding for science, spurred by an interest in national defense, led to exponential growth in the percent of the federal budget spent on research, support that peaked during the Apollo program in the 1960s. After the Cold War, as defense-research spending declined, federal spending on the life sciences grew. MIT faculty began reorienting their research to address new opportunities provided by the revolution in molecular biology.

For more than 60 years, MIT and other American research universities have led the world in discovery and innovation—with benefits to the entire country—due to federal funding. This vital support, however, is now on the decline. In 1960, for example, 55 percent of MIT’s campus revenue came from federal research dollars. By 2013, it fell to 22 percent. Chisholm says the decline is disrupting the research process.

“Researchers are focusing on projects with a high probability of results, because these projects have a better chance of getting funded. What’s happening is faculty are doing safe things because they know they’ll work. They take fewer risks, but then the probability of discovering something really new and exciting goes down,” she says.



Dina Katabi says anytime is time to invest in basic research.



Nobel Laureate Richard Schrock: "I got here by doing basic research." Photos Richard Howard

Sasisekharan, whose work on complex sugars had a powerful impact on the multibillion-dollar industry behind Heparin, a sugar-based blood thinner, adds: "NIH funding is vital. If I had not had that, it would have been a lot more difficult to do things. Clearly, it is getting harder because we are getting far more risk-averse, and hence, funding basic science definitely has gotten a lot harder than it used to be."

Chisholm adds that it's now great that foundations and private donors are funding high-risk basic research in fields with limited funding. "That's changed my research life," she says. "And it's changing the landscape of science."

Maintaining Competitiveness

Erosion of federal support has consequences, faculty say. Graduate programs shrink; we lose young faculty to institutions with more money; it becomes tougher to inspire the next generation to pursue basic research; and as the U.S. gives up its lead in various fields, eventually it loses its competitiveness.

"There's been a decline in the size of the graduate programs in the last few years," says Richard Schrock. "The number of graduate students now in chemistry is about half of what it has been historically."

Chisholm adds: "As funding shrinks, there's less support for postdocs, less fellowship support. And," she says, "we risk losing mid-career star faculty to universities in countries that are investing more in basic research. The U.S. is at risk of losing its position as a world leader in science and engineering—both in terms of research and education."

"Any time is the time to invest in basic research," says Dina Katabi, who works at the brink of computer science, electrical engineering, and physics to improve the speed, reliability, and security of data exchange. "If we don't, after 10 or 20 years we'll be facing other countries whose foundational science platform will be much stronger than ours. We have always been the leader in science, but very quickly, we may find ourselves behind."

"A commitment to basic science and the convergence of disciplines will propel us to stay ahead and stay competitive globally," Sasisekharan says. "Anything that derails us will have a price. And," he says, "less federal funding makes it difficult to inspire a younger generation to be excited about basic science."

Faith in the Future

Kwanghun Chung is a young assistant professor of chemical engineering who joined MIT last fall and is a researcher at the Institute for Medical Engineering and Science (IMES). He's collaborating with engineers, neuroscientists, biologists, and doctors on brain disorders and is developing new techniques. Recently, he developed Clarity, a new technology to understand large-scale complex biological systems like the brain. "Our technique is in its very early developmental stages, but it has a great potential to transform the way we do biological research and diagnosis," he says.

Many faculty members are excited about Chung's work and where it will lead in 10, 25, or 50 years.

"Everybody knows funding is getting more difficult," Chung says. "The pot is small, and competition is really fierce. It's too early to be discouraged. I don't want to think about it. I just love doing research, so that makes me feel optimistic."

Dan Kleppner says his 50-year career has led him to focus only on the positive. "One quality of science I really appreciate is its inherent optimism. In spite of all the problems the world faces, I am fundamentally an optimist."

Schrock believes that basic research *is* the future. And that MIT's scientific leadership in the world depends on it. He swings open a cabinet door in his office, closes his hand around a gold medal, and hands a visitor his Nobel Prize.

"I have so much faith in the future," he says. "I wish I could come back 50 years after I die and look around. Think of what we'll know. I mean, we'll no longer have to worry about breast cancer, or cervical cancer, or heart troubles. And wouldn't it be great if we could just drive a car with power from the sun?"

"Won't it be great to harness that energy to power trains, and cars, and airplanes? I mean, think about it," he says. "It will be fantastic."

— LIZ KARAGIANIS

SEE MORE: SLIDESHOW

MIT innovations, thanks to federal funding

spectrvm.mit.edu/webextras

NO FUTURE ON THE SIDELINES

Joseph Azzarelli, president of the MIT student group Science Policy Initiative (SPI), describes “science for policy” and “policy for science” as separate but interrelated. By educating its members and advocating for science funding, he says, SPI is “connecting the dots between science and policy.” Scientific research informs government policy on a range of issues, from health care to climate change; lawmakers influence scientific progress through budgets and regulations. How many MIT students understand this relationship — or their potential role in it?

“SPI’s mission is to provide opportunities for the MIT community to gain insight into how these processes work,” explains Azzarelli, a PhD candidate in chemistry. The organization’s monthly discussions draw 20–30 grad students plus the occasional curious undergrad, but the centerpiece of its activities since its 2007 inception has been annual trips to Washington, D.C. Students from SPI promote science and

tech funding at Congressional Visits Day (CVD) each spring, and each fall they explore the workings of such federal agencies as the Department of Energy and the National Nuclear Security Administration.

William Bonvillian — director of MIT’s Washington Office, which supports SPI — notes a big advantage students have on Capitol Hill: they can relate as contemporaries to the early career congressional staffers who typically attend the meetings. “The students come in and say, ‘Here’s this nanotechnology I’m pursuing that could enable a whole series of medical advances,’ and the jaws of the staffers drop,” Bonvillian says.

Making the case for research to legislators and their staff, however, is an acquired skill. This year’s 18-student delegation prepped for Congressional Visits Day with the help of the American Association for the Advancement of Science. The AAAS workshop covered, among other topics, how to frame these meetings as

“MIT students come in and say, ‘Here’s this nanotechnology I’m pursuing that could enable a whole series of medical advances,’ and the jaws of the staffers drop.”

the start of an ongoing dialogue, as well as how to describe one’s research clearly and memorably. Azzarelli, for example, designs sensors that detect gases at low concentrations — and he’s learned that the phrase “digital nose” is handier in conversation at a legislative office than an explanation of electron transport properties.

To further expose MIT students to the interplay of science and policy, Bonvillian teaches a 20-hour SPI “boot camp” on campus during Independent Activities Period each winter. His curriculum emphasizes the vital historical connections among government, industry, and research. “Science is always looking ahead,” Bonvillian points out, “yet we’ve got to make the case better based on what we’ve accomplished in the past.” The popular course is now a requirement in MIT’s new Graduate Certificate Program in Science, Technology and Policy (a less intensive alternative to the Master’s degree offered by MIT’s Technology and Policy Program).

READ MORE:

The SPI model goes national

spectrvm.mit.edu/webextras

Can students make a difference in the struggle for R&D support? Both Azzarelli and Bonvillian cite SPI’s Stand With Science project, a reaction in 2011 to the looming threat of budget sequestration. SPI members penned an appeal to Congress and disseminated a video of grad students urging people to sign. With a second letter in 2012, Stand With Science ultimately gathered more than 10,000 signatures. While last December’s federal budget deal granted some temporary relief, Stand With Science lives on as a national network dedicated to speaking up for science funding, and it has spawned a multi-university consortium of science policy groups, led by former SPI president Samuel Brinton.

Whether or not a single petition or D.C. visit yields the desired results, the long-term effect of policy education on the students themselves will be invaluable as they advance in their careers and assume leadership roles.

“We’re in a democratic system, a system of contending interests,” Bonvillian observes, “and there’s no future in sitting on the sidelines.”

– NICOLE ESTVANIK TAYLOR

Team members of the Science Policy Initiative include (from left): Arthur Yip, Erhardt Graeff, Dillon Gardner, Joseph Azzarelli, Yuly Fuentes-Medel, and Samuel Brinton. Len Rubenstein





Maria Zuber, Vice President for Research, represents MIT's research interests in Washington, D.C. Len Rubenstein

ADVOCATING FOR U.S. INVESTMENT IN SCIENCE AND TECHNOLOGY

To make new scientific discoveries, scientists need two things: time and money. One entity that supports discovery through basic research and the time horizon to accomplish it is the federal government.

“Basic research reveals and explains the natural world, from subatomic particles, to the function of the cell, to the structure of the universe,” says Maria T. Zuber, MIT Vice President for Research and the E.A. Griswold Professor of Geophysics. “Even when a basic research result enables a breakthrough product or helps humankind, the payoff is far down stream.

The possible utility of a discovery is most often not known at the onset.”

Zuber, who oversees more than a dozen of MIT's largest research centers including the Research Laboratory for Electronics and the David H. Koch Institute for Integrative Cancer Research, is also responsible for research administration and policy. She represents MIT's research interests in Washington, D.C. and advocates for investment in science and technology at the federal level. In 2012 President Obama appointed Zuber to the National Science Board.

Federal agencies, including the National Institutes of Health (NIH), the National Science Foundation (NSF), and Advanced Research Projects Agency-Energy (ARPA-E), offer grants in basic research to universities and research centers through a competitive, peer-reviewed process. Competition for federal grants is increasing; the funding rate for some agencies is now around 10 percent. Even so, federal agencies are able to fund big projects that answer big questions in a way that science philanthropy or foundations are not set up to do.

For example, 75 percent of philanthropic investment in science is toward medical and biological research, with the majority of this support focused on disease-specific cures. But basic biology research may study the fundamental function of a cell and produce a discovery that leads to an understanding of how an array of diseases, like cancer or Alzheimer's, develop — and then, how they might be cured. With increasing cuts in the federal budget, Zuber appreciates how philanthropy is covering some of the shortfall, but says it is no substitute for federal funding. “Without continued investment our progress in science and technology will surely decelerate, and so will our economy and quality of life.”

Federal investments in basic research have created the technologies and the markets associated with them for many things we take for granted today. Consider smartphone features, such as GPS, touchscreens, speech recognition, LED lighting, all developed out of federally funded initiatives. “Society is now benefiting from investments in basic research made in preceding decades. Knowledge of basic physics led to the development of radar which was crucial in World War II; advances in the life sciences have resulted in a dramatic increase in human life expectancy, almost doubling from the early 1900s,” reports Zuber.

“There are many mysteries in the world around and beyond us — from the deep structure of Earth's interior to upper reaches of the atmosphere — for science to solve. We should explore the ocean beneath the surface of Europa, the methane lakes of Titan, the endless numbers of planets around other stars, the nature of dark matter and dark energy and how they relate to the origin of the universe. Closer to home, human health, from cancer to the function of the brain, the health of the planet, clean energy, and national security are examples of the many critically important issues MIT researchers are pursuing that will benefit from investments in basic research.”

At MIT results from basic research can be on a fast track to practical applications. “Our scientists and technologists work side by side,” says Zuber. “Scientific discoveries can be rapidly embraced into engineering solutions. Our research enterprise and innovation ecosystems depend on the foundation provided by basic research.” — LAURIE EVERETT

“Advances in the life sciences have resulted in a dramatic increase in human life expectancy, almost doubling from the early 1900s.”



Nergis Mavalvala aims to detect gravitational waves, which are so aloof they've dodged efforts to track them down for a century. Len Rubenstein

ERA OF ASTRONOMICAL DISCOVERY

For much of her professional life, Nergis Mavalvala has been devoted to a singular goal: creating a device to detect gravitational waves. These ripples in the fabric of space-time, the signature of violent cosmic events, are “extremely aloof,” says Mavalvala. In fact, gravitational waves have been dodging elaborate efforts by scientists to track them down since Einstein predicted their existence a century ago.

But last March brought a possible breakthrough: Astronomers at the Harvard-

Smithsonian Center for Astrophysics discovered what appears to be the first direct evidence of gravitational waves. For Mavalvala, the Curtis and Kathleen Marble Professor of Astrophysics, the news could not be more thrilling. She believes it may herald a new era of astronomical discovery: “It will be exciting beyond measure, and the greatest excitement will be finding things we can’t yet imagine.”

Mavalvala is certainly ready. Since her graduate school days in the early 1990s at MIT, she has been helping to design and build the Laser Interferometer Gravitational-wave Observatory (LIGO). For the part she played in developing this complex, grand-scale and finely tuned scientific tool for detecting gravitational waves, Mavalvala won a MacArthur Fellowship in 2010.

Many large heavenly bodies and events in the universe such as the birth and death of stars generate energy in

different wavelengths of light, which existing telescopes can find, she says. But compact astrophysical objects such as neutron stars and light-eating black holes, which are believed to produce energy in the form of gravitational wave radiation, remain concealed from human view. These waves, unlike light, she says, “flow through everything, because matter is basically transparent to them. They come to us unobstructed right from the source.” For Mavalvala, gravitational waves are “a clean

messenger bearing information about how the universe is put together.” LIGO’s instrument for detecting the extremely faint signature of gravitational waves is “an exquisitely sensitive interferometer,” says Mavalvala. It works on the principle of measuring the time it takes for light beamed from a laser to strike a mirror four kilometers away and reflect back. Theoretically, a gravitational wave arriving on earth and passing between laser and mirror will slow down the light as it bounces, thus changing the distance between the two infinitesimally. LIGO is built to identify a change in distance of 10^{-18} meters — 1,000 times smaller than a proton.

Members of an international team, Mavalvala and her lab colleagues have been refining the laser interferometer, specifically the optical sensing and control system. In the past several years, two observatories have started up, one in Washington State and the other in Louisiana, but have not yet

yielded results. LIGO researchers are now sharpening their focus by a factor of 10. “This allows us to be sensitive either to weaker gravitational waves, or to the same sources, such as a pair of neutron stars colliding, but farther out,” says Mavalvala.

Engaged with LIGO’s second-generation detectors, Mavalvala is contending with a critical problem involving the instrument’s measuring precision. But she has some clever tricks to sidestep these

constraints. One deploys “squeezed light sources,” laser beams whose quantum properties are manipulated to reduce noise fluctuations, which may improve the sensitivity of the LIGO detectors and render more accurate measurements.

“The big picture mission drives you. When you work in the lab, [it’s like] you bang your head against the wall for weeks at a time, working on a state of the art circuit, for example,” says Mavalvala. “Yet this is what enables scientific discovery, when the smaller to bigger pieces of experiments succeed, when the whole thing does what it is supposed to, and then you hope nature gives you the event you’ve been waiting for.”

— LEDA ZIMMERMAN

SEE MORE: VIDEO

How LIGO works

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SEARCHING FOR LIFE

“I call it ‘the awakening.’ The whole world is waking up to the fact that we’re getting close to finding other Earths and signs of life...It will change the way we see our place in the universe,” says Sara Seager, an astrophysicist and 2013 winner of a MacArthur “genius” award, who is working to find life on other planets outside the solar system.

Every star in the sky is a sun. “And if our sun has planets, we expect that other stars will have planets too, and they do,” says the professor of planetary science and physics who holds the Class of 1941 Professorship. In fact, such exoplanets are common. More than 2,000 have been discovered since 1995, and there are probably many more.

“Statistically we think each of the approximately 100 billion stars in the Milky Way has at least one planet,” says Seager. Of those, as many as one in five stars like the sun has a rocky, Earth-sized planet that could have the right surface temperatures for life.

Those are the exoplanets that Seager, who was recruited by MIT to build its exoplanet program, is searching for. And it’s a challenge. “Other Earths are so small and dim compared to the star they’re right beside.” Our own sun, for example, is ten billion times brighter than Earth.

Although a few Earth-sized candidates have already been found, current telescopes are not powerful enough to tell us if they harbor life. Many projects are in the works, however, to change that; each will get us closer to that goal, Seager says.

She is working on three of these projects. One, dubbed ExoplanetSat, involves a space-based fleet of some 50 to 100 rectangular telescopes roughly the size of a milk carton. Each Exoplanet-Sat — the first could launch in a year — will be pointed at an individual star with the goal of detecting any planet that passes in front of the star during its orbit. The changes in brightness associated with such a transit can be analyzed to determine, among other things, the planet’s density. ExoplanetSat was first developed by Seager at MIT and is now a collaboration with Draper Lab and NASA/JPL.

The light from a transiting planet can also give insights into its atmosphere — something Seager predicted that led to the first-ever discovery of an exoplanet atmosphere. Another part of her work is searching for the atmospheric gases that could indicate life.

Seager notes that although her research is focused on the detection of an Earth twin, it has other applications. “Some of the technology developed for ExoplanetSat is being adapted for long-distance laser communication and also Earth-imaging applications. Basic research inspires fundamental discoveries on which applications flourish.”

Seager is excited about the future. “We stand on a great threshold in the human history of space exploration,” she told Congress last December. “...If life is prevalent in our neighborhood of the galaxy, it is within our resources and technological reach to be the first generation in human history to finally cross this threshold, and to learn if there is life of any kind beyond Earth.”

— ELIZABETH THOMSON

LEARN MORE: TESTIMONY

Seager asks Congress, “Are we alone?”

spectrvm.mit.edu/webextras

Sara Seager is searching for life beyond the solar system and says the world is ready.

Len Rubenstein

SURPRISING REACTIONS

Yogesh Surendranath was mesmerized by a magnet his parents gave him when he was five. Digging up the iron-rich soil in his Ohio backyard, he easily found treasure. What most fascinated him, though, was the inexplicable way the magnet functioned — a problem he could not immediately fathom. Surendranath recalls “being imbued with a curiosity about how the natural world works.”

An assistant professor of chemistry today, and a researcher for the MIT Energy Initiative, Surendranath has lost neither his sense of wonder nor his drive to understand natural processes. Both come into play frequently in his work on the chemistry of solid-liquid interfaces. At these common borders between different types of matter, materials react to each other, making and breaking chemical bonds as atoms swap electrons. Sometimes these reactions prove surprising, which Surendranath especially relishes: “The most interesting result is the one that runs counter to our expectations,” he states.

Surendranath, who earned a PhD in inorganic chemistry from MIT in 2011, has long appreciated the “beauty and power of correlating material structure to function and property.” As an undergraduate, he grew “captivated by how electron transfer mediates chemical bond formation and breaking” — the basis for elec-

trochemistry. He became particularly interested in understanding the behavior of metal atoms at interfaces, and their role in complex reactions. “I like to work on problems where we know less than 5 percent of what’s going on rather than 95 percent, and put in the rest of the puzzle. Electrochemical systems are a rich ground for discovery,” Surendranath states.

There is another motivation for his research besides discovery. Efficient electron transfer in chemical reactions “lies at the heart of most major energy storage platforms, including batteries and fuel cells,” says Surendranath. These technologies, which stockpile electrical energy in chemical bonds, and discharge that energy as needed, are limited in efficiency and scope by current knowledge.

Fundamental advances in electrochemistry could shrink these constraints, paving the way to cost-effective, large-scale storage of electricity from renewable energy sources such as wind and solar. “The solid-solution interface is where the rubber meets the road,” Surendranath states. “If we could engineer at the atomistic, molecular level a more efficient and selective reactivity, we could make new fuel cells, or fuel products.”

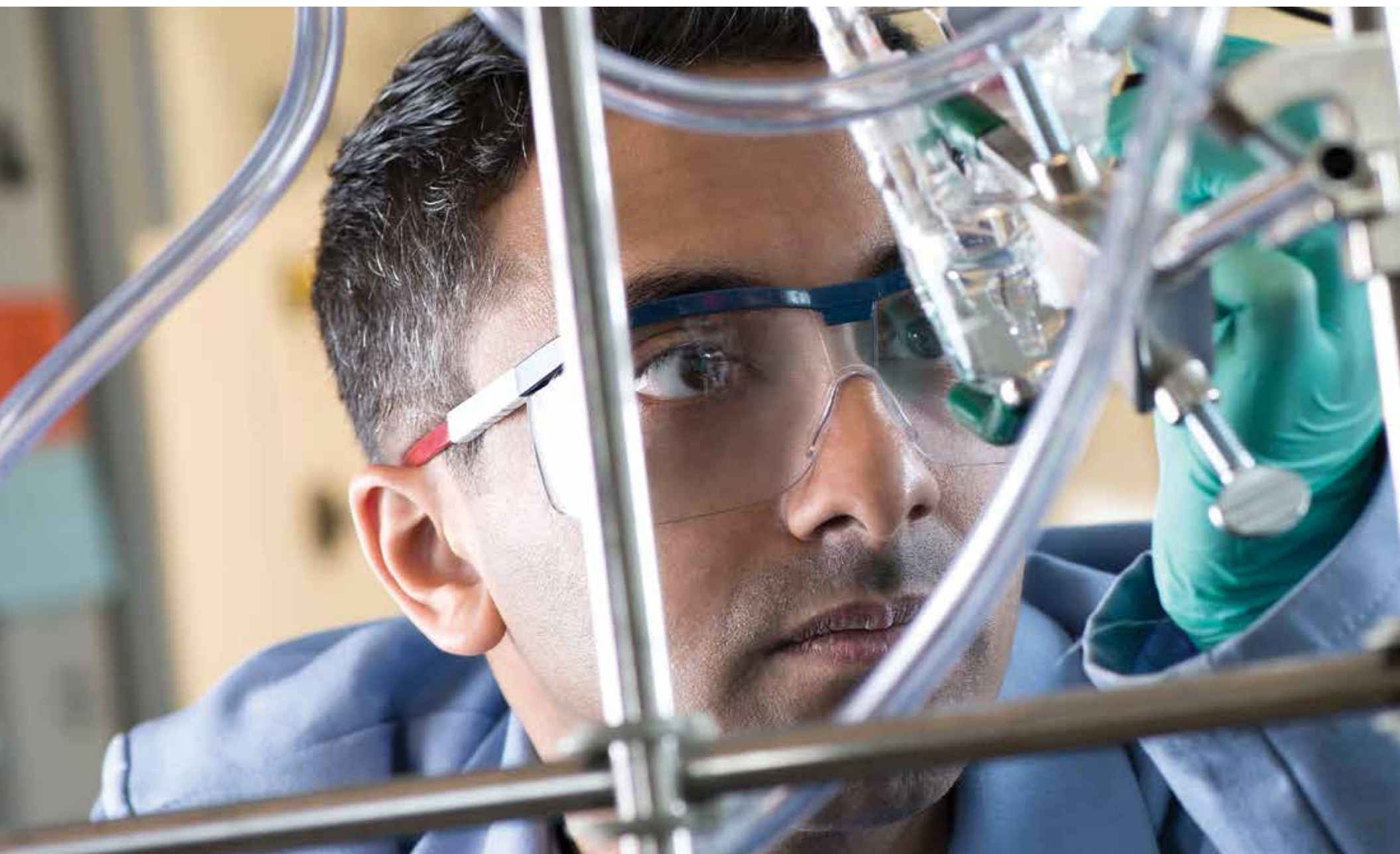
One intriguing possibility Surendranath is pursuing: reducing carbon dioxide to a fuel, a trick accomplished by green plants, but not yet

very efficiently by humans. Surendranath would like to “short-circuit nature’s route,” which relies on solar energy to rupture the chemical bonds of water and carbon dioxide. He is designing alternative catalysts, agents that can trigger rapid reactions between inert compounds, to see if he can speed up the process. “It could be a game-changing method for energy storage,” he says.

Surendranath is the first to acknowledge that there are big, basic science questions to answer on the way to a renewable energy economy. “The fundamental problem holding us back is catalysis,” Surendranath states. “How do you drive a very complicated reaction that involves many electrons, and the rearrangement of many bonds down a single pathway, all with very low energy input? These are difficult things to achieve.”

In a laboratory that employs a range of techniques, including molecular, thin film, and nanocrystal synthesis, Surendranath hopes to uncover new principles of catalyst design that might eventually form the basis for advanced batteries, fuel cells or electrolyzers. “This would be the home run,” says Surendranath. “Getting to the bottom of how things behave is very gratifying. Things become beautiful once you understand them, and that’s what we’re really trying to do.” — LEDA ZIMMERMAN

Yogesh Surendranath says there are big questions to answer on the way to a renewable energy economy. Len Rubenstein



“The most interesting result is the one that runs counter to our expectations.”



“We try to turn failure into functionality.”

Pedro Reis was recently named one of *Popular Science*'s “Brilliant Ten.” Len Rubenstein

TODAY'S ANNOYANCES, TOMORROW'S TECHNOLOGY

Paper wrinkles, tape tears, cables kink, columns buckle, eggshells break. Pedro M. Reis hopes to transform today's annoyances into tomorrow's technology.

Reis, who holds a dual appointment in mechanical engineering and civil and environmental engineering and recently named one of *Popular Science*'s “Brilliant Ten,” explores the mechanics and physics underlying natural and manufactured structures with the goal of identifying, classifying, and predicting the ways thin objects deform — and using that knowledge to solve other engineering problems.

In the engineering world, material failure through buckling or fracture can be merely annoying or completely catastrophic. Reis seeks to exploit apparent weaknesses in different realms. “In our lab we do science-enabled engineering coupled with engineering-motivated science,” he said, “and we try to turn failure into functionality.”

Working with objects in which one dimension is smaller than the other — hair, rods, pipes, paper, plates, shells — Reis pursues “curiosity-based research” at the interface of science and engineering. “The ultimate goal is to discover, understand, and harvest mechanical instabilities in soft mechanical structures,” he says, “and then exploit those as novel functionalities over a wide

range of length scales.”

Hence the device he dubbed the Elastopipette, a petal-shaped sheet inspired by floating flowers that grabs and holds water droplets. And the rubbery self-foldable Buckliball with its intricately strutted structure, which, when squeezed, collapses on itself in a predictable way. Besides illuminating a fascinating phenomenon in its own right, the Buckliball can be used to encapsulate miniscule things, but it has also attracted the attention of a nuclear engineer who thinks it might be just the thing for the next generation of particle detectors.

As a teenager, Reis decided to become a physicist after meeting a couple of physics graduate students at a cousin's wedding. If he had met a NASA scientist that day he might have ended up wanting to be an astronaut, he joked, but his fascination with the confounding tendencies of thin materials can be traced to a distinctly outmoded technology: the compact disc.

Unlike the unpredictable result of a drinking glass or a porcelain plate encountering a tile floor, the packaging film of a CD case, when opened, tears in a regular, visually arresting, almost poetic fashion, creating a fan of delicate sine waves. Reis wondered why.

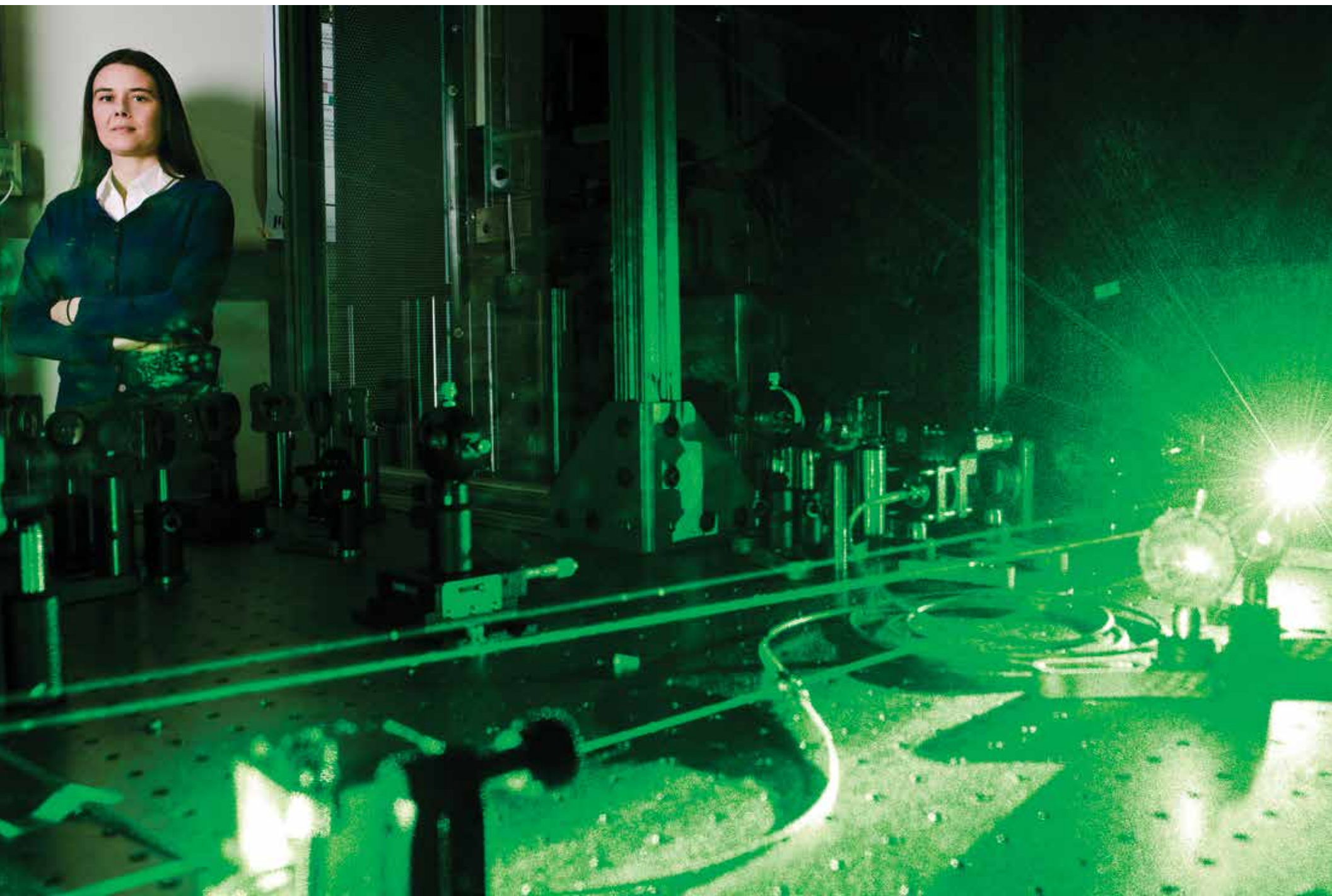
Now, in his lab, at one bench researchers

analyze what looks like an undulating strand of green spaghetti falling onto a treadmill; at the next is a tank filled with water. The first experiment relates to the laying of kilometers-long communication cables onto the seabed; the next explores how a bacterium propels itself with its whip-like tail. What they have in common is the structures are slender and their mechanics are scalable.

The resulting knowledge can be applied to stretchable electronic components, 3-D printing, microfabrication of ultra-thin carbon nanotubes and graphene, or problems encountered by wellbore drilling or kinked transoceanic pipelines, to name a few. Understanding why scotch tape tends to tear in a certain way led to a new way to fabricate tapered graphene nanoribbons. Illuminating the delamination of adhesive films is informing the design and layout of components in novel stretchable electronics devices. Reis's lab found that the pattern of wrinkles in drapes is identical to that of wrinkled ultrathin films such as graphene.

“There's nothing like playing in the lab,” Reis said. “When you play with things, you can discover new things. There's always a surprise around the corner” that might help turn a sow's ear into a high-tech version of a silk purse.

— DEBORAH HALBER



Paola Cappellaro's work with nanoscale diamonds opens a route to computers that can search huge databases in a flash or crack virtually any secret code. Len Rubenstein

QUANTUM ENGINEERING

It can be difficult to distinguish between basic and applied research in the nascent field of quantum engineering. One person's exploration of quantum systems like atoms and electrons yields another's building block for quantum computers, and vice versa. Paola Cappellaro's lab operates at the interface of basic and applied research. "We sometimes go more in one direction and sometimes more in the other," she said.

Cappellaro works with nanoscale diamonds that contain a defect consisting of an embedded nitrogen atom next to a gap in the diamond crystal. If you had a large enough gem-quality diamond with this type of defect throughout, it would be pink. These nitrogen vacancy, or NV, centers have spins that can be readily controlled, said Cappellaro, who is an Associate Professor in the Department of Nuclear Science and Engineering and holds an Esther and Harold E. Edgerton Career Development Professorship.

Atoms and electrons have a spin, or orientation, that's up or down—similar to the two poles of a magnet. Unlike ordinary magnets, however, atomic and subatomic spins can be a mix of up and down at the same time. This superposition of spins is the source of the fuss about quantum computing. If you use the up and down of a particle's spin to represent the 1 and 0 of a bit, then a quantum bit, or qubit, is both a 1 and 0 at the same time. A string of qubits, therefore, can represent a phenomenally large range of numbers. This opens the possibility for computers that can crack virtually any secret code or search huge databases in the blink of an eye.

One thrust of Cappellaro's research is how information is transferred in a chain of spins. Transferring information between qubits is critical for being able to build quantum computers, Cappellaro said. "What you would like to have is not only computing units, but also some wires to connect them."

NV centers are also potentially useful beyond quantum computing. They're very sensitive to magnetic fields. "You can use this spin, which is basically just a magnetic dipole, just like a compass, to sense an external magnetic field," she said.

These miniscule magnetic sensors can detect magnetic fields from extremely small, closely spaced objects. One potential use is inspecting magnetic bits in the production of data storage devices. Unlike most quantum devices, the NV center magnetometer operates in a wide range of temperatures, she said. This opens the possibility of detecting magnetic fields from superconducting devices, which operate at very low temperatures.

Another possibility is detecting magnetic fields inside living cells. For example, neural cell signaling operates via exchanges of ions, which are positively or negatively charged atoms. In theory, an NV center magnetometer could monitor neural cell functioning, Cappellaro said.

Knowing that her research could have a significant impact in practical applications like these is very satisfying, but Cappellaro is also motivated by basic science. "Very often what drives us is intellectual curiosity about how our system behaves," she said. "It's nice to be able to go toward both directions at the same time."

— ERIC SMALLEY

ORDINARY MATERIALS, FANTASTIC OPPORTUNITIES

For Michael Demkowicz, some of the greatest scientific mysteries and major engineering opportunities lie in everyday materials. “Structural materials are sometimes seen as low-tech,” he says. “Who thinks about steel, who thinks about aluminum, who thinks about concrete? But those are probably some of the materials we understand the least.”

One mystery of structural materials is why they degrade under corrosion, heat, and radiation — their performance isn’t what it could be by a long shot. Theoretical performance levels are much higher than what current materials are capable of, says Demkowicz, an associate professor in the Department of Materials Science and Engineering. This has major practical implications. The lack of high-performance structural materials makes it harder to develop efficient energy production, resilient infrastructure, and sustainable transportation, he said. The combination of the technological need and the scientific mystery is “a huge opportunity that cries out to be taken advantage of.”

Demkowicz’s lab models the physics of structural materials to better understand how they degrade, and ultimately break down. He aims to use the models to design new materials that

are resistant to radiation damage, fracturing, and corrosion. The result could be jet engines that run more efficiently, bridges and buildings that withstand earthquakes, and nuclear power plants that produce less waste.

In all those cases — environmental conditions, mechanical loading, and radiation — failure is ultimately related to the formation and growth of defects in the metal’s crystal structure, Demkowicz says. The challenge is controlling the defects. “Can we do some kind of ‘defect engineering’ to make the material behave the way we want?”

An ideal behavior for structural materials is self-healing. Demkowicz’s lab is on the trail of several methods of producing materials that repair microscopic damage from environmental and mechanical stresses. One potentially groundbreaking method is a surprise discovery that emerged from research about hydrogen embrittlement, which occurs when hydrogen atoms infiltrate metals in acidic environments. Demkowicz and his graduate student, Guoqiang Xu, discovered that, under the right conditions, putting metal under tension can close rather than open microscopic cracks.

Another method addresses helium embrittle-

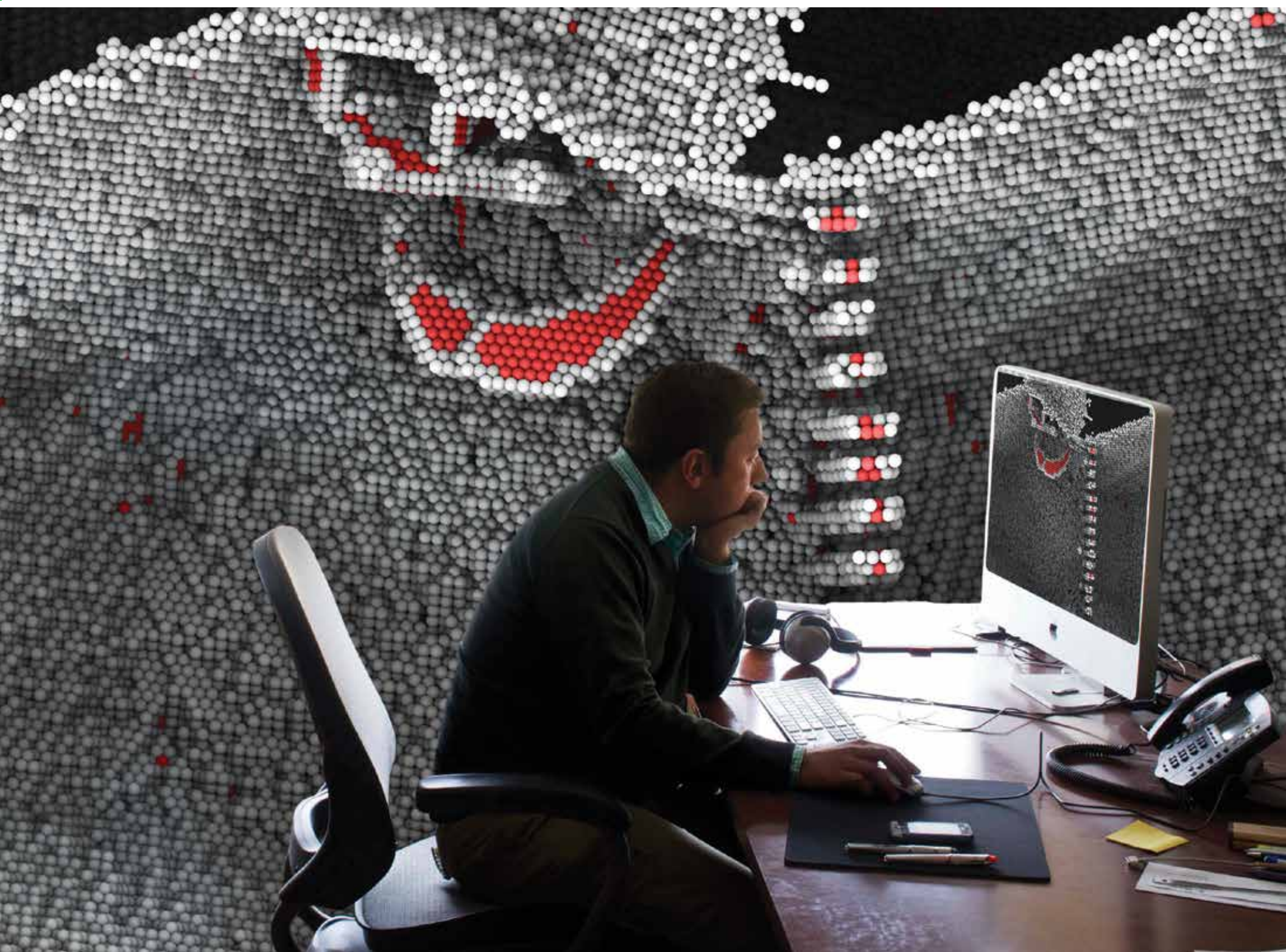
ment, which occurs when metals are exposed to radiation. Demkowicz’s lab is designing metals that spontaneously form microscopic channels in the presence of embedded helium atoms. The channels would allow the helium to escape rather than form tiny bubbles that weaken the metal.

The intimate connection between basic research and technology is readily apparent in the field of materials. The common name for the field, materials science and engineering, makes the connection explicit. Demkowicz and Xu chose to publish their crack-healing paper in a physics journal rather than in a materials journal to highlight the fundamental science of the discovery.

The effort to develop self-healing metals is one example of technological innovation emerging from basic research. Given the abundant opportunities for basic research in structural materials, we’re likely to see many more, says Demkowicz. “In my own research I see it all the time,” he says. “We discover something new and unexpected that helps us understand a material better, and it’s never long before we come up with an idea of how to use it.”

— ERIC SMALLEY

Michael Demkowicz says that steel, aluminum, and concrete are among materials we understand least, but all have big possibilities for engineers. Len Rubenstein



FUTURE OF ENERGY STORAGE

Fikile Brushett is in the process of taking the power generated by wind and solar, chemically lashing it to molecules derived from flora and fauna and storing it in liquids until it's needed to electrify our homes.

The fact that such a system — if it's even feasible — is likely years from reality doesn't deter Brushett, who holds the Raymond A. & Helen E. St. Laurent Career Development Chair in chemical engineering. Brushett, an electrochemical engineer, works on applying fundamental electrochemistry to boost the performance and durability of our future energy storage systems.

A key 21st century challenge, Brushett says, will be storing and distributing energy in an efficient, sustainable fashion. "Converting energy from one form to another allows us to change the way we think about different energy-storage processes," he said. A robust, cost-effective storage system, he says, is essential to make the intermittent electricity generated by wind and sun available 24/7, and might help boost the 4 percent of overall power now generated by these renewable sources in the U.S. to 25 percent or higher.

Our laptops and cell phones contain batteries with solid electrodes; Brushett and colleagues hope to transform energy storage with liquid electrode redox flow batteries. NASA introduced a version of these in the 1970s but they never took off, partly because of their reliance on pricey electroactive metal salts.

Unlike conventional rechargeable batteries, redox flow batteries store energy in solutions of electroactive compounds, which are housed in external tanks and pumped to an electricity-generating reactor. This system offers advantages in scalability, manufacturing, service life, and safety.

The chemicals can be stored in a tank as big as a water heater for home use, or as massive as a big-box store for powering an entire community.

Brushett, who says he'd "always been fascinated by engineering" and was drawn to energy research because of its societal relevance, envisions replacing redox flow batteries' expensive metal salts with engineered versions of organic electroactive materials derived from biomass, such as quinones — naturally abundant compounds that play important roles in photosynthesis, respiration, and even the defense

mechanisms of bombardier beetles.

"Organic molecules can, in principle, help us take that extra jump to make cheaper, more energy-dense flow batteries that are more economically viable," he says.

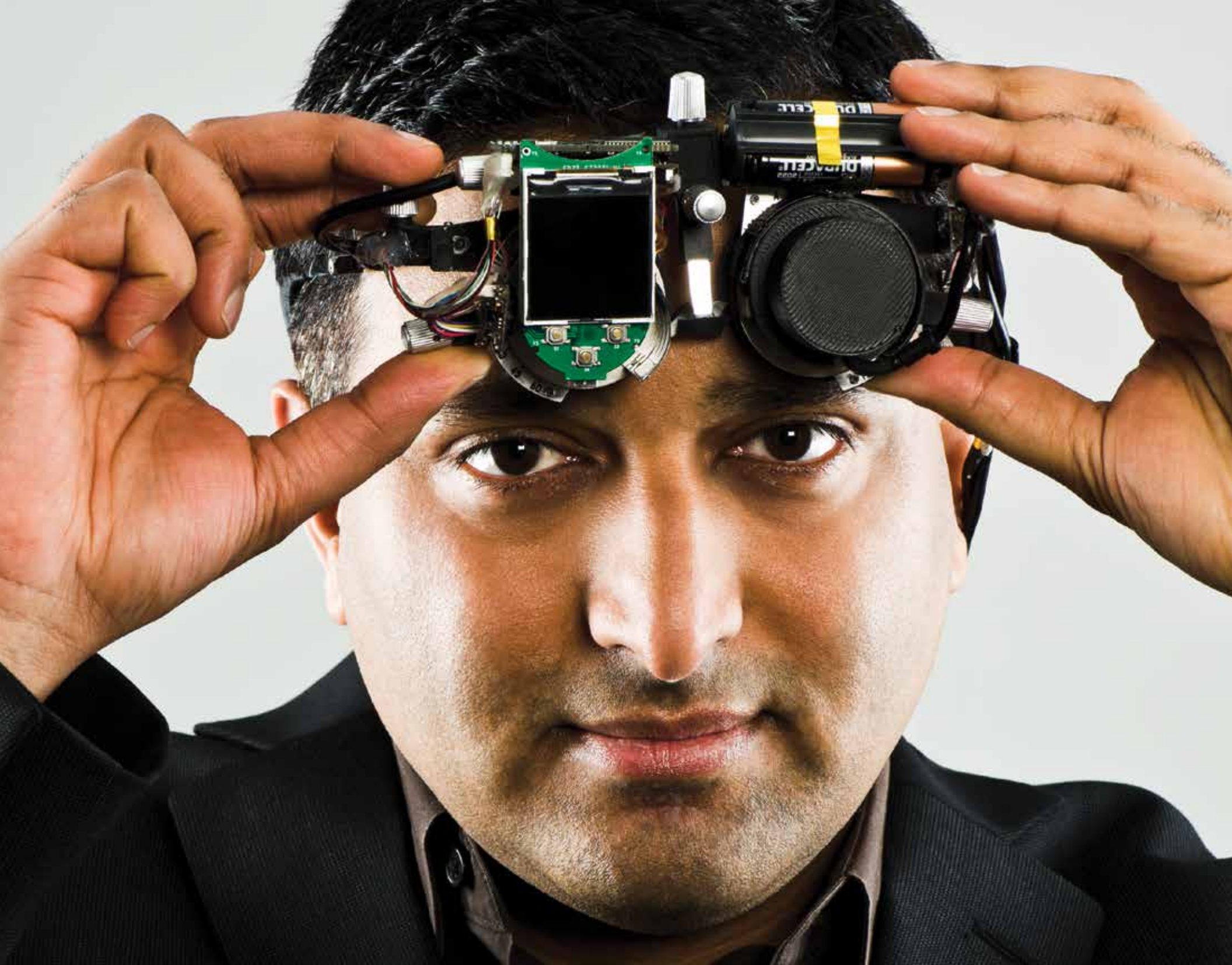
Brushett's is one of few research groups in this emerging field, which takes the "different, riskier approach of re-purposing and engineering natural molecules not designed to do the kind of energy storage we'd like them to do," he says. "We don't understand a whole lot about how to store energy in these molecules, how to make them practically applicable. No one knows how to do that just yet," but the potential payoff is huge: high-powered fuel cells, next-generation rechargeable batteries, and amped-up photovoltaics, all from carbon-friendly, renewable sources.

"The bottom line is, the lights have to come on when we flip a switch, but we have to think about where those electrons are coming from," Brushett says. "This approach could be much more efficient and a lot greener than the processes we use today."

— DEBORAH HALBER

Fikile Brushett is applying fundamental electrochemistry to boost the performance and durability of future energy storage systems. Len Rubenstein





Ramesh Raskar, who as a child wished for eyes in the back of his head, invents a camera that can see around corners. Len Rubenstein

SUPERHUMAN VISION

All through his childhood, Ramesh Raskar wished fervently for eyes in the back of his head. “I had the notion that the world did not exist if I wasn’t looking at it, so I would constantly turn around to see if it was there behind me.” Although this head-spinning habit faded during his teen years, Raskar never lost the desire to possess the widest possible field of vision.

Today, as director of the Camera Culture research group and associate professor of Media Arts and Sciences at the MIT Media Lab, Raskar is realizing his childhood fantasy, and then some. His inventions include a nano-camera that operates at the speed of light, and do-it-yourself tools for medical imaging. His scientific mission? “I want to create not just a new kind of vision, but superhuman vision,” Raskar says.

He avoids research projects launched with a goal in mind, “because then you only come up with the same solutions as everyone else.” Discoveries tend to cascade from one area into another. For instance, Raskar’s novel computational methods for reducing motion blur in photography suggested new techniques for analyzing how light propagates. “We do matchmaking; what we do here can be used over there,” says Raskar.

Inspired by the famous microflash photograph of a bullet piercing an apple, created in 1964 by MIT professor and inventor Harold “Doc” Edgerton, Raskar realized, “I can do Edgerton millions of times faster.” This led to one of the Camera Culture group’s breakthrough inventions, femto-photography, a process for recording light in flight.

Manipulating photons into a packet resembling Edgerton’s bullet, Raskar and his team were able to “shoot” ultrashort laser pulses through a Coke bottle. Using a special camera to capture the action of these pulses at half a trillion frames per second with two-trillionths of a second exposure times, they captured moving images of light, complete with wave-like shadows lapping at the exterior of the bottle.

Femto-photography opened up additional avenues of inquiry, as

Raskar pondered what other features of the world’s superfast imaging processes might reveal. He was particularly intrigued by scattered light, the kind in evidence when fog creates the visual equivalent of “noise.”

In one experiment, Raskar’s team concealed an object behind a wall, out of camera view. By firing super-short laser bursts onto a surface nearby, and taking millions of exposures of light bouncing like a pinball around the scene, the group rendered a picture of the hidden object. They had effectively created a camera that peers around corners, an invention that might someday help emergency responders safely investigate a dangerous environment.

READ MORE: START-UP

Eye tests via smartphone

spectrvm.mit.edu/webextras

Raskar’s objective of “making the invisible visible” extends as well to the human body. The Camera Culture group has developed a technique for taking pictures of the eye using cellphone attachments, spawning inexpensive, patient-managed vision and disease diagnostics. Conventional photography has evolved from time-consuming film development to instantaneous digital snaps, and Raskar believes “the same thing will happen to medical imaging.” His research group intends “to break all the rules and be at the forefront. I think we’ll get there in the next few years,” he says.

Ultimately, Raskar predicts, imaging will serve as a catalyst of transformation in all dimensions of human life — change that can’t come soon enough for him. “I hate ordinary cameras,” he says. “They record only what I see. I want a camera that gives me a superhuman perspective.”

— LEDA ZIMMERMAN

FROM CONFLICT, COOPERATION

“I am drawn to doing research in tough places,” says political scientist Fotini Christia. “The questions I’m interested in involve a dimension of conflict.” Her resume teems with references to Afghanistan, Bosnia, Iran, Syria — a veritable atlas of unrest.

For her recent book *Alliance Formation in Civil Wars*, Christia interviewed Afghan warlords and mujahideen. Her “counterintuitive” finding was that alliances among warring factions were fluid, owing more to pragmatic power dynamics than to religious or ethnic identities. She discovered, however, that identity narratives were often retrofitted to justify shifts from foe to friend and back again.

In another study, Christia evaluated the role of local councils in Afghanistan’s largest development aid program. She observed that mandating female inclusion in development councils appeared to bolster women’s standing in other aspects of community life. This notion — that compulsory inclusion might beget genuine teamwork — reverberated in her field work in Bosnia. She layered her own measures for diversity and cooperation on top of the “natural experiment” the city of Mostar created by integrating two of its Croat and Muslim high schools. When she asked students to play public goods games in which they distributed resources, kids from the ethnically integrated schools showed more willingness to contribute to the greater good.

Christia’s newest project, focused on Yemen, involves integration of another kind: she’s collaborating across disciplines. Together with Munther Dahleh, director of the Engineering Systems Division, along with computer scientists from Stanford University and network scientists from the University of Pennsylvania, she will analyze a massive body of anonymized cell phone records spanning the events of the Arab Spring. Though the content of calls and texts is unknown, the researchers will form a picture of how Yemeni civilians mobilized by zeroing in on key locations and timeframes. “It’s not just about how protests affected the way people

communicate,” Christia explains, “but also how communication affected the way protests happened.”

The foray into big data “is not an idea that comes intuitively to a political scientist,” Christia says. “Having connected with these brilliant individuals from very different disciplines, I figured this was an opportunity to think of a project where we could leverage our unique interests—a project none of us could be doing on our own.”

Christia’s investigations in Yemen echo the themes of conflict and coalitions that define her previous work, and which have fascinated her since growing up in northern Greece. Yugoslavia’s disintegration was common dinner conversation, she recalls of her childhood, but Greece’s own civil war five decades past remained so divisive that it wasn’t taught in schools. Her interest in political upheaval was reignited in college by events in Kosovo. In the six years since she completed her PhD in public policy at Harvard, she’s become the Mark Hyman Jr. Career Development Associate Professor of Political Science; her expertise on Afghanistan has been endorsed by the former director of U.S. Central Command; she’s weighed in on international crises for publications including *Foreign Affairs* and *The New York Times*; and she’s earned an entry in *The Washington Post’s* WhoRunsGov, an online catalog of “key players in the Administration, Congress, and federal agencies.”

The dynamics of one conflict zone cannot be applied wholesale to other regions — or extrapolated to times of peace, Christia emphasizes. But as she moves her gaze to Yemen, she continues to ask questions that matter deeply to anyone interested in Afghanistan, or Bosnia, or the Arab world, or anywhere ravaged by violence.

“In periods of conflict, how do you get people to join your side?” she wants to know. “How do you get from instability to stability? How do you get to some sort of equilibrium?”

— NICOLE ESTVANIK TAYLOR

Fotini Christia, an expert on conflict, asks in times of unrest, “How do you get people to join your side?” Len Rubenstein





Juanjuan Zhang says that a tendency to follow the crowd has broad social implications — even affecting human health. Len Rubenstein

DECISIONS AGGREGATE INTO SOCIAL BEHAVIOR

When faced with a decision, we read restaurant and movie reviews and ask friends to recommend plumbers and dentists because it's easier than gathering all the information ourselves. But this tendency to follow the crowd has broad social implications — even affecting human health, according to Juanjuan Zhang, associate professor of marketing at the MIT Sloan School of Management.

Sometimes that downside is no more serious than the failure of a good yet unpopular restaurant, but Zhang has found that the tendency to act based on what others do — observational learning — also applies to the decisions being made by patients on the kidney transplant list. The result has been the loss of viable organs.

In the United States, kidneys are allocated on a first-come, first-served basis and potential recipients know their place on the waiting list. So, when a kidney is offered to the fifth person in line, he knows that four people have already refused that kidney. He doesn't know why — everyone has the same information on donor age, gender, and health status — but Zhang found organs are disproportionately rejected

simply because other people have declined them. A bias has developed.

“If I know that I'm on the bottom of the waiting list and all of a sudden they offer me a kidney, I can infer that people above me already said no,” Zhang says. “People may say no because they didn't have time for the transplant that week or they were sick. But that information's not communicated.”

As the kidney is offered to one potential recipient after another, crucial time passes (a cadaveric kidney must be transplanted within 72 hours) — leading to the loss of about 10 percent of donated kidneys each year in the United States. “Individual decisions aggregate into social behavior,” says Zhang, who investigated the transplant data for her PhD dissertation at the University of California Berkeley.

While marketing experts like Zhang more often examine decisions about consumer products, the fundamental questions apply equally to the organ market, she says. “Hospitals provide organs and the patients choose, and they don't always choose based on the same criteria.”

Understanding observational learning has

public policy implications as well, according to Zhang, whose recent research centers on the hot topic of whether to label foods as deriving from genetically modified organisms (GMO). Currently, 70 percent of US foods fall into this category, with no labeling required. But, several states have considered mandating GMO labeling.

Zhang surveyed shoppers and discovered that even proposing a mandate affects public opinion. “[The proposal itself] is sending a negative signal, a sort of social stigma,” she says. “People's perception of GMO safety is lower once we give the impression of mandatory disclosure.”

The bottom line, Zhang says, is that actions can have unexpectedly significant societal consequences — which is why it's so valuable to study human behavior. “From the purely scientific perspective, we just want to know why things happen in the way that they're happening,” she says. “We always talk at a high order about social behaviors, but no matter what we observe in the end, that's coming from individual decisions.”

— KATHRYN M. O'NEILL

Investments in the Future



Jonathan Rothberg in front of an image representing the portal he invented between the biological and digital worlds.

Courtesy Jonathan Rothberg

Funding Basic Research

What fascinates Jonathan Rothberg about science is the ability to either learn something no one knew before or to create an instrument that enables the discovery of something new. He is a serial entrepreneur best known for inventing high-speed, massively parallel DNA sequencing. The company he founded, 454 Life Sciences, brought to market a new method for sequencing genomes. After creating the next-generation sequencing, he went on to develop the first sequencing on a semiconductor chip, thus enabling the \$1,000 genome. With this discovery he founded Ion Torrent, where they actually sequenced the genome of Intel cofounder Gordon Moore.

The idea for the high-speed sequencing came to him when his infant son was rushed to intensive care and he realized how critical personal genomes were to human health. That invention is now in use at major pharmaceutical companies, universities, genome centers, and medical centers around the world — and his son, Noah, lived to inspire yet another company.

Rothberg has supported Physics Professor Max Tegmark's research; he decided to get involved because of the tremendous scope of the project and the vision behind it. Tegmark notes that "Jonathan's generous support has

been invaluable for our Omniscope project, which is developing technology to help make the largest-ever 3-D map of our universe. He is an inspiration to me, with his knack for overcoming daunting challenges through outside-the-box technological innovation." Rothberg says of Tegmark: "He is one of those people who, as Steve Jobs was fond of saying, is actually putting a dent in the universe" and that "he intends to map the universe at a resolution never before obtainable."

Although Rothberg's undergraduate degree in chemical engineering is from Carnegie Mellon University and his PhD in biology from Yale, he encourages others to support science at MIT. "Ultimately, it is research that raises the quality of life, and if you love science and discovery and people, then you should support basic research."

Ion Torrent was acquired in 2010 by Life Technologies. Rothberg also founded CuraGen Corporation, a company dedicated to using genome technologies in drug development; RainDance Technology, a company developing general droplet microfluidic lab-on-chip technologies; and Clarifi Corporation, an analytical software company. Rothberg is inspired to create companies that impact the quality of life and is always looking for like-minded people to join him.

— ERIN MCGRATH (*A version of this story ran in physics@MIT.*)



Victoria Seaver Dean is president of The Seaver Institute, a foundation that supports basic research.

Richard Howard

Philanthropic Support

Victoria Seaver Dean is president of The Seaver Institute, a foundation that since 1983 has supported nine MIT projects involving basic research in a wide range of fields, from marine science to musicology to the molecular causes of aging. Those projects have since launched the careers of several MIT professors who have gone on to distinguish themselves in their fields and in the academy. Two, for example, have won the National Medal of Science, and one is an MIT Institute Professor.

“In 1983, The Seaver Institute introduced a program that I call ‘seed money for research,’ where we give money to start a project to see if a novel idea will work. If it works, we know that other people will fund it and ramp it up from its seed phase into a larger phase. We generally provide the first two years of support to get a high-risk idea off the ground.

“That’s important because the government doesn’t really support research at that stage anymore. Over time, government agencies like the National Science Foundation and the National Institutes of Health have become conservative. They want to know that a project is going to be successful. We don’t mind the prospect of failure. Frankly, there are very few projects that, quote, fail. Something is always learned even if it isn’t necessarily what was originally intended.

“So we fill a gap in the funding cycle, and we’ve been told since the get-go that this is very important. And it doesn’t have to be a young researcher. It could be someone who has a lot of skill and experience in one area, but who wants to take that skill to another field. It’s often hard to get funding for that because it’s not the main focus of their work.

“Unlike other foundations, we sprinkle our funds around to launch a number of potential ideas as opposed to focusing on one particular problem or area.

“One MIT project is my poster child for what we like to fund because, first of all, it’s cross-disciplinary. In music21, Dr. Michael Scott Cuthbert bridged the fields of computer science and music theory to create software for the analysis of music.” [Cuthbert is a pioneer in digital musicology, the idea that if you turn huge numbers of songs into data and analyze it with a computer, you can learn things about music that are otherwise difficult or impossible to know.]

“You could use music21, for example, to determine what makes French music French. Plus, it’s an open-source program so everybody can use it, and it encourages modifications so people can adapt it to different musical styles.

“Anyway, he had a problem that needed to be solved, but no one would fund his innovative idea. And now, music21 has made a huge difference in the music world. The whole world is enhanced.” — ELIZABETH THOMSON

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URIECA MOMENT



Julia Berk says that reliving a professor's eureka moment opened up the world. Len Rubenstein

“That I’ll have my own eureka moment. That’s the dream,” says senior Julia Berk.

The eureka moment is famously attributed to Greek scholar Archimedes. The story goes that one day he stepped into a bath and in a flash of insight suddenly realized that the volume of the displaced water must be equal to the volume of his submerged body.

Often at MIT, these moments occur for students in the Undergraduate Research Inspired Experimental Chemistry Alternatives (URIECA). It’s a lab curriculum in the Department of Chemistry, where undergraduates replicate cutting-edge faculty research, experiencing the same process that led MIT faculty to glorious eureka moments.

Berk recently recreated a leading experiment originally done by Prof. Christopher Cummins. “Nitrogen is one of the most stable molecules in the world, the second strongest bond in chemistry,” she says, adding that Cummins miraculously found a way to break the triple bond in nitrogen under moderate conditions. “It was a huge discovery, a huge deal. You don’t ever think it can happen, and then all of a sudden, there it is.”

Discovery is sheer thrill, she says, and although she didn’t experience the initial discovery herself, reliving his eureka moment was a blast of inspiration.

“It opens the door to a whole new world of opportunities. I keep thinking that there might be things never done before that I can do. Maybe I can synthesize a new compound that would be useful in pharmaceuticals. Or maybe I could create a new color I can make into paint.

“When you do something novel, you don’t always know what you can do with it. But,” she adds, “it doesn’t have to become a product. There’s a lot of value in scientific discovery just for discovery. There’s value in knowledge. It’s a way of thinking. It’s just so interesting to study because it’s beautiful, new, unexpected, and interesting.”

— LIZ KARAGIANIS