DISCOVERY

RESEARCH AT PRINCETON

2017-2018

PRINCETON UNIVERSITY

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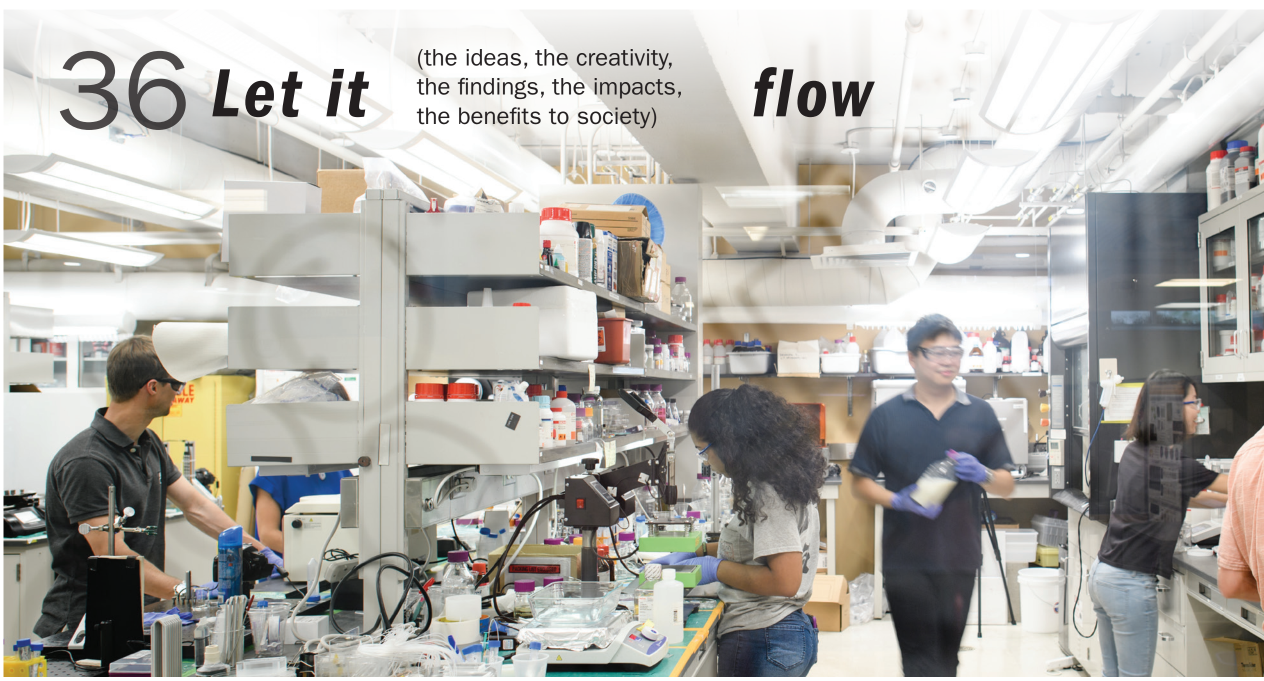

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From the Dean for Research

Pablo Debenedetti

Dean for Research, Class of 1950 Professor in Engineering and Applied Science, Professor of Chemical and Biological Engineering

PHOTO BY FRANK WOJCIECHOWSKI

The opportunity to grow

It is always exciting to welcome new faculty to Princeton. In this issue of *Discovery: Research at Princeton*, I am pleased to introduce our readers to some of these passionate individuals, ranging from early-career faculty who are setting up their first laboratories to seasoned leaders who bring to campus their experiences in mentorship, teaching and intellectual leadership.

At Princeton, our faculty, students and postdoctoral researchers collaborate and share insights as a way to expand the realm of human understanding. Whether from the departments of classics or computer science, molecular biology or mathematics, our researchers pursue knowledge that benefits humanity. The full impact of this research may not always be immediately realizable or recognizable, but the contribution to our collective knowledge inspires further creativity and fosters the innovations of tomorrow.

As you read about our newcomers and their dedication to improving our lives and our planet, I hope you'll reflect on the importance of continued support for research funding. Our nation's universities train some of the best scientists and educators in the world. Their ability to generate innovations and insights stems in large part from public support for research.

This support enables early-career researchers like Nathalie de Leon in electrical engineering, who is developing ways to image single molecules, and Martin Jonikas in molecular biology, who studies algae to learn the secrets of their rapid growth with the long-range goal of boosting the growth of crops, to come to the lab each day motivated to make new discoveries. I hope this magazine gives you insights into the inspirations and motivations of these faculty members and their teams of students and postdoctoral researchers. These are the people who hold our future in their hands.

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Cover: Algae grow fast. Could we learn their secrets and speed up the growth of crops? Researchers led by Martin Jonikas, an assistant professor of molecular biology, are studying a component of algae called the pyrenoid (pictured) that concentrates carbon dioxide for photosynthesis. The blue ball-like structures are enzymes that help convert carbon into sugars for plant growth. The yellow tubules inside the green tubes are thought to bring carbon and other materials into the pyrenoid. Read more starting on page 20.

IMAGE COURTESY OF BENJAMIN ENGEL, MAX PLANCK INSTITUTE OF BIOCHEMISTRY

RESEARCH NEWS

A challenge to **help kids**

A COLLABORATIVE APPROACH to sociology aims to target fundamental and perhaps overlooked issues to improve policies that affect the lives of disadvantaged children.

The effort, called the Fragile Families Challenge, brings together researchers from around the world, most of whom haven't met before, to ask them to analyze existing data and create models that can identify problems and lead to potential policy solutions.

"I am very excited about the idea of seeing what it is that we can all do together that none of us can really do alone," Matthew Salganik, a professor of sociology and one of the founders of the challenge, said. "Hundreds of biologists worked on the human genome project and thousands of physicists worked on the search for the Higgs boson, so what would happen if hundreds or thousands of social and data scientists work together on this problem?"

Analyses of data on families can inform sociologists about trends that affect children's well-being. For example, researchers might learn that "eviction is related to poor school performance," which can be useful for policy decisions.

To improve these analyses, Salganik and colleagues sent a request to researchers from across the globe to create predictive models using data from the Fragile Families and Child Wellbeing study, funded by the National Institutes of Health, which has been following nearly 5,000 U.S.-born children since their birth. The challenge for the scientists was to use data on children ranging from birth to age 9 to create models that would successfully predict the well-being of the families when the children reached age 15. Then Salganik and his team compared the predictions to how well the families were actually doing in terms of outcomes such as material hardship, eviction and layoffs.

Salganik and his colleagues combined the most accurate of these models — those that came closest to predicting the real conditions of the families — into a single community model that can be used by other researchers. They are now conducting interviews with the teenagers and their parents to discover important factors that even the best models didn't account for.
–By Yasemin Saplakoglu

PHOTO BY DENISE APPLEWHITE

The new 22-acre Lewis Arts complex includes spaces for the creation and performance of dance, theater, music and more.

New arts complex opens

THE NEW multi-building Lewis Arts complex on the south edge of campus significantly expands the performance, rehearsal and teaching spaces for the arts at Princeton. The complex anchors a 22-acre development that includes two restaurants, a convenience store and the new Princeton train station, surrounded by a park-like setting with extensive landscaped plazas, pathways and green spaces.

The complex houses the Lewis Center for the Arts' programs in dance, theater, music theater and the Princeton Atelier — a unique academic program that brings together professional artists from different disciplines to create new work — as well as additional rehearsal and instructional facilities for the Department of Music. **–By Catherine Zandonella**

FOCUS ON UNDERGRADUATE RESEARCH

New journal highlights **student research**

THIS SPRING marked the debut of the *Princeton Undergraduate Research Journal*, a peer-reviewed publication where students can publish original research findings. "The entire goal of research is to communicate new discoveries to a larger academic community," said Daniel D. Liu, who co-founded the journal with fellow Class of 2018 student Yash M. Patel. "We felt that a lot of valuable independent work by Princeton undergraduates was going unnoticed." The journal, peer-reviewed by an executive board of undergraduates and by a faculty advisory board, is open access, meaning it is available for anyone to read online. Liu and Patel aimed to introduce undergraduates to the process of peer review and to implement a rigorous review process parallel to that of established academic journals.

The editorial board encourages submissions from a broad range of disciplines from the sciences to the humanities and arts. "I personally have learned a lot about what's going on in other disciplines by going through this process, and I'm hoping that other readers of the journal will also," said Liu, who is majoring in molecular biology. The team plans to distribute the publication to prospective students and alumni. Interested undergraduates can submit their original research findings at purj.org. **–By Yasemin Saplakoglu**

Self-powered system makes
smart windows smarter

A NEW SOLAR CELL technology could make it inexpensive to create and install smart windows that automatically vary their tint to augment lighting, heating and cooling systems in buildings.

The new transparent solar cells selectively absorb near-ultraviolet (UV) light and convert it to electricity that powers chemical reactions to lighten or darken the glass of the smart window as needed. Smart windows are usually bulky to install because they require an external power source. The new solar cells allow smart windows to be self-powered and occupy the same footprint as the glass.

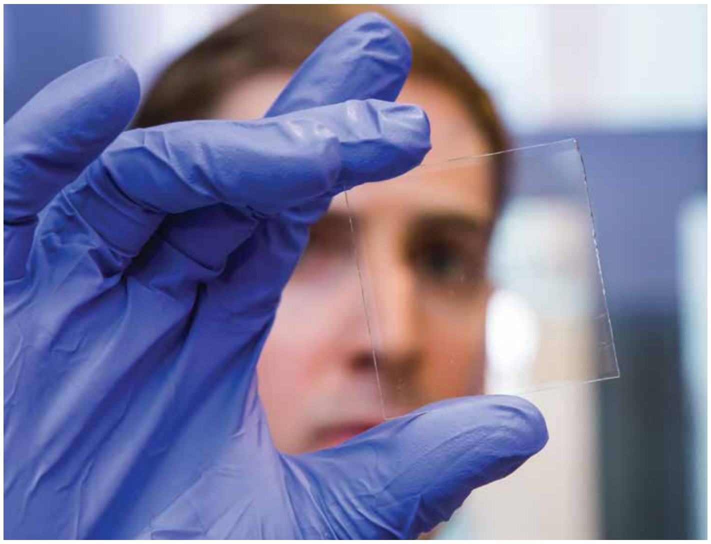
"We wanted the smart window to dynamically control the amount of natural light and heat that can come inside, saving on energy costs and making the space more comfortable," said Yueh-Lin (Lynn) Loo, director of the Andlinger Center for Energy and the Environment, the Theodora D. '78 and William H. Walton III '74 Professor in Engineering, and professor of chemical and biological engineering.

The study, published June 30, 2017, in the journal *Nature Energy*, received funding from the National Science Foundation.

Nicholas Davy, a doctoral student in the chemical and biological engineering department and the paper's first author, said the new transparent near-UV solar cells are better suited to power smart windows than existing transparent solar cells, which target the infrared portion of sunlight and thus complicate the control of heat.

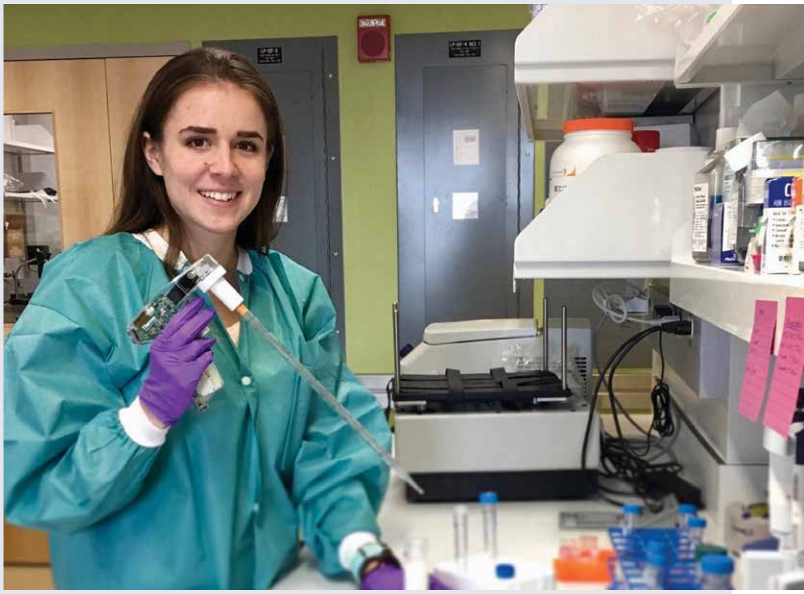
The Princeton team's aim is to create a flexible version of the solar-powered smart window system that can be applied to existing windows via lamination. Davy and Loo have started a company called Andluca Technologies to bring this energy-saving solution to residential and commercial buildings. **–By Sharon Adarlo**

PHOTO BY DAVID KELLY CROW



Graduate student Nicholas Davy holds a sample of glass that uses near-ultraviolet light to generate electricity, which powers chemical reactions that lighten or darken the glass.

PHOTO BY ALEXIS BAILEY



Emily Shuldiner, Class of 2016, was a co-first author on a study published in the journal *Science Advances* on genetic changes linked to dogs' social behaviors toward humans.

FOCUS ON UNDERGRADUATE RESEARCH

Probing the genetic basis for
dog-human relationships

A NEW STUDY has identified genetic changes that are linked to dogs' human-directed social behaviors and suggests there is a common underlying genetic basis for hyper-social behavior in both dogs and humans.

An interdisciplinary team of researchers, including those from Princeton University, sequenced a region of chromosome 6 in dogs and found multiple sections of canine DNA that were associated with differences in social behavior. In many cases, unique genetic insertions called transposons in the Williams-Beuren syndrome critical region were strongly associated with the tendency to seek out humans for physical contact, assistance and information.

In contrast, in humans, it is the deletion of genes from the counterpart of this region on the human genome, rather than insertions, that causes Williams-Beuren syndrome, a congenital disorder characterized by hyper-social traits such as exceptional gregariousness. The study, which was supported by the National Science Foundation and the National Institutes of Health, was published July 19, 2017, in *Science Advances*.

"It was the remarkable similarity between the behavioral presentation of Williams-Beuren syndrome and the friendliness of domesticated dogs that suggested to us that there may be similarities in the genetic architecture of the two phenotypes," said Bridgett vonHoldt, an assistant professor in ecology and evolutionary biology at Princeton and the study's lead author.

Emily Shuldiner, Class of 2016 and a co-first author, pinpointed the commonalities in the genetic architecture of Williams-Beuren syndrome and canine tameness as part of her senior thesis research.

VonHoldt's findings suggest that only a few transposons on this region likely govern a complex set of social behaviors. "We haven't found a 'social gene,' but rather an important [genetic] component that shapes animal personality and assisted the process of domesticating a wild wolf into a tame dog," she said.
–By Pooja Makhijani

Better decision-making
for the planet

PHOTO BY JESSICA BAL

Elke Weber studies the science of human behavior with the goal of encouraging environmentally responsible behavior.

WE might think we have control of the mix of decisions we make during the day. But it turns out that our brain gives us subconscious nudges, preferring some choices over others.

Elke Weber, the Gerhard R. Andlinger Professor in Energy and the Environment, studies how the science of human behavior can inform policies that encourage people to make good choices for the environment.

"For far too long, we've assumed that people's decisions are rational," said Weber, who is also a professor of psychology and public affairs in the Woodrow Wilson School of Public and International Affairs. "My research asks, in what ways can we understand what goes on in the brain and use that knowledge to help us all make better decisions?"

Weber researches how to design solutions to society's greatest problems, such as climate change. "It turns out we can do some psychological jiujitsu to convert seemingly negative choices into something positive," Weber said. In the psychology field this is called "choice architecture."

For example, merely renaming a choice to avoid negative associations can make an impact on people's decisions. Weber and colleagues found that airline passengers were far more willing to pay a surcharge to combat climate change if the fee was called a "carbon offset" instead of a "carbon tax."

Another aspect of choice architecture comes into play when talking about present versus future activities. Climate change seems far off to many people. But people tend to make choices based on the present or the immediate future, which psychologists call presence bias. "We focus on the here and now, which makes evolutionary sense," Weber said. "If you might not survive until tomorrow, what's the point of planning for next year?"

One way to combat presence bias is by tapping into people's desires to be remembered in a positive light, Weber and colleagues at Columbia University and the University of Massachusetts-Amherst found. If first prompted with questions about how they would like to be remembered, individuals are more likely to think about their future rather than their present selves, and therefore make pro-environmental choices. The research, funded in part by the National Science Foundation, was published in *Psychological Science* in 2015.

Then there's our inability to concentrate on more than one option at a time when we are presented with a choice. Weber and her colleague Eric Johnson, a business and marketing professor at Columbia, coined the "query theory" to explain how people internally generate more arguments favoring the first option they consider, temporarily inhibiting arguments in favor of all other options.

When a "default" option is given, it becomes the option we think of first, which puts it at an advantage. Weber gives the example of a hypothetical electric utility company that offers customers the opportunity to switch to "green" energy. Typically, fossil fuel energy is the default option, and few customers end up switching to the cleaner though somewhat more expensive green power. In contrast, when in lab and field studies the company made it the default option to choose "green" energy, a large majority of customers did just that. "In terms of what influences people's decisions, the million-dollar question is which option gets considered first," Weber said.

Weber's research demonstrates that changing the way choices are presented can play a role in conserving the environment through influencing people, the instigators of our warming planet.
–By Yasemin Saplakoglu

How cancer stem cells evade the immune system

WHEN Daniel D. Liu first encountered the world of research, he saw giants in white lab coats shaking flasks and squirting liquids into small vials. He was 4 years old, and his parents, both biochemists, would bring him to work and set him down with a book and instructions to keep quiet.

"I didn't really understand what was happening, but I guess that was my first impression of what adults do," said Liu, Class of 2018, who is majoring in molecular biology. It was no wonder that he went into the family business at a young age. During summer breaks in high school, he worked at the National Institutes of Health near his home in Potomac, Maryland.

At Princeton, Liu joined the laboratory of Yibin Kang, the Warner-Lambert/Parke-Davis Professor of Molecular Biology, where he focuses on breast cancer stem cells, which are a subset of cancer cells that can self-renew and cause tumors to spread or grow back after treatment.

In a study published earlier this year in *Nature Cell Biology*, Liu helped identify a molecule that protects cancer stem cells by shielding them from the immune system. When the immune system cannot attack the cancer cells, the cells can spread to surrounding tissues, a process known as metastasis and a leading cause of cancer-related deaths.

The team found that when cells produce a lot of this molecule — actually a short strand of genetic information called microRNA-199a — both healthy and cancerous cells take on stem cell-like properties such as a heightened ability to regenerate breast tissue and to create spherical clumps of cells called mammospheres.

This stem cell-like property is necessary for normal breast tissue functioning, but it is also fuel for cancer cells to survive and duplicate, helping them to escape from the suppressive effects of immune cells.

The findings may shed light on the puzzle of why immunotherapy, a cancer treatment that spurs the immune system to attack tumors, is highly successful against some types of cancer patients but does not work well for others.

"Everyone is really banking on immunotherapy as a breakthrough in cancer treatment, but it only works really well for some types of cancers," Kang said. "In breast cancer the response isn't great, and we don't really understand why."

As a result of this study, made possible through funding from the National Institutes of Health and the U.S. Department of Defense, Kang now thinks the lack of response to immunotherapy by some patients could, in part, be due to the microRNA's role in protecting the cancer stem cells.

Since the team now understands what guards the cancer cells, Liu said, "perhaps we can target this pathway so as to sensitize cancer stem cells to immunotherapy."

Liu's contributions to the lab go beyond bench experiments. Recently, he coded a user-friendly program that enables the team to sift through large patient data sets quickly, improving upon the lab's previous, manual approach. He also co-founded the *Princeton Undergraduate Research Journal* (see page 2) to help fellow students publish their work and learn firsthand about the peer-review process.

"Daniel not only does his own work but also makes life much easier for everyone in the lab," Kang said. "It's quite unusual for an undergraduate to make fundamental contributions to the lab that enable everyone to do research in a better way." **–By Yasemin Saplakoglu**

Undergraduate Daniel D. Liu co-authored a *Nature Cell Biology* study on the discovery of an RNA molecule that protects stem cells.

PHOTO BY WEIHONG XU

Professors Julian Zelizer (left) and Sam Wang record the weekly podcast *Politics and Polls* at the University's broadcast studio.

PHOTO BY EGAN JIMENEZ

Historian and neuroscientist team up for podcast

WHEN history professor Julian Zelizer and neuroscientist Sam Wang started the podcast *Politics and Polls* prior to last year's presidential election, they never dreamed it would still be going a year later. "We thought there wouldn't be much to talk about after Hillary won," Zelizer said.

Instead, the pair found themselves with plenty of new ground to cover. And Wang, who'd boasted on Twitter that he would eat a bug if Donald Trump won, found himself swallowing a cricket on national television.

Fast-forward to the present, and Zelizer and Wang continue to record weekly interviews with guests ranging from renowned journalists and politicians to playwrights. The podcast has become an influential source of commentary and analysis for policy-makers, journalists and the public. In the past year it has been downloaded 170,000 times on iTunes and it is ranked in the top 20 for political podcasts.

The discussion resembles a dinner table conversation among friends trying to make sense of the political world around them. The hosts contemplate unfolding events such as the Trump-Russia story, or discuss the impact of gerrymandering on elections. Or they may talk about immigration with an expert in that field, or debate Brexit's parallels to U.S. events.

Zelizer, who is also a commentator on CNN, said his background as a historian provides perspective on Trump's victory. "I don't tend to see partisanship as a product of 2017 as much as a product of 30 years of change in American politics, whose players I have been following closely," said Zelizer, the Malcolm Stevenson Forbes, Class of 1941 Professor of History and Public Affairs in the Woodrow Wilson School for Public and International Affairs. "At the same time, I'm sensitive to the way in which certain individuals can make a huge difference in key moments, in ways that historical data may not be able to predict."

The use of data to predict election outcomes is one of the areas of expertise that Wang, a professor of molecular biology and the Princeton Neuroscience Institute, brings to the podcast. In 2004, he started the Princeton Election Consortium, a blog that analyzes and predicts the outcomes of U.S. elections using polling data. While he stands behind statistical methods, he admits that the outcomes of the 2016 presidential election taught some new lessons.

"In news coverage and polling, there is this naive view that the way to find out what people think is to ask them," he said. But many people don't feel comfortable revealing information, he said, and it is useful to augment polling with information from people's online searches, social media posts and other behaviors.

The podcast is produced by the Woodrow Wilson School. Additional research for each week's episode is conducted by undergraduate Sophie Helmers, Class of 2019, who provides background information on speakers and possible questions to ask.

As to the future direction of the podcast, Wang and Zelizer haven't a clue — and they want to keep it that way. "I think it's a virtue that there is no grand strategy for where this goes," Zelizer said. "The election was so dramatic that it gave us an endless number of topics to talk about, and who knows what is going to happen next." **–By Yasemin Saplakoglu**

Listen to the Politics and Polls *podcast at woodrowwilsonschool.podomatic.com or download via iTunes, Soundcloud or other podcast services.*

Egyptian translation highlights
the beauty of hieroglyphs

SINCE he was in fourth grade, Tom Hare has been fascinated with Egypt. Although his career as a professor of comparative literature has focused mainly on Japanese works, he never forgot his love for the images and symbols of ancient Egyptian culture.

Now, Hare has written and illustrated a new book that brings the picture-based writing of ancient Egypt to audiences in an experimental way, as a "graphic translation" of a 4,000-year-old Egyptian fable. In the slim volume called *Sinuhe: Flight and Homecoming*, Hare weaves hieroglyphs and prose to create a narrative that retains the rich and colorful beauty of the symbols.

"It bothered me that translations of Egyptian works took these beautiful hieroglyphs and converted them into text," said Hare, the William Sauter LaPorte '28 Professor in Regional Studies. "The result is that you've lost the visual character of the original language."

The book tells the story of Sinuhe, a nobleman who flees Egypt during a period of unrest that follows a pharaoh's death. He finds a new and prosperous life in a land to the east, and returns home in his later years, uncertain of his reception from the new king.

The story was written during the age of the Middle Kingdom, which spanned from 2030 B.C.E. to 1700 B.C.E. It was preserved across the ages on two papyrus scrolls and on pieces of broken pots, and today is a well-known fable in the region.

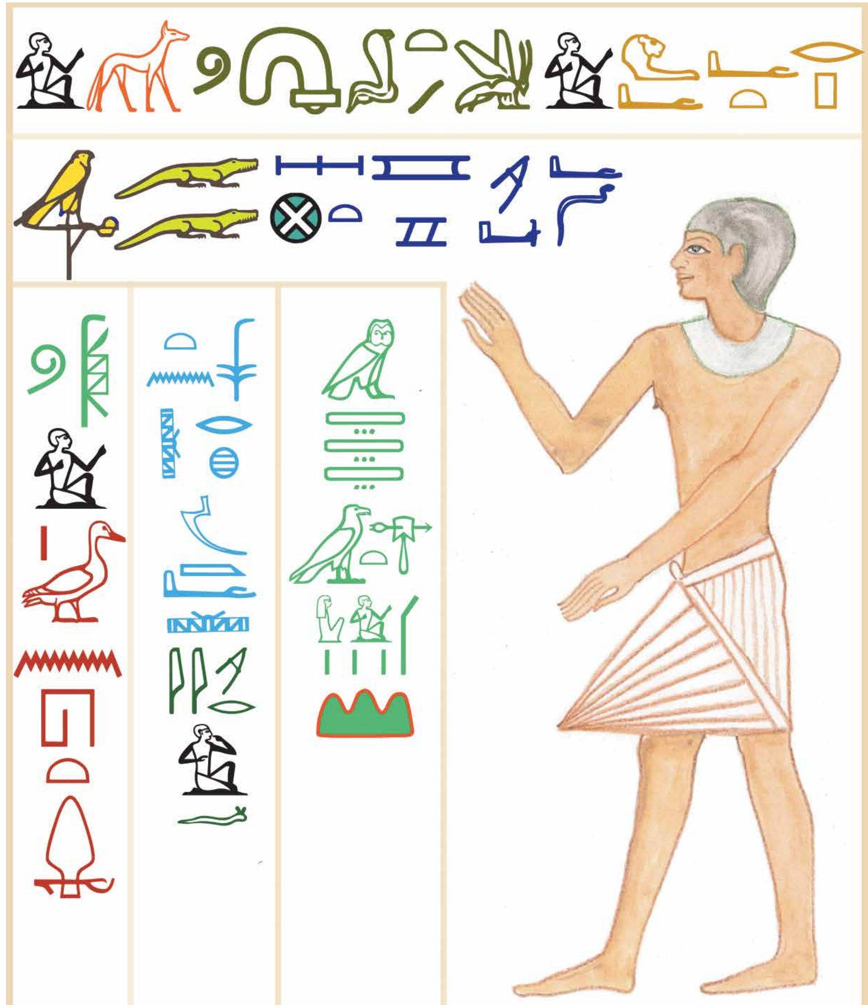
One of the challenges of creating the graphic translation was choosing which hieroglyphs to include, Hare said. Many hieroglyphs have a literal translation. For example, the cow represents livestock, so when the story says that Sinuhe amassed a fortune in livestock, Hare included several columns of cows. Other hieroglyphs are less literal but still evocative, like the dead goose that represents fear. Some hieroglyphs represent sounds, like the horned viper that represents the sound "f" but can also mean "he," "his" or "him."

Still other symbols were part of a Middle Egyptian form of cursive called hieratic. The latter half of the book contains notes on the translation, including discussions of where experts have disagreed on the exact meaning of a passage.

While preparing the book, Hare found that the visual nature of the volume demanded a great deal of experimentation on where to put the hieroglyphs and text, leading him to self-publish a limited number of copies. He is now editing it and eventually plans to seek a publisher.

Hare hopes the story of Sinuhe presented in this graphic format will help people channel their inner 10-year-old and learn to read hieroglyphs. "The visual elements make it possible for people today to get insight into what Egyptian culture was like," he said. "This is important given the foundational role of Egyptian culture in Western civilization." **–By Catherine Zandonella**

IMAGE COURTESY OF TOM HARE



PEER, ROYAL SEALBEARER,
DIGNITARY
SENIOR MAGISTRATE
FOR THE SOVEREIGN
IN THE LAND OF THE SYRIANS
TRUE INTIMATE OF THE KING,
WHO LOVES HIM
A FOLLOWER, SINUHE, IT IS

A classic Egyptian tale of a nobleman's adventures in foreign lands is the subject of an experimental translation that blends the art of hieroglyphs with English text.

PHOTO COURTESY OF ITER

Discovery provides a path to safe, clean, plentiful **energy**

The construction of a major new experimental fusion facility called ITER in Cadarache, France, will enable researchers to test the feasibility of fusion power. A Princeton Plasma Physics Laboratory discovery could help the giant reactor achieve success.

FUSION — the energy-producing reaction that powers our sun and most stars — can be a safe, clean and virtually limitless source for generating electricity on Earth, ending reliance on fossil fuels and curbing greenhouse-gas emissions. In the sun, gravity traps particles inside an ultra-hot charged cloud of gas known as plasma, forcing them to fuse and release their energy. On Earth, we use powerful magnets to force plasma particles to fuse and release their power at temperatures many times hotter than the center of the sun.

At the U.S. Department of Energy's Princeton Plasma Physics Laboratory (PPPL), which is managed by Princeton University, scientists have been making great strides in determining how to trap those particles in doughnut-shaped facilities called "tokamaks" — fusion devices that confine the plasma in magnetic fields in place of gravity.

Now, PPPL scientists have for the first time reproduced the key elements that double the tokamak's ability to prevent heat and energy loss that could slow or halt fusion reactions. Finding the factors that enable a doubling of the confinement of particles inside a plasma marks a major advance on the path to fusion energy and to creating an artificial sun on Earth to help power the world.

"This discovery provides understanding of a path to improved plasma performance," said Michael Zarnstorff, deputy director for research at PPPL. "It will enable physicists to predict with confidence the heating power required to keep plasma well-confined and to provide energy for the world."

This doubling of confinement, which has been poorly understood, is vital to current and future fusion devices, sometimes called "star jars," on the planet. The new understanding stems from a computer simulation that shows how a barrier can form to prevent the escape of heat and energy in plasmas.

PPPL scientists used a sophisticated computer code to show how the formation of the barrier occurs and reduces the turbulence at the edge of the plasma that produces such losses. The simulation took three days and 90 percent of the capacity of Titan, the fastest U.S. supercomputer, which can perform 27,000 trillion calculations per second.

"After 35 years, the fundamental physics has been simulated, thanks to the rapid development of the computational hardware, software and detailed physics understanding," said Choong-Seock Chang, managing principal research physicist at PPPL and leader of the nationwide team that developed the sophisticated code and produced the model.

Full understanding of the spontaneous transition to this mode, called high confinement, or H-mode, is essential for the demonstration of the feasibility of fusion power planned for a new international fusion facility known as ITER under construction in France. Operators of the seven-story, 23,000-ton machine must achieve H-mode to reach the goal of producing 10 times more energy than ITER will consume.

Understanding the transition will allow operators to predict the heating power needed to reach H-mode. The goal: to have predictions that are more accurate than projections based on today's tokamaks, since conditions inside ITER, the largest and most powerful fusion facility so far conceived, will be significantly different.

Coming enhancements of the code will be part of the Exascale Computing Project, a nationwide program to develop computers that will run up to 50 times faster than Titan, improving U.S. security, economic competitiveness and scientific capability. PPPL leads an initiative that will develop the first complete model of an entire fusion plasma that could fuel a promising new era of energy production. **–By John Greenwald**

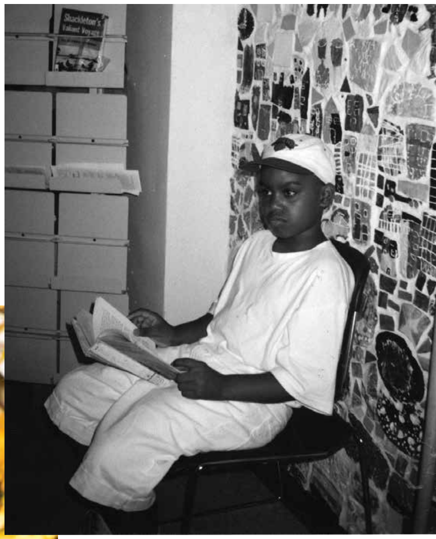
Professor reflects on growing up undocumented
and the power of books

WHEN DAN-EL PADILLA PERALTA WAS 4, he and his parents left the Dominican Republic and traveled to the United States for better medical care for his mother. Although his father returned to Santo Domingo, Padilla Peralta and his mother overstayed their temporary visas, subsisting partly on the public assistance funds received by Padilla Peralta's younger brother, who was born in the United States. The family spent a year in the New York City shelter system.

With support from a scholarship, Padilla Peralta attended a private high school, and he graduated from Princeton in 2006 as salutatorian with a degree in classics and a certificate in the Woodrow Wilson School of Public and International Affairs. After earning a master's degree in classics at the University of Oxford and a Ph.D. at Stanford University, Padilla Peralta was a postdoctoral fellow at Columbia University. His memoir, *Undocumented: A Dominican Boy's Odyssey from a Homeless Shelter to the Ivy League*, was published in 2015.

Padilla Peralta, undocumented no longer, joined Princeton as an assistant professor of classics in 2016. In this excerpt from the University's "What I Think" faculty interview series, he reflects on his childhood inspirations and his current area of inquiry. **–By Jamie Saxon**

PHOTO BY JEFF COWAN



Above: Dan-el Padilla Peralta, age 9, reads a book in spring 1994 in the Bushwick Family Center, one of the shelters he lived in with his mother and brother. Left: Padilla Peralta on campus in the fall of 2016.

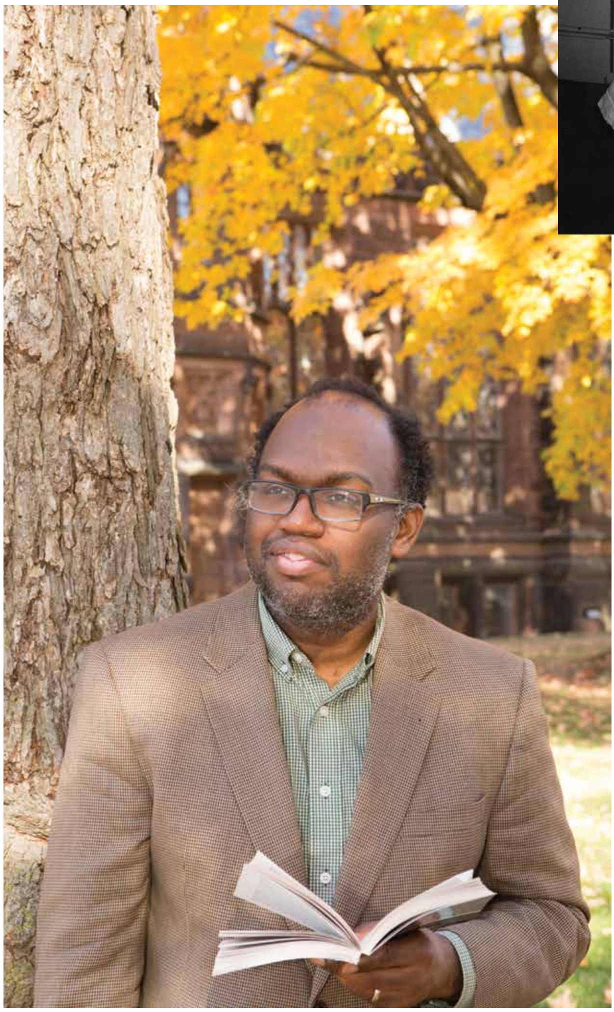


PHOTO BY DENISE APPLEWHITE

Growing up, I drew sustenance from books. Books provided me with the raw material I needed to construct a vision of what not only my future but my family's future, my community's futures, should look like.

One of the most salient memories I have of the first shelter we stayed in was the smell of the bathroom; it was rank and overpowering. It was very loud in the hallways. In the shelter's library, I discovered the book *How People Lived in Ancient Greece and Rome*.

I started reading* The Odyssey *in middle school, and it spoke to me. Initially, Telemachus' constant negotiation of the challenges of adolescence and young adulthood and his acute feeling of loss from not having a father figure resonated with my own experiences.

I'm fascinated by the influence of ancient Greek on rap music. Jay-Z raps in one song on the album "Watch the Throne" he made with Kanye West, "Is pious pious 'cause God loves pious?" This is a pretty unmistakable reference to Plato's Euthyphro, in which one of the questions raised by Socrates and Euthyphro is, "Is the pious known as the pious because the divinity has defined it as pious?"

I'm challenging my students to do some serious thinking about the long history of exclusion. For example, Romans understood their own cultural history as being pluralistic, yet they repeatedly defined themselves by excluding certain others. You have a culture that is, on the one hand, preoccupied with targeting and expelling certain communities and yet at the same time is aware of the degree to which its own origins are implicated in cultural difference, in migration, in mobility — this is the scope of the paradox that I want my students to appreciate.
–By Dan-el Padilla Peralta

Money matters:

An economist on the Fed, the banks and the future

By Catherine Zandonella

IT'S BEEN NINE YEARS since the start of the Great Recession, and economies are still recovering worldwide. Economists are still debating — not about the causes of the crisis, which involved shoddy lending standards and economic opportunism — but about what can be done to prevent future calamities.

Markus Brunnermeier's research explores the underlying mechanisms behind the crisis and suggests possible solutions. His insights are part of a new *Money and Banking* video series he created to explain these concepts to his students and the public.

The German-born economist has been studying bubbles and their inevitable messy bursts since coming to Princeton in 1999. Brunnermeier grew up in Bavaria under the expectation that he

Markus Brunnermeier is the co-author of *The Euro and the Battle of Ideas* with Harold James, the Claude and Lore Kelly Professor in European Studies and professor of history and international affairs at Princeton, and Jean-Pierre Landau, a professor at Sciences Po, Paris (Princeton University Press, 2016).

PHOTO BY DAVID KELLY CROW

would take over his family's carpentry business, but in his early 20s, he pivoted to follow a dream he'd had since 10th grade — to study economics and apply his knowledge to improving how people live.

He does this through his research on how government central banks like the U.S.'s Federal Reserve System (the Fed) can keep the economy healthy. Central banks can inject money into a wobbly economy. But how can they do this in a way that stabilizes the economy without unleashing inflation? Should they rescue banks, or help consumers?

These are questions that Brunnermeier, the Edwards S. Sanford Professor of Economics and director of the Bendheim Center for Finance at Princeton, and an academic consultant to the Federal Reserve Bank of New York, has studied for the past several years with his collaborator, Yuliy Sannikov, a former Princeton professor of economics who is now at Stanford University. They put forth their ideas last year in a working paper titled "The I Theory of Money."

More about what the "I" stands for in a moment, but first, it helps to have a little background. Many people do not realize the role that banks play in injecting new money into the economy. Although some of the money in the economy comes from the Federal Reserve, money is also created when banks grant loans, including mortgages. These loans do not come from stacks of bills retrieved from a vault — rather, they stem from newly issued electronic money. In fact, banks and other financial institutions have become the largest source of new money in the economy.

These loans can carry some risk, however. When the financial crisis of 2008 hit, some borrowers defaulted, leaving financial institutions with less money to meet their obligations. To compensate, banks sold some of their existing loans to other financial institutions at fire-sale prices. With few buyers for these risky loans, the prices fell even more, driving a "liquidity spiral."

The banks also granted fewer new loans, creating less new money. Consumers, fearing job losses, started holding more savings. In short, banks lowered their money supply at the same time that consumers expanded their demand for money. To attract buyers, producers lowered the prices of goods, causing deflation.

Deflation is bad for banks because they have to pay depositors in money that has become more valuable than it was when deposited. Deflation is also bad for the economy as the value of the debt rises for indebted homeowners and businesses. As businesses earn fewer profits, they may lay off workers and cut expansion plans. The economy stagnates instead of recovering. Each bank tries to be more prudent by reducing its leverage, but when all banks do this, the overall risk in the economy rises, leading to what Brunnermeier and Sannikov call the "paradox of prudence."

One key to stopping these negative feedback loops is to restore the banks' ability to start lending again, Brunnermeier and Sannikov argue. Once banks start lending, they can again create new money, which the researchers call "inside" money. This is the "I" in the I theory of money.

The I theory suggests that when faced with the choice to help floundering banks or flailing consumers, the right choice is to help the financial sector because it is the bottleneck to recovery.

One way that the Fed can help switch off the adverse feedback loops is by cutting interest rates. To see how, imagine that a bank holds long-term loans that are being repaid at a fixed 5 percent interest rate. If the rate goes down, those old loans increase in value because they bring in more money than new loans issued at the lower rate. "This is like a helicopter drop of money to the banks," Brunnermeier said.

The I theory suggests that the Fed's decision after the 2008 crisis to lower interest rates, and to shore up banks by buying their troubled assets, both helped individual consumers by keeping home prices from falling and helped stabilize these bottlenecks in the economy. "Before the financial crisis, people thought that as long as you keep inflation in check, everything will be fine on the financial stability side, too," Brunnermeier said. "What the crisis has shown is that price stability does not automatically imply financial stability."

How can this research lead to a safer future? Monetary policy — the toolbox of central banks — as well as an economy-wide prudential policy that limits risky lending, needs to be proactive and take steps before a crisis occurs, Brunnermeier said.

"Economists are like doctors — we can warn about the risks of too much cholesterol but we cannot tell you exactly when the heart attack will strike," Brunnermeier said. Economists also cannot always force patients to take their medicine or change their lifestyles. And patients can usually find someone willing to give them a different second opinion.

Brunnermeier hopes his research will help central banks make sound policy decisions. They are already picking up on his research. "Economics as a field is about helping policymakers and the public make better decisions, whether on monetary policy or on how to save for retirement," he said. "Without it we would be poorer not only financially but also in terms of our well-being." **D**

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Jane Cox

on LEDs, lighting design and the role of light in storytelling

By Catherine Zandonella

PHOTO BY DAVID KELLY CROW

WHEN PRINCETON'S NEW LEWIS ARTS COMPLEX was under design, Jane Cox was one of the primary advocates for going all-LED in the new theatrical performing spaces.

"It was a risk to go to all LEDs because the technology for entertainment is changing fast, but the decision was for Princeton to be at the forefront of energy efficiency in design," said Cox, director of the Program in Theater and a senior lecturer in the Lewis Center for the Arts. "We also decided that our basic lighting systems should be automated for maximum flexibility, and are betting on the sophistication of our students to learn to engage with these systems and maximize their potential."

With the opening of the new complex, Cox will oversee one of the first all-LED theaters in an educational setting. Automated LED lights provide versatility in creating different lighting states and they consume vastly less power than traditional light sources.

The lighting systems also honor the vision of Cox's predecessor as director of the theater program, Tim Vasen, who died in 2015. "Tim loved to push boundaries and embrace technology," she said. "I think he would be happy to see what has been accomplished."

Cox has created lighting designs for theaters from London to Los Angeles and has twice been nominated for a Tony Award for her lighting designs in Broadway productions.

Learning to work with light as a form of creative expression means learning how light functions, how we see it and how we relate to it, Cox said. She was drawn to lighting design while studying music as an undergraduate at the University of London, and she finds many parallels between lighting and music.

"Both lighting and music are about temporal relationships," Cox said. "Everything is experienced in relationship to what you just heard or just saw. Light is experienced in time, and has a harmony and a melody. Changes in light are experienced physically, and can profoundly alter the relationship between the performers and the audience," she said.

Light's color, angle, intensity, movement — each can bring meaning to a character's lines and arouse emotions in spectators. For example, for a 2016 production of New York Theatre Workshop's *Othello* starring Daniel Craig and David Oyelowo, Cox lit the set using only contemporary military lighting gear. "It is hard to put into language the psychological impact of sharing a space lit with emergency lights or by red headlamps," she said.

With the new theater lighting, Cox is excited to be able to explore with her students ways that technology can enhance person-to-person interactions. "I'm in theater because I am interested in what happens when we put people in a room together," she said.

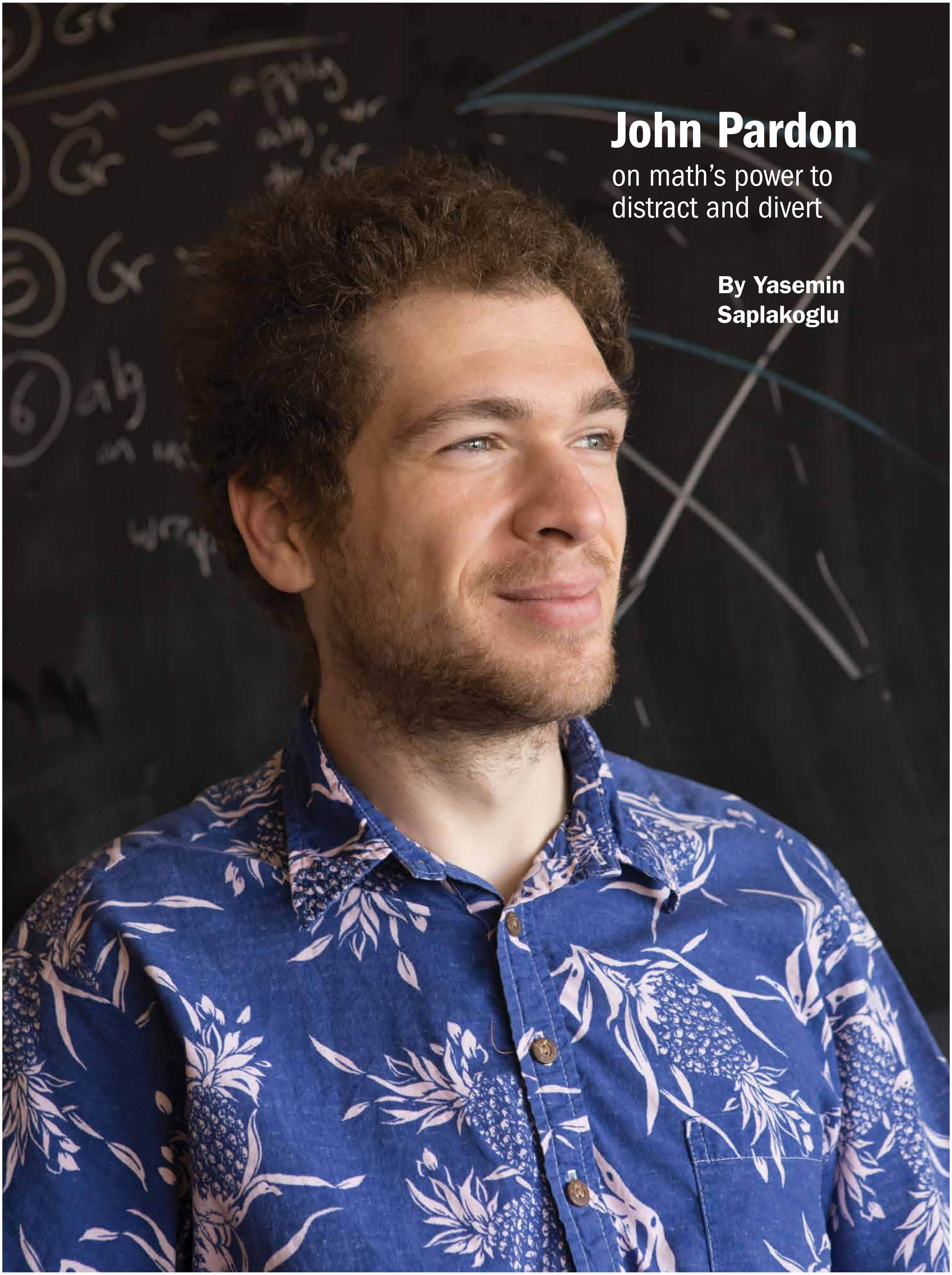
Our response to light infuses the art of visual storytelling, whether it is in a play, a film, a video game or virtual reality, Cox said. "Our relationship to light is so primal. Light is one of the first things we experience in life," she said, "so it is no surprise that it is integral to how we experience theater." **D**

PHOTO BY DENISE APPLEWHITE

John Pardon

on math's power to distract and divert

By Yasemin Saplakoglu



GETTING A TIRED and hungry 12-year-old to hike another mile up a steep mountain is a daunting task. But John Pardon's parents quickly figured out a simple solution that saved many of their family vacations from stress and despair: distract him with math.

Pardon's father, William Pardon, a mathematics professor at Duke University, would ask him probing algebra questions as soon as his son's legs began to ache and his pace slowed down.

It was a tactic his parents used on many occasions. When he was 5, his parents whispered something in his swim teacher's ear. Pardon, too scared to tread water, suddenly found his arms and legs moving as he answered his swim teacher's multiplication questions.

Pardon, appointed a professor of mathematics in 2016 just five years after he was the valedictorian of Princeton's undergraduate Class of 2011, grew up in Durham, North Carolina. He spent his childhood solving puzzles, building circuit boards and robots, and eventually writing computer programs as he entered his teenage years.

During high school, Pardon took math classes at Duke and attended a handful of programming competitions, most notably the International Olympiad in Informatics where he won a gold medal three years in a row.

As an undergraduate at Princeton, his successes culminated in solving a problem posed in 1983 by the Russian-French mathematician Mikhail Gromov.

"I knew about this problem for a couple of years before I actually did anything about it," Pardon said, recalling how he scrolled through various math problems online in preparation for a national science competition as a rising senior in high school.

The summer before he entered Princeton, Pardon continued to think about the problem, which asked whether a specific type of knot without any ends, called a "torus knot," could be tied without altering its shape.

"The most interesting problems, like this one, are the ones where you have absolutely no idea where to start," he said. Pardon typically doesn't start on paper, but spends time working out the problem in his head and imagining possible directions it could take.

A few years later, as a junior who was not only majoring in math but also finding time to play the cello and learn Chinese, he almost figured out a solution. "I thought I solved it for like two weeks," Pardon said, laughing. "It was complete nonsense."

When his senior year rolled around, he finally figured out the answer. He realized that if he were to unwind the complex, mind-boggling mathematics, the answer was: no, you could not tie a torus knot without altering its shape.

"He walked into my office, handed me the manuscript of his proof and asked me if I could read it, without making a big deal out of it," said David Gabai, the Hughes-Rogers Professor of Mathematics and the chair of the department. "This exemplifies his modest, unassuming persona."

This finding was published in the *Annals of Mathematics*, one of the top journals in the field. The accomplishment landed Pardon a top honor for undergraduates, the 2012 Morgan Prize, given jointly by the American Mathematical Society, the Mathematical Association of America, and the Society for Industrial and Applied Mathematics.

As an undergraduate, Pardon also received the 2010 Barry Goldwater Scholarship, a national award for sophomores and juniors in the natural sciences, mathematics and engineering.

"The most interesting problems are the ones where you have absolutely no idea where to start."

John Pardon
Professor of Mathematics

He also published a paper on a generalization of a solution to something called the carpenter's rule problem, which asks whether a polygon in a plane made of rigid metal rods connected end-to-end with hinges can be moved continuously so that it becomes convex.

Pardon later went on to receive a National Science Foundation Graduate Research Fellowship to support his graduate studies at Stanford University, where he became an assistant professor after receiving his doctorate.

At Stanford, Pardon proved a special case of the Hilbert-Smith conjecture, which involves the mathematics of "manifolds" — shapes that include spheres and doughnut-shaped objects. Then he began to explore a question about intersecting shapes.

Pardon brought this question back to Princeton, where he focuses on geometry and topology. He is now counting intersections in infinite-dimensional spaces. For example, the space of configurations of a piece of string, which has infinitely many points, on a plane are infinite-dimensional. "Ideally I want to develop a framework for doing this that just always works and you don't have to think about it anymore," Pardon said.

In April 2017, Pardon received the National Science Foundation Alan T. Waterman Award, a $1 million grant awarded to early-career scientists and engineers.

On the occasional evening, Pardon can be found in an empty classroom in the mathematics building, playing Bach or Kodály on his cello. "I really cannot think about math when playing music," he said. "Both require my full attention." **D**

Diamonds' flaws

hold promise for new technologies

By Yasemin Saplakoglu

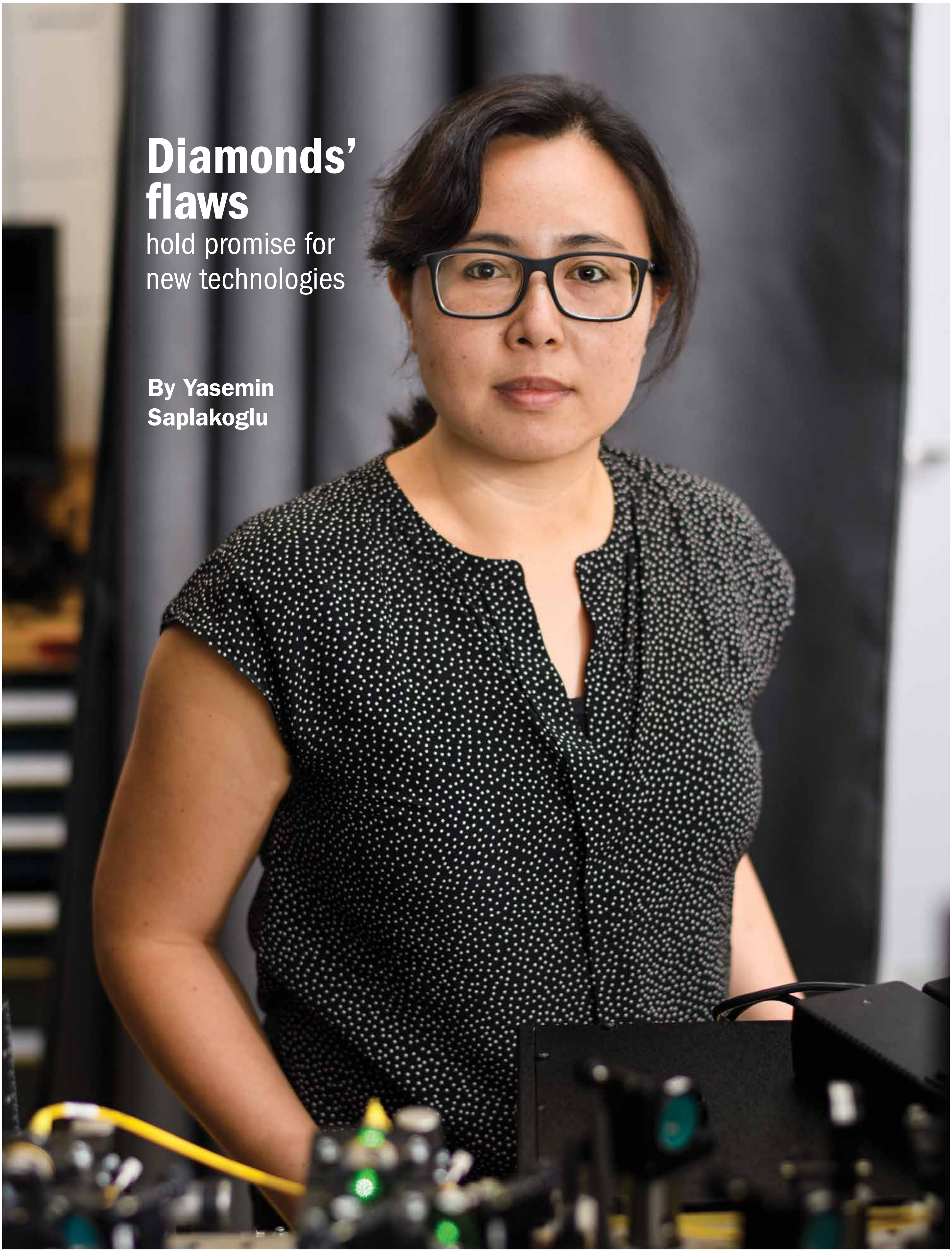


PHOTO BY SAMEER A. KHAN/FOTOBUDDY

DESPITE THEIR CHARM AND ALLURE, diamonds are rarely perfect. They have tiny defects that, to assistant professor Nathalie de Leon, make them ever so appealing. These atom-sized mistakes have enormous potential in technologies for high-resolution imaging and secure communication lines.

"Historically, people called these defects 'color centers' because when you shine light on a diamond you see a bunch of pretty colors come back," said de Leon, who is appointed in the Department of Electrical Engineering. She wants to harness the properties of these defects to image molecules and proteins.

A diamond is a tightly knit lattice of carbon atoms. By kicking out one of the carbons and adding a nitrogen atom nearby, the researchers can create a defect known as a "nitrogen-vacancy color center." The nitrogen atom and the dangling bonds around the missing carbon atom form a sort of molecule within a small area of the diamond lattice. This area of the diamond acts like a verdant oasis in the middle of a desert, displaying very different properties than the rest of the material.

De Leon is working on using a nitrogen-vacancy color center near the surface of a diamond to capture images of molecules. The approach takes advantage of a property of the defect known as "spin," which is analogous to the momentum of a spinning top. These spins interact with the molecule's magnetic field, which varies from one part of the molecule to another. The signals from these interactions can be collected and processed to make an image that is very high in spatial resolution — high enough to image a single molecule of DNA.

For this to work, the only signal emanating from the surface of the diamond has to be the one from the color center. But that's a difficult feat, as the moment the diamond is exposed to air, its surface atoms latch onto molecules floating around. Further, cutting or polishing one of the hardest materials in the world brings other unwanted defects to the surface.

All of these extra signals cloud the measurement. In fact, when researchers try to remove the unwanted defects from an initial polish, they inadvertently create more defects that again need to be removed. "You have a mouse problem, so you release the cats, and you have a cat problem, so you release the dogs. It just keeps going," de Leon said. Finding ways to improve the diamond surface is an ongoing area of research, and de Leon is hopeful that a combination of chemical treatments and a high-purity environment might do the trick.

Color centers for communication

While these color centers may eventually serve as sensors for biological applications, they can also be the basis for new communication networks — ones that would make eavesdropping impossible.

In quantum communication systems, an eavesdropper would not be able to read a message without immediately altering its state, thus exposing the attempt to pry into the message. It would also be impossible to copy a quantum message.

Making the signals robust enough to travel long distances has stalled the development of quantum technologies, de Leon said. She is working to build a "repeater" that can boost the signal and forward it through a cable until it reaches its destination. This would require a material capable of making quantum memories. The material would store and recover the original signal to propel the signal through the cables.

"What we are looking for is the heart of this quantum repeater," de Leon said. Her team recently discovered a candidate for such a heart: a defect within a diamond in the form of a large silicon atom hovering between two holes in the lattice.

It turns out this defect has very good charge and light properties, two necessary ingredients for a good quantum memory. The defect is also more resilient to interference by electric fields from the environment than other approaches.

De Leon, who arrived at Princeton in 2016 after completing her Ph.D. and a postdoctoral stint at Harvard University, is now exploring how to make this quantum repeater. Her work is supported by the National Science Foundation, the Air Force Office of Scientific Research and the Alfred P. Sloan Foundation.

"Nathalie came to Princeton with materials knowledge and combined it with physics," said Stephen Lyon, a professor of electrical engineering who directs Princeton's Program in Engineering Physics. "There are all these quantum things that people want to do and in the end everything depends on materials — it all comes down to how you get the material to do what you want."

De Leon wonders whether quantum communication can be made secure and robust before our current encryption schemes succumb to security challenges.

She hopes the hearts of quantum repeaters will start to beat before that happens. **D**

Researchers led by Nathalie de Leon are turning diamonds into devices that can image single molecules. The device uses a defect in the crystal structure called a nitrogen-vacancy color center. When disrupted by the molecule's faint magnetic field, the defect gives off red signals that can be used to construct an ultra-high resolution image of the molecule.

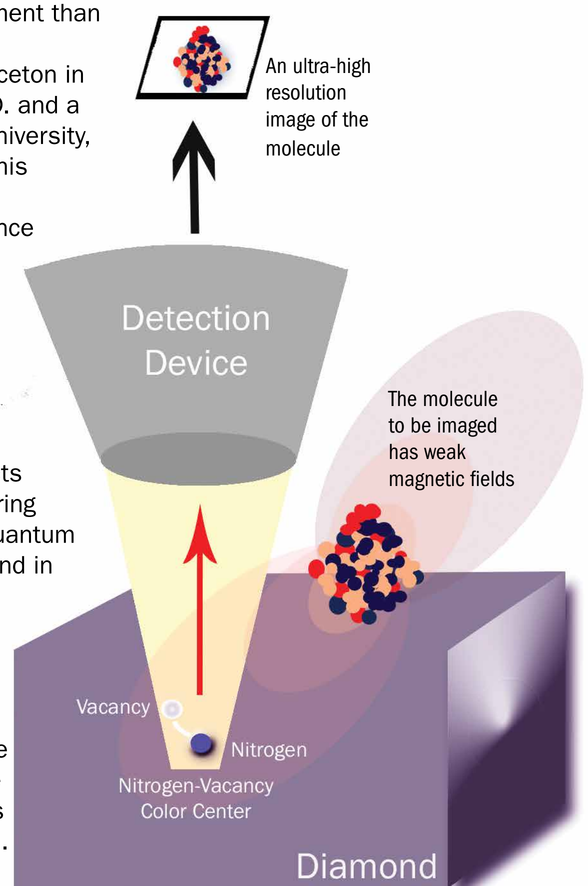


ILLUSTRATION BY YASEMIN SAPLAKOGLU

Lights, camera, action
of genes in development

By Yasemin Saplakoglu

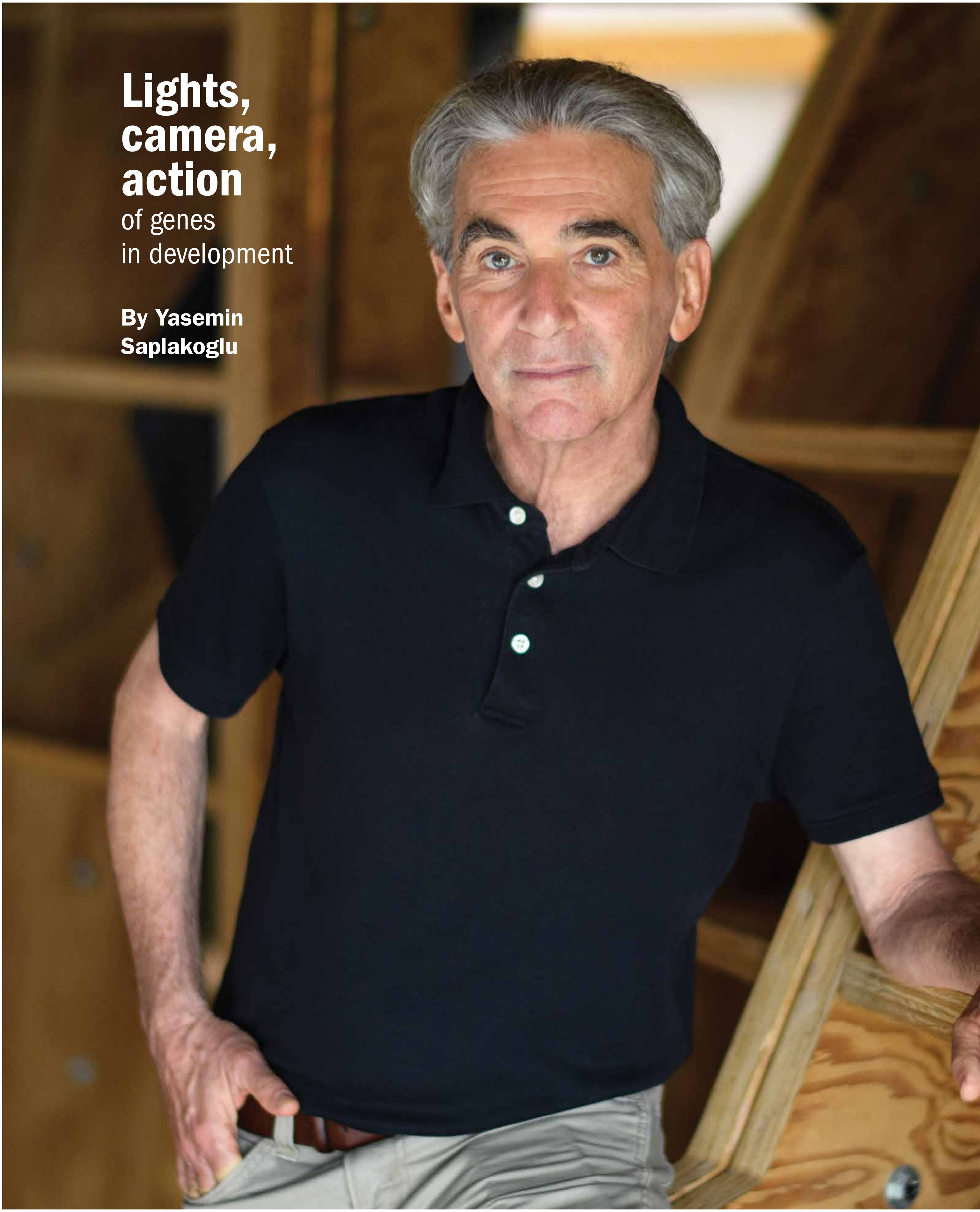


PHOTO BY SAMEER A. KHAN/FOTOBUDDY

MOLECULAR BIOLOGIST MIKE LEVINE likes to recall his childhood when he talks about the reason he came to Princeton. "I grew up near Hollywood and I always loved movies as a kid, so when I saw that Princeton scientists were capturing videos of gene expression in living organisms, it personally resonated with me."

Levine uses live-imaging and other methods to study the regulation of genes involved in the development of an organism from embryo to adulthood. He aims to reveal the secrets of how hidden pieces of the genome precisely dictate development so that each fruit fly has two wings and each human has five fingers and five toes.

Live-imaging makes it possible to see genes in action, Levine said, sitting in his office at Princeton, where he is director of the Lewis-Sigler Institute for Integrative Genomics. He points to a video of a fruit fly in the very early stages of life. Within the football-shaped embryo, the genes, labeled with fluorescent dyes, flicker on and off, eventually creating seven segmentations across the organism. Each section will differentiate into a different part of the insect's body. "This is a very magical period where the genes are creating the blueprint of an adult fly," he said.

This flickering effect occurs due to bursts of activity when genes are repeatedly turned on and off within a couple of minutes. Levine, the Anthony B. Evnin '62 Professor in Genomics and professor of molecular biology, and his team use the fly to explore how and why gene expression occurs in staccato bursts rather than smoothly, as was once thought. Many of the genes responsible for fly development were identified by Princeton's Eric Wieschaus, a Nobel laureate and the Squibb Professor in Molecular Biology, professor of molecular biology and the Lewis-Sigler Institute for Integrative Genomics.

Levine, who joined the Princeton faculty in 2015, previously studied development in the fruit fly, a widely utilized model for higher forms of life, for nearly two decades at the University of California-Berkeley. Most of those studies involved taking snapshots of the fruit fly's growth at various times. Now, he uses the imaging technique developed by Princeton pioneers Elizabeth Gavis, the Damon B. Pfeiffer Professor in the Life Sciences and professor of molecular biology, and Thomas Gregor, associate professor of physics and the Lewis-Sigler Institute for Integrative Genomics, to capture live footage of gene expression.

In recent work, Levine and two postdoctoral research fellows in his lab, Takashi Fukaya and Bomyi Lim, discovered that gene activity is correlated with the frequency of bursts. The team is now exploring how the expression of genes — which genes are turned on and when — is controlled by small fragments of DNA called enhancers.

The human genome is thought to have 400,000 enhancers, yet we only have about 20,000 genes, so on average, 20 enhancers control a single gene. Understanding exactly how enhancers control gene expression is a major area of study.

"Some people call enhancers the dark matter of the genome," Levine said. "Here we are, 36 years after enhancers were first discovered, and we're still not sure how they work."

Levine's team found that some enhancers led to many bursts, whereas others led to only a few bursts, which points to their important role in gene control. Further, they found that enhancers could activate multiple genes at the same time, a finding they published in 2016 in the journal *Cell,* with support from the National Institutes of Health. That finding contradicted a widely accepted model of how enhancers work.

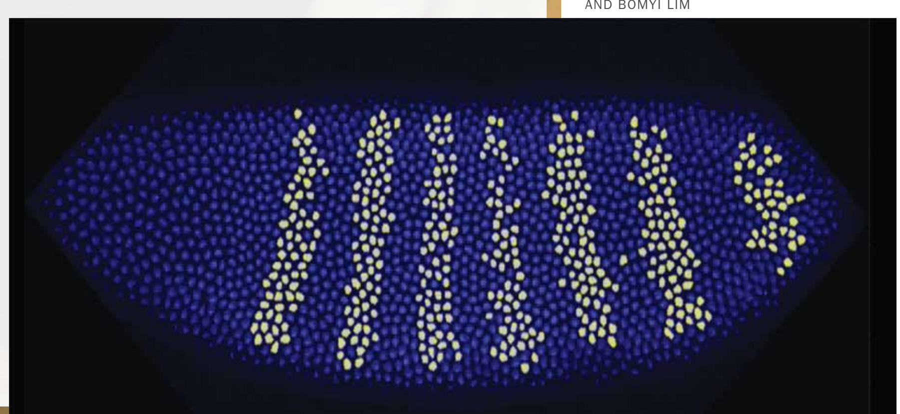
In this widely known model, the enhancer — sometimes near and sometimes very far from the gene it controls — physically loops over and latches onto the DNA, hangs around a bit to start gene expression, and then comes off and prepares for the next burst.

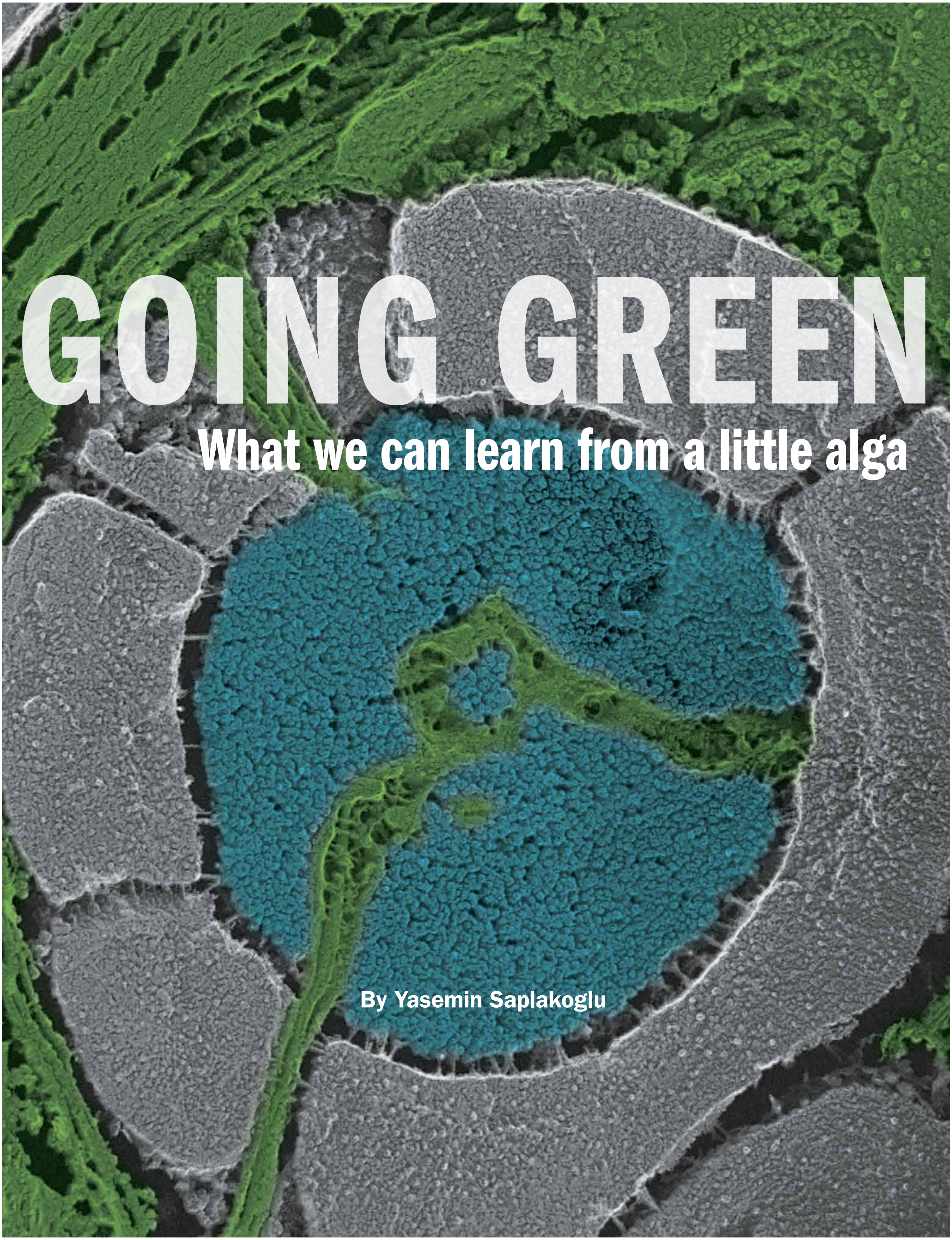
But the enhancer can activate multiple genes at once, so Levine and his group proposed a new model that instead involves a "hub" containing multiple proteins. In their model, the enhancer stimulates the hub to release the proteins responsible for gene activation.

Levine's team is working on validating this model using techniques including those developed at Princeton, and he sees imaging as transforming how researchers study gene expression. "You get a different view of what is going on," he said. "There is something about a movie that connects with the human brain." D

Researchers in the laboratory of Mike Levine are studying the genes involved in fruit fly development using live-imaging techniques. Genes labeled with fluorescent dyes flicker on and off, eventually creating sections that differentiate into different parts of the insect's body.

IMAGE COURTESY OF TAKASHI FUKAYA AND BOMYI LIM





GOING GREEN

What we can learn from a little alga

By Yasemin Saplakoglu

IMAGE COURTESY OF URSULA GOODENOUGH, UNIVERSITY OF WASHINGTON IN ST. LOUIS

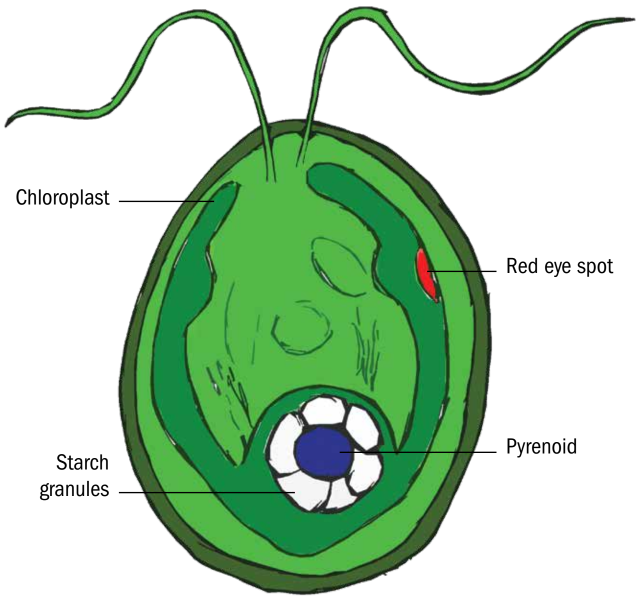
WE ARE CONCERNED, rightly so, about the amount of carbon dioxide accumulating in the Earth's atmosphere. But to most plants, which use carbon for photosynthesis, the amount we have is not enough.

Far back in Earth's history, the atmosphere is thought to have contained a thousand times as much carbon dioxide as it does today. Over the years, photosynthetic bacteria, and later, algae and plants, gradually consumed the carbon dioxide to a point where it now makes up just a tiny fraction of air. In today's atmosphere, many plants, including most crops, are literally starving for carbon dioxide.

But some of these enterprising organisms have come up with ingenious ways to overcome this limitation by siphoning carbon dioxide from the air and concentrating it for use in photosynthesis. These carbon-concentrating mechanisms make algae and a handful of land plants able to grow faster than they otherwise would. Could scientists learn the secrets of carbon-concentrating mechanisms so that they can engineer crops to grow more quickly?

One scientist who thinks this may eventually be possible is Martin Jonikas, an assistant professor of molecular biology at Princeton. He and his team are trying to reverse engineer the carbon-concentrating machinery in algae to find out how it works, with the idea that researchers could apply some of these tricks to crops.

ILLUSTRATION BY YASEMIN SAPLAKOGLU



Researchers are exploring how single-celled algae like the one pictured are able to grow so quickly. The secret of this growth stems from a structure called the pyrenoid, which concentrates carbon dioxide from the air to make photosynthesis run faster. By learning the secrets of algae's success, the researchers hope eventually to engineer the faster growth of crops such as wheat and rice. Opposite page: A cryo-electron micrograph of the pyrenoid.

Jonikas' companion in this quest is a single-celled, freshwater alga named *Chlamydomonas reinhardtii*, which grows naturally in ponds and lakes throughout eastern North America and is known to the plant biology community by the nickname "Chlamy." In Jonikas' lab, Chlamy is the main character. Deep green soups of Chlamy fill the flasks that sit in the laboratory incubator. Plastic plates dotted with Chlamy colonies are stacked on the laboratory benches. This unassuming alga plays the starring role in the researchers' mission to understand the molecular machinery that enables carbon concentration.

"Chlamy is evolutionarily related to higher plants, so most of what we learn from it still applies to them," Jonikas said. "But because Chlamy is a single-celled organism, we can work with it much more easily and much more rapidly than we can with other organisms."

From the sky to the lakes

That Jonikas studies molecular machines for a living is no surprise. Since childhood he has been fascinated with machines, especially those that fly. As a child, he would build remote-controlled airplanes and spend his afternoons chasing after them. He followed this fascination by studying aerospace engineering at the Massachusetts Institute of Technology.

His career took an unexpected turn late during his undergraduate years. "An inspiring biology professor opened my eyes to the concept that living organisms are actually complex machines that can be engineered," he said. He soon transitioned from aerospace engineering to pursuing a Ph.D. in biochemistry and molecular biology at the University of California-San Francisco. One day, a colleague gave a talk on biofuels — fuels produced from plants. "It got me interested in biofuels, but more generally it opened my eyes to the importance of photosynthetic organisms to life on Earth," Jonikas said.

By 2010, Jonikas had earned his Ph.D. and had started his own laboratory at the Carnegie Institution for Science's Department of Plant Biology, located on the campus of Stanford University. He began studying the molecular machinery that makes photosynthesis possible using Chlamy as a model, and moved his laboratory to Princeton in the fall of 2016. Soon after his arrival, Jonikas was named a Howard Hughes Medical Institute-Simons Foundation Faculty Scholar.

Alga as muse

In his office at Princeton, Jonikas picks up an oval stuffed animal from the windowsill. It's a green, plush version of Chlamy. It has a red dot representing the part that the alga uses like an eye, two antenna-like protrusions that the alga uses for movement, and a silver spot on its abdomen where carbon is concentrated. Jonikas' lab members had the toy made by a craftsperson they found online.

Pointing to the circle of silver cloth sewn on its front, Jonikas says it represents a structure inside the cell called the pyrenoid.

He explains that all photosynthetic plants, including algae, use an enzyme called Rubisco to "fix" carbon dioxide as the first step in converting carbon into sugars that the plant can use for growth. But in most plants, Rubisco does not work at maximum capacity because there isn't enough carbon dioxide to keep it running at full steam. "Humans have been working for decades to make Rubisco run faster, and nature has been working on it for much longer than we have, but so far, neither has been successful," Jonikas said.

Many plants — including rice and potatoes — have tried to deal with this problem by making huge amounts of the enzyme. As a result, Rubisco makes up nearly half of all the protein in the leaves of many plants, making it the most abundant protein on Earth. But this strategy only goes so far, because making Rubisco uses up resources that plants could otherwise use for growth.

Algae and some other fast-growing plants like corn have found other solutions. They use carbon-concentrating mechanisms to suck carbon dioxide from the environment and force-feed it to Rubisco. This solution allows Rubisco to run at maximum speed, leading to faster growth.

Chamy's solution is to crowd its Rubisco into the pyrenoid, ensuring that high amounts of carbon dioxide come in contact with Rubisco enzymes. The pyrenoid remains something of a black box, which is what makes it so interesting to study, Jonikas said. "Researchers have been very limited by the few tools that are available for studying algae, so we know almost nothing about the protein composition of the pyrenoid, or even how it functions," he said. "Even the simplest of experiments reveals a lot of interesting new biology."

Learning how nature builds a pyrenoid, so we can too

One of the key questions has to do with understanding the structure of the pyrenoid. Without a basic understanding of these organelles, building one from scratch in a higher plant seems like an unachievable dream.

Years ago, scientists who took some of the first electron microscopy images of the pyrenoid concluded that the structure was a crystalline solid. But something wasn't adding up for Jonikas and his colleagues. They observed that when algae reproduce — which they do by dividing in half — the pyrenoids also usually divide, with a portion going to each daughter cell. But how could they do this if the structure is so rigid?

To explore this question, Elizabeth Freeman Rosenzweig, then a graduate student, and Luke Mackinder, then a postdoctoral researcher in the lab, attached a fluorescent protein called Venus to Rubisco enzymes in some Chlamy cells. In each cell, this fluorescently labeled Rubisco made the pyrenoid light up. The researchers used a high-powered laser to turn off the fluorescence in one half of the pyrenoid and observed what happened to the fluorescent Rubisco remaining in the other half. Within minutes, some of the fluorescent Rubisco had moved to the dark side, indicating that the contents of the pyrenoid were mixing like a liquid.

The finding that the inside of the pyrenoid is liquid-like, published in a September 2017 issue of the journal *Cell*, is a step in the direction of transferring the carbon-concentrating mechanism to higher plants, said Freeman Rosenzweig, who recently earned her Ph.D. in Jonikas' lab. "If we can figure out how nature does it, maybe we can engineer it."

In another set of experiments, Mackinder and colleagues identified a protein that they think serves as a molecular glue that holds Rubiscos in the pyrenoid. This protein, which they named Essential Pyrenoid Component, or EPYC-1, appears to be necessary for packaging Rubisco into the pyrenoid. Another study, published in the same issue of *Cell,* revealed 89 new pyrenoid proteins and gave the most detailed look yet at how the pyrenoid is structured.

To learn more about what is going on in the pyrenoid, Jonikas and his team are looking at the genes involved, starting with those involved in concentrating carbon. To do that, the researchers created thousands of Chlamy strains, identical except for the fact that each one has a different single gene disrupted in its genetic code. Each one of these cells is a mutant.

"To study the function of a gene, you can make its mutant — a strain that lacks that gene — so that you can watch how the mutant performs differently than the original organism," said Xiaobo Li, an associate research scholar in Jonikas' lab. "But in algae, for many years, we only had a few mutants so we had no idea what most genes were doing."

Li led the development of a "mutant library" that helped the team study the pyrenoid, revealing dozens of candidate pyrenoid proteins. The library is also helping researchers around the world, who frequently request mutants that they can use to do their own research. "This is the first genome-wide collection of mutants in any single-celled photosynthetic organism," Jonikas said. In the past year, through a collaboration with the Chlamydomonas Resource Center at the University of Minnesota and funding from the National Science Foundation, Jonikas and his team have made available over 2,300 mutants to nearly 200 labs around the world.

Martin Jonikas, assistant professor of molecular biology, studies how algae are able to grow so quickly, with the goal of eventually engineering faster growth of crops such as wheat and rice.

PHOTO BY SAMEER A. KHAN/FOTOBUDDY

PHOTO BY SAMEER A. KHAN/FOTOBUDDY

Xiaobo Li, an associate research scholar, extracts frozen trays of algae from a storage vessel filled with liquid nitrogen. The trays contain individual strains of algae that have been mutated so that each strain lacks a single gene, allowing researchers to study how the loss of that gene affects growth and other functions.

When Jonikas first moved his lab to Princeton, he sat down with Ned Wingreen, the Howard A. Prior Professor in the Life Sciences and professor of molecular biology and the Lewis-Sigler Institute for Integrative Genomics. Wingreen, whose team uses computational models to study biological systems, remembered that within 10 minutes both professors had an "aha!" moment.

Wingreen was working on how different polymers could undergo phase separations, such as when steam condenses into water droplets. He became interested in pyrenoids after speaking with Jonikas. His team created a simulation of Rubisco and the linker protein that glues Rubiscos together. The researchers found that the number of binding sites on both the Rubiscos and the linker proteins precisely dictated whether they were condensed into a liquid-like structure, like the pyrenoid, or dissolved into the surrounding chloroplast, as happens during cell division. The work provided a possible explanation for how the pyrenoid can rapidly switch between the two forms.

"Martin has been a tremendous force in the field by taking the modern tools of genomics and adapting them to this understudied organism," Wingreen said. "He has this wonderfully powerful and motivating vision that what we learn from Chlamy may eventually be immensely beneficial for society."

The dream

Jonikas and his team have a vision of meeting the world's rising food demand by engineering pyrenoids into crops such as rice and wheat, so the crops can feed on carbon as efficiently as Chlamy does.

In parallel to studying the genes of the pyrenoid to explore how it photosynthesizes so efficiently, the team has already begun early efforts to inject Rubisco and other algal proteins into higher plants. In collaboration with Alistair McCormick, a molecular plant scientist, and his team at the University of Edinburgh, the researchers found that most of the carbon-concentrating proteins taken from Chlamy traveled to the correct location in tobacco when injected into the plant, as published in the journal *Plant Biotechnology* in 2015.

"These two organisms are a billion years evolutionarily diverged and yet the little ZIP codes on the algal proteins that point them to their destinations still work in higher plants," Jonikas said. "They know where to go in a new land."

Jonikas and his team hope in the coming years to successfully identify and transfer enough components of Chlamy's carbon-concentrating machinery to produce a functional pyrenoid in higher plants and increase crop yields.

On Jonikas' windowsill, propped up next to the Chlamy, are other plush toys in the shape of crops — a pea pod, a cabbage, a carrot and stalk of wheat. These characters starred in a video that Jonikas' team created and posted online to explain their research to a broader audience. In the video, the other plants make fun of Chlamy for being different, but when they realize that Chlamy is so good at photosynthesis, they come to respect the lime-colored alga. From Chlamy, they learn the secrets of carbon concentration and become fast-growing crops. Perhaps, someday, this story will come true. D

Researchers grow algae for experiments aimed at discovering how the single-celled aquatic plants are able to concentrate carbon dioxide and thus grow more quickly than most land plants.

PHOTO BY SAMEER A. KHAN/FOTOBUDDY

Coming home to document

Sociologist Yu Xie is the director of Princeton's Paul and Marcia Wythes Center on Contemporary China, which aims to conduct research on Chinese society through an interdisciplinary approach. Known for the statistical rigor he brings to sociology, Xie joined the faculty at Princeton in 2015.

ON A VISIT TO CHINA in 2003, sociologist Yu Xie realized he had something to offer that no one else did.

He'd been living and working in the United States for 21 years and was a highly regarded social scientist with a reputation for applying numbers-driven analysis to study the breadth of human experience. "My whole career has been devoted to the systematic and empirical understanding of the social world around us," said Xie, the Bert G. Kerstetter '66 University Professor of Sociology and the Princeton Institute for International and Regional Studies.

Xie had come to the U.S. in 1983 as part of an academic program that sent a select few Chinese students abroad for graduate study. At the University of Wisconsin-Madison, he studied the history of science and then earned a Ph.D. in sociology. He became a professor at the University of Michigan and went on to publish on provocative subjects like why women haven't reached the same levels as men in science, and why there is a growing achievement gap between Asian American students and white classmates.

Settling in Ann Arbor, Xie focused primarily on U.S. issues during his early career. Xie's wife, who had earned her Ph.D. in materials science, climbed the career ladder in industry. They raised children. Xie wrote papers and books, mentored students, and became one of the University of Michigan's most respected faculty members in the study of structural shifts in populations.

By 2003, it was clear to Xie that a significant structural shift was occurring in one of the largest populations on the planet. China was changing rapidly in every area — income, education, urban migration — and the cultural changes alone dwarfed anything going on in the U.S. "It was like witnessing the Renaissance, or the French Revolution," Xie said. "In the past, researchers didn't have the tools to

a rapidly changing China

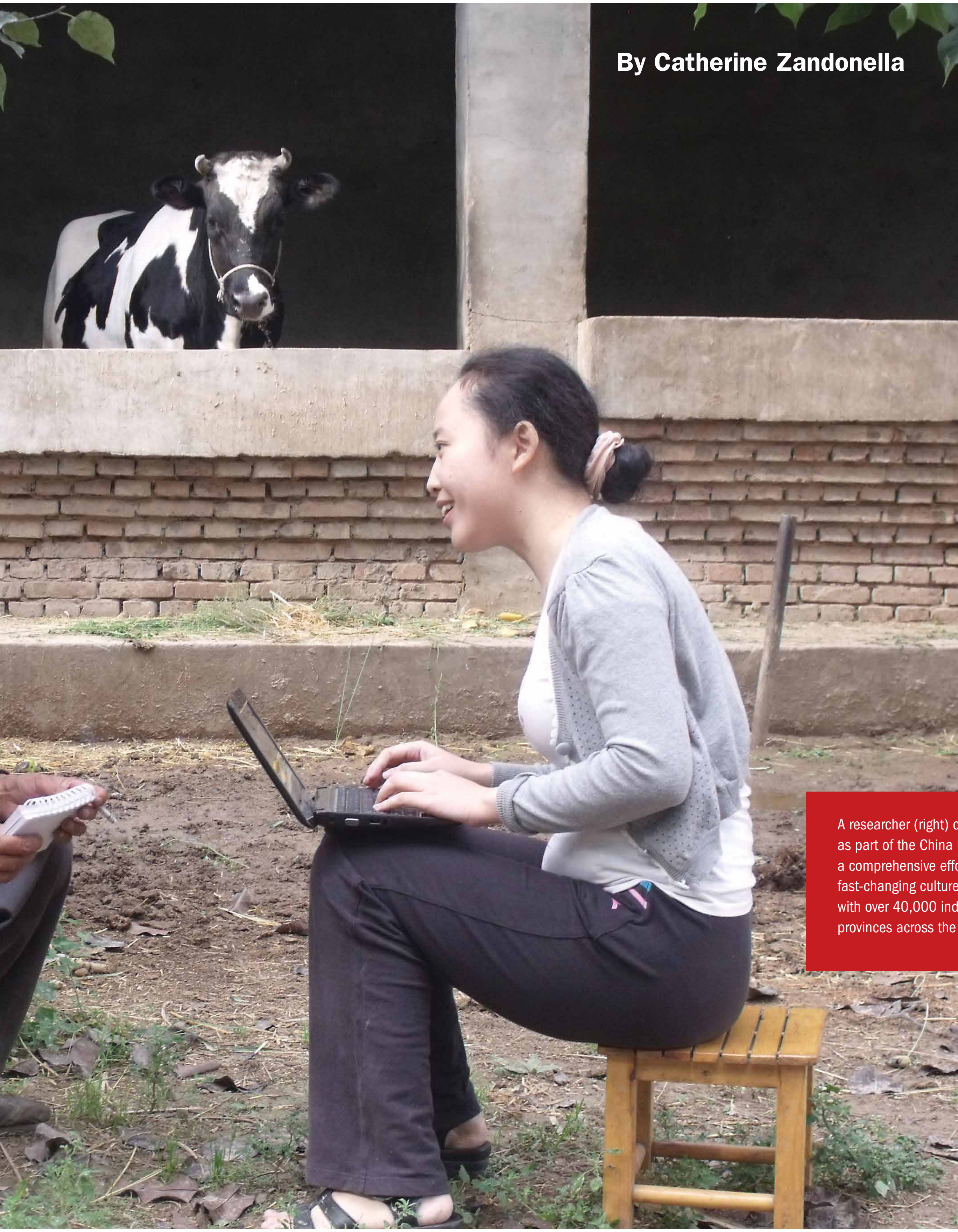


PHOTO COURTESY OF PEKING UNIVERSITY INSTITUTE OF SOCIAL SCIENCE SURVEY

A researcher (right) conducts an interview as part of the China Family Panel Studies, a comprehensive effort to capture China's fast-changing culture through interviews with over 40,000 individuals in 25 provinces across the country.

analyze societal change as it was happening. Now, we do."

Only, in 2003, China didn't. Chinese social scientists were not trained in the empirical methods that Xie and others had pioneered while at the University of Michigan's Institute for Social Research's Survey Research Center. These methods can separate opinion from fact and reveal trends across large swaths of populations.

Also missing were data. The government collected limited information — mainly population statistics — and released even less. With out quality metrics on the everyday experience of Chinese people across various backgrounds and geographical locations, Xie knew it would be impossible to make solid conclusions about how people's lives were changing.

PHOTO BY MARK CZAJKOWSKI

After spending decades studying the U.S., sociologist Yu Xie has turned his efforts toward capturing the cultural shifts in his native China.

It was here that Xie saw that he could make a difference. He dreamed of conducting a large-scale study to gather data on typical Chinese households. He knew it wouldn't be easy. Xie had already tried collecting data in the 1990s. He and his graduate students made trips from Michigan to China to interview families, but the researchers faced obstacles in gaining the consent of local officials.

Xie needed a trusted Chinese entity to support the study and, ideally, to help fund it. He eventually found both at Peking University, one of the top universities in China.

After some negotiations, the university's Institute of Social Science Survey agreed to organize a comprehensive study that would follow Chinese families over several years to obtain information about family size and composition, marital status, education level, health and many other aspects of daily life.

Called the China Family Panel Studies (CFPS) — a panel study is one that tracks the same research subjects at different time points — the project would survey 15,000 randomly selected families, covering a total of more than 40,000 people in 25 provinces across the country and representing 95 percent of the Chinese population.

The effort kicked off in 2008 with a pilot study. Xie led the study design, traveling frequently from Michigan to Peking University, where Xie holds a visiting professorship, to train the staff and put in place procedures for storing and processing the data.

Yan Sun, an assistant research scientist at Peking University, remembers those early days. She joined the project in 2009 and today is the manager of survey operations for the CFPS. She oversees the recruitment and training of interviewers, mostly students at colleges and universities in each study region, who go house to house. Conducting the interviews wasn't always easy, especially at the outset of the initiative. "You would have people calling the police to ask, 'Why is this person in my neighborhood walking around with a laptop?'" Sun recalled.

The interviewers enter the respondents' answers into a computer-assisted interview system, and Sun tracks the responses, using them to improve the questions. Sun can find out how long the interviewer took between questions and whether the interviewer went back to a previous question. "We use these data to analyze the interviewer performance and whether the questions were clearly understood by the respondents," she said.

One of the CFPS's findings is that inequality in China is steadily climbing. In an article published in 2014 in the journal *Proceedings of the National Academy of Sciences*, Xie and then-graduate student Xiang Zhou, now an assistant professor at Harvard University, reported that China's income inequality was among the highest in the world. The extra data were essential for this finding, Xie said, because the government's official estimate of income inequality was much lower. He and Zhou attributed the inequality to regional economic differences and the urban-rural divide.

An issue that the CFPS has revealed more recently is the rise in cohabitation in place of marriage among young Chinese. Xie and Jia Yu, now an assistant professor at Peking University, looked at data from the CFPS in 2010 and 2012, which, before the CFPS, had never been collected in a systematic way.

They found that cohabitation is becoming more common among young, educated, primarily urban Chinese professionals, a finding they reported in the journal *Population and Development Review* in 2015. This contrasts with the pattern in the U.S., where living together is more common among people of lower socioeconomic status.

'Do not play poker with him'

Robert Hauser, a professor of sociology emeritus at the University of Wisconsin-Madison and one of Xie's advisers when Xie was earning his Ph.D., serves on the advisory board for the CFPS. "There are three aspects of this survey in China that are really important: First, it is comparative — the whole scheme is designed to be comparable with surveys in the U.S.; second, it is state-of-the-art in field methods used; and third, the data are all public," he said.

Hauser has known Xie since shortly after Xie arrived in the U.S. and remembers him as one of the most energetic, assertively intellectual and driven students of the time. "He is utterly brilliant and good at everything," Hauser said. "Do not play poker with him."

Another long-time friend and mentor of Xie agrees. "He seeks advice, he is thoughtful, and then he makes up his own mind," said Donald Treiman, a professor emeritus of sociology at the University of California-Los Angeles. "He is a strong mentor and he goes out of his way to make sure that his students are prepared for future careers in academia. That is an important part of his persona."

In addition to holding a visiting professorship at Peking University, Xie is an adjunct professor at the Chinese University of Hong Kong and three other Chinese universities (Shanghai University, Renmin University and the Hong Kong University of Science and Technology). These appointments allow him to mentor and serve as a graduate adviser to a large number of Chinese sociology students.

Chunni Zhang is one of Xie's former students from the Chinese University of Hong Kong. Now an assistant professor of sociology at Peking University, Zhang said Xie has been instrumental not only in introducing sociological study methods in China, but also in shifting the conversation about what should be studied.

"In the past, most scholars focused their research interests on 'major' social issues such as economic reform," Zhang said. "Xie and his students, however, conducted studies on 'smaller' issues in China, family topics in particular, which broadened people's vision and attracted more interest in studying these issues. Today, family-related issues are very hot topics in China."

Xie's studies serve as examples of how China's issues could be framed into the research questions that have also been asked and answered in the West, Zhang said. "Instead of copying the Western studies, however, he maintained that Chinese studies should highlight the uniqueness or variation of the social context and tell different stories," she said.

'I want to find the truth'

In addition to his interest in Chinese society, Xie studies matters relating to Asian Americans, including why Asian Americans have higher grades and standardized test scores, and are more likely to attend college, than whites in the U.S. With Amy Hsin of the City University of New York, Xie reported in a study published in the *Proceedings of the National Academy of Sciences* in 2014 that academic effort, and not advantages in tested cognitive abilities or sociodemographics, was the greatest factor in Asian American successes.

A subsequent study, however, did uncover some relevant socioeconomic factors, especially among non-Asians. With Airan Liu of the University of Michigan, Xie found differences between Asian American parents and non-Asian parents with regard to educational aspiration for their children. Asian parents, regardless of socioeconomic status, wanted the best possible education for their children. Among non-Asian U.S. parents, however, parents from low socioeconomic backgrounds tended not to have high expectations for their children, while more affluent and educated non-Asian parents did hold high expectations. The study was published in 2016 in the journal *Social Science Research*.

These studies on the Asian American achievement gap got a lot of attention, and references to Xie's publications appear frequently in articles in the mainstream media. Xie resists getting pulled into discussions about the policy implications of his work. "I want to find the truth," he said.

Two years ago, Xie moved to Princeton to head up its new Paul and Marcia Wythes Center on Contemporary China, part of the Princeton Institute for International and Regional Studies (PIIRS). The center focuses on studying the sociology of China through an interdisciplinary approach. "Princeton was one of the few places that could tempt me to leave Ann Arbor," he said.

The center aims to study the social changes in China from an interdisciplinary perspective that combines faculty expertise in economics, East Asian studies, anthropology, politics, religion and Princeton's Woodrow Wilson School of Public and International Affairs. The center also hosts visiting scholars and holds lecture series and graduate-level workshops.

Each summer, Xie leads groups of Princeton undergraduates to study in China through the PIIRS Global Seminars program. "There is no better way to educate future scholars about China than by having them visit the country and teaching them firsthand," Xie said. "Some students arrive at Princeton having studied Mandarin in high school. Even those who have never studied Chinese are ready for new challenges."

These summer trips, combined with regular visits to monitor the progress of the CFPS and advise graduate students at the five universities where he serves as an adjunct or visiting professor, mean that Xie spends about a quarter of each year in China. But that is as it should be, he said.

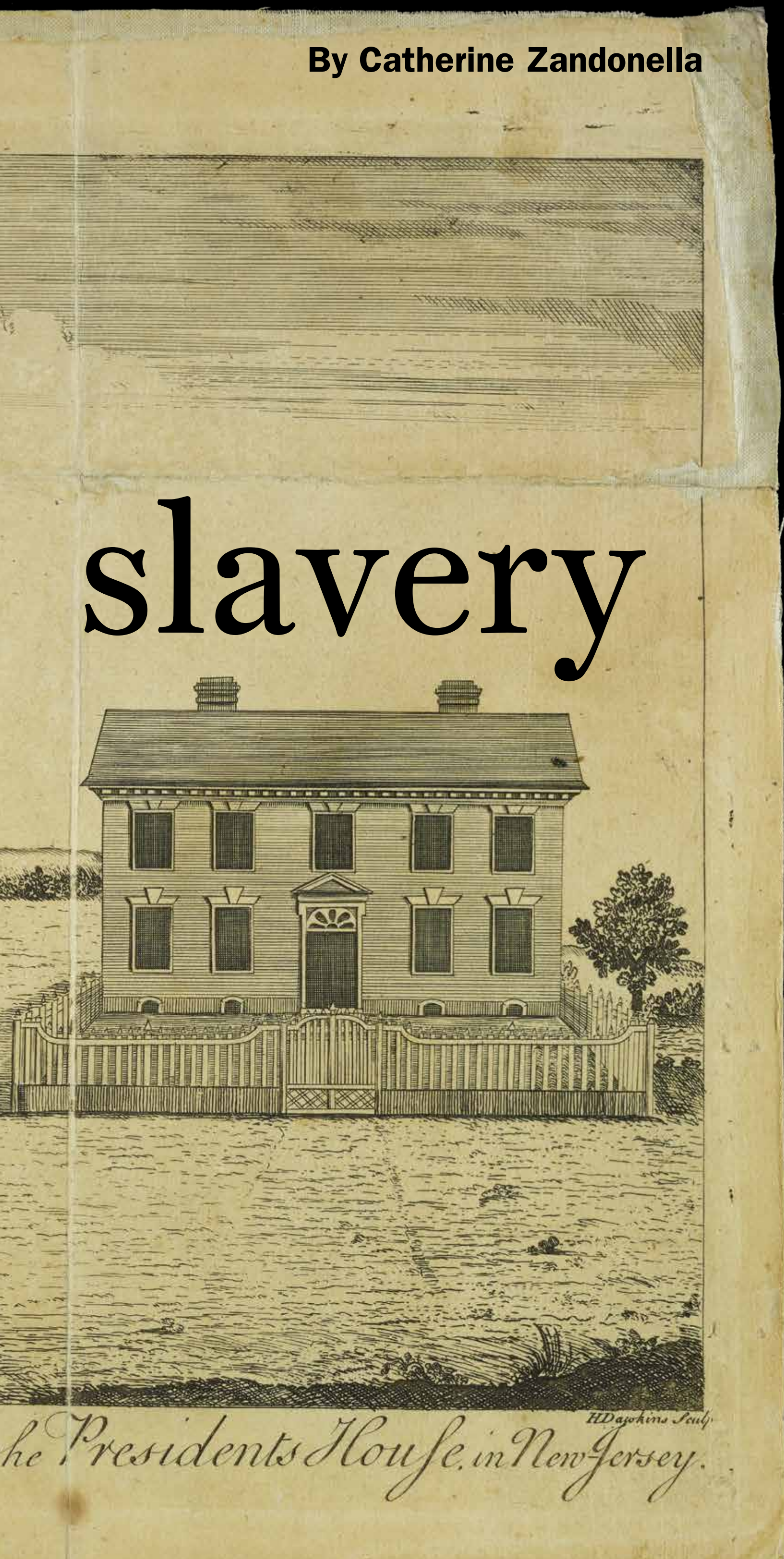
"You need to visit often or you might miss something." D

Princeton project explores past ties to

PHOTO COURTESY OF PRINCETON UNIVERSITY ARCHIVES

slavery

By Catherine Zandonella



A 1764 copper engraving by artist Henry Dawkins of the earliest campus buildings, Nassau Hall (left) and the President's House (now Maclean House), which still stand today.

"TO BE SOLD AT PUBLIC VENUE on the 19th of August next … all the personal effects of Revd. Dr. Samuel Finley, consisting of two Negro women, a Negro man, and three Negro children, household furniture, horses … some hay and grain, together with a variety of farming utensils."

The "personal effects" belonged to the estate of the Reverend Dr. Finley, the fifth president of the College of New Jersey, now known as Princeton University. The sale, advertised in the *Pennsylvania Journal and Weekly Advertiser*, took place in 1766 in front of the President's House near two newly planted sycamore trees. The house and the trees still stand today near the north border of campus.

That a slave sale took place on campus and that the first nine Princeton presidents were slaveholders at some point in their lives are two of the major findings from a sweeping new endeavor by Princeton scholars and students to explore the ties of early University trustees, presidents, faculty and students to the institution of slavery.

The Princeton and Slavery Project has released the findings on a public website. The online materials include over 80 articles, video documentaries, interactive maps and several hundred primary source documents.

Leading the project is Professor of History Martha Sandweiss, who was surprised when she joined the faculty in 2009 to find that Princeton had never conducted a comprehensive study of its ties to slavery, as many other universities had done. Those studies revealed that slavery was an integral part of the history of American higher education, in both the North and the South.

The Princeton project did not find evidence that the University as an institution owned slaves, nor that students brought slaves to campus, but the scholars and student researchers involved in the project did establish that the man who deeded the University's original 4.5 acres, Nathaniel FitzRandolph, was a slave owner. Funds from donors with ties to slavery funded the construction of several prominent campus buildings, and all seven of Princeton's founding trustees were slave owners.

Much of the research was conducted by undergraduates in Sandweiss' upper-level history seminars, which she organized starting in 2013 with the dual goals of investigating slavery and exposing students to methods of archival research. The project received support from the University's Humanities Council, as well as the Princeton Histories Fund, which provides funding to explore "aspects of Princeton's history that have been forgotten, overlooked, subordinated or suppressed." Many other departments contributed to the project.

"Professor Sandweiss and her colleagues and students have brought creativity, diverse perspectives and rigorous academic standards to bear on research that sheds new light on previously unexamined aspects of this University's past. Although the project began before we established the Histories Fund, it exemplifies the innovative work that we hope the fund will support," said Princeton President Christopher L. Eisgruber. "The symposium that the project has organized brought a remarkable group of scholars and artists to our campus to reflect on its findings; I expect that the symposium and the project will stimulate ongoing discussion, additional research, and a more comprehensive and nuanced understanding of our history."

For help finding original materials, she approached University Archivist Daniel Linke. Linke taught students to navigate the nearly 400 collections in the University archives, which include alumni records, student letters, Commencement speeches, sermons, treasurers' reports, and trustee and faculty meeting minutes. Students also used digital resources purchased by the Princeton University Library such as newspaper collections and business and court records. "When students would make a discovery, I would help them find additional documents to identify the context of the information and corroborate their findings," Linke said.

The nation's fourth-oldest college

Chartered in 1746 as British North America's fourth college, the institution then known as the College of New Jersey was located first in nearby Elizabeth and then Newark before moving in 1756 to its current location in "Prince-Town." The University took its present name in 1896.

The young college, founded by Presbyterian ministers who embraced the Enlightenment, nurtured several American independence leaders, including John Witherspoon, Princeton's sixth president and a signer of the Declaration of Independence, and James Madison, the nation's fourth president. Both were slave owners.

To fund the college's growth, Witherspoon actively cultivated students from well-off Southern and Caribbean families. Before his tenure as college president began in 1768, about 20 percent of students came from the South, but by 1790 the percentage was 67 percent.

As cotton plantations spread into states such as Mississippi and Louisiana, and slavery spread westward, so too did the states of origin of the student body. Between 1746 and 1865, Southern-born students made up about 40 percent of the class on average. "You can see the westward spread of slavery as you track our student body," Sandweiss said.

The finding helps explain why the anti-slavery movement at Princeton was relatively weak compared to peers like Harvard and Yale universities. Princeton was the founding location of the American Colonization Society, which was a movement to send free blacks back to Africa. "Princeton was a place where people with vastly different viewpoints came together, and the emphasis was on 'keeping the peace,'" Sandweiss said.

Southern wealth was not the only money that came tainted by human bondage, however. One of the most prominent donors in Princeton's history is Moses Taylor Pyne, a Northerner whose name adorns several campus buildings and a prestigious undergraduate prize.

In the records of the New York Historical Society, Maeve Glass, who earned her Ph.D. in history at Princeton in 2016 and is now an academic fellow at Columbia University, discovered that Pyne's fortune — which he inherited from his grandfather — stemmed from a shipping business that transported sugar grown by slaves on Cuban plantations. Glass and other students traced the sources of funding for many of Princeton's buildings to slavery.

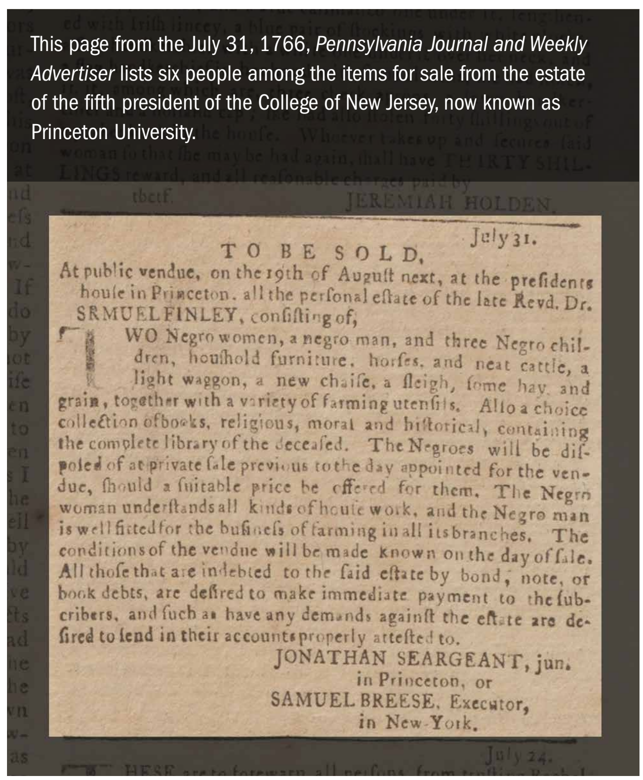
Gown and town

Despite its location in the North, New Jersey was one of the last Northern states to ban slavery, and its "gradual emancipation" law, enacted in 1804, kept some individuals in bondage right up until the end of the Civil War. But the town of Princeton was home to a vibrant free black community — in 1862, one-sixth of Princeton's 3,700 residents were of African descent — a fact that did not sit well with some of the Southern-born students.

In 1846, when a black man accused two students of harassing a black woman on a town street, violence broke out. A mob of 14 students, angered by the black man's "insolence," went to the farm where the man worked. Despite resistance from a "dozen brawny Irish laborers" who tried to protect the man, the mob forcibly took him into town, threatening to lynch him. A professor, John Maclean Jr. — a future president of the college — tried to stop the mob but failed, and the students whipped the man to "within an inch of his life," according to a classmate's account.

Isabela Morales, a graduate student in history, described how she felt when she read about this event. "I was sitting in Firestone Library, reading the diary of a long-ago student, John Robert Buhler," she said, "and I gasped at what I found. In some ways this incident was a preview of the kinds of divisions that would happen among the students at the start of the Civil War. Some would go home to fight for the Confederacy and others would fight for the Union."

Another spate of violence broke out in 1843 over the plight of a fugitive slave named James (Jimmy) Collins Johnson. He'd escaped from a Maryland plantation and was working as a janitor at the college when a student from a nearby plantation recognized him. Although the law required Johnson to be returned to his master, many townspeople came out in his support, and the case was



July 31.

TO BE SOLD,

At public vendue, on the 19th of August next, at the presidents house in Princeton, all the personal estate of the late Revd. Dr. SRMUEL FINLEY, consisting of,

TWO Negro women, a negro man, and three Negro children, houshold furniture, horses, and neat cattle, a light waggon, a new chaise, a sleigh, some hay and grain, together with a variety of farming utensils. Also a choice collection of books, religious, moral and historical, containing the complete library of the deceased. The Negroes will be disposed of at private sale previous to the day appointed for the vendue, should a suitable price be offered for them. The Negro woman understands all kinds of house work, and the Negro man is well fitted for the business of farming in all its branches. The conditions of the vendue will be made known on the day of sale. All those that are indebted to the said estate by bond, note, or book debts, are desired to make immediate payment to the subscribers, and such as have any demands against the estate are desired to send in their accounts properly attested to.

JONATHAN SEARGEANT, jun.
in Princeton, or
SAMUEL BREESE, Executor,
in New-York.

This page from the July 31, 1766, *Pennsylvania Journal and Weekly Advertiser* lists six people among the items for sale from the estate of the fifth president of the College of New Jersey, now known as Princeton University.

PHOTO COURTESY OF PRINCETON UNIVERSITY ARCHIVES settled only when a local citizen paid $500 for his freedom. Johnson was allowed to stay, and over his lifetime he worked off his debt, including by selling sundries to students outside Nassau Hall.

A long reach into people's lives

To make these and other findings available to the public, Sandweiss and her team created a public website hosted by the University library. Joseph Yannielli, a postdoctoral research associate with the Humanities Council and the Center for Digital Humanities, is the website's project manager and lead developer.

"The sheer size of the project is staggering," Yannielli said. "It is, by far, one of the largest studies of a university's relationship to slavery yet attempted. We have over 6,000 files in our archive, covering thousands of students and dozens of faculty members across three centuries of history. Grappling with all of that data is an ongoing challenge."

To ensure that the local community learns of the findings, Sandweiss collaborated with the Princeton-area public schools to create lesson plans for high school students. "Most students are surprised to find that there was slavery in the town of Princeton," Sandweiss said. "I hope that high school teachers not just in Princeton but around the country will be able to use the lessons we've developed."

Sandweiss also reached out to the University's arts community to suggest creating public works of art and theater. "I believe in sharing history with the broadest possible audience," Sandweiss said, "so I wanted to collaborate with artists who, while honoring the facts of the past, can elaborate and speculate in ways that historians — always bound by footnotes — cannot."

Sandweiss said she is touched by how the findings about the University's past resonate with today's students and alumni. In a freshman seminar, Sandweiss asked students to create videos from interviews with their peers, alumni and others with Princeton connections who are descended from slaveholders, slaves or both. For example, in one video, a student of African American descent learns that she is descended from a family of mixed-race slaveholders in New Orleans.

"This isn't a story that ended in 1865," Sandweiss said. "This is a story that has a long reach into people's lives."

Impact on students

The project has been a rare opportunity for students to conduct original archival research that will reach a wide audience. Many of the historical articles on the website were written by Princeton undergraduates under the guidance of Sandweiss and graduate students. "Each time the class was taught, the students had greater success, because we became better at framing questions for them to research," Sandweiss said. "But it is impossible to overstate how open-ended this was at the beginning."

Craig Hollander recalls the excitement of those early days of discovery. He was then a postdoctoral researcher at Princeton and is now an assistant professor of history at today's The College of New Jersey, located about 10 miles from Princeton. Hollander spent hours hunched over boxes of documents, photographing them as fast as possible, and then bringing them back to the computer to blow up the images so he could examine them.

Professor of History Martha Sandweiss leads a research project to explore the role slavery played in the early days of Princeton University.

PHOTO BY DENISE APPLEWHITE

"We would marvel over the discoveries we were making every day," Hollander said. "You had to read these documents with a fine-tooth comb, because you didn't know if a sentence or phrase was the smoking gun that provided evidence for a larger finding. Sometimes I would come away from a day's work with a single document and say to myself, 'This is why I got up in the morning.'"

One undergraduate who contributed to the project is Sven (Trip) Henningson. Although he graduated with a bachelor's degree in history in 2016 and now works in Washington, D.C., Henningson still spends some of his free time on the research.

Henningson remembers going to the Library of Congress one Saturday morning and finding an original 1864 memorandum from a former Princeton student demanding that his escaped slaves hiding behind Northern lines be returned to him. "Holding that document in your hand is just something that gets you fired up and ready to go for another round in the archives," he said.

An American story

This fall, a new group of students enrolled in Sandweiss' research seminar and began to delve into Princeton's history, this time in the post-Civil War era. "We've been examining issues of how people were talking about race in the aftermath of the Civil War," Sandweiss said, "and how people wrote the history about what the war meant."

The natural question to ask is what do these findings mean for Princeton? But the broader question, Sandweiss said, is how does what we are learning change our feelings about America's history?

In many ways, the story of Princeton is the story of America writ small — how its leaders ignored the economy's ties to slavery so that it could continue to thrive on the fruits of human bondage. The young nation espoused liberty while rationalizing its deeply troubling footings.

"To acknowledge that history, to be upfront about it, that is what universities do best," Sandweiss said. "Educational institutions should sponsor this kind of inquiry no matter where it goes, and Princeton has done that. What we've uncovered does not set us apart in any way, nor should it embarrass us. Our institutional history embeds us in the paradox of liberty and bondage that underlies the development of our nation.

"We are not special, we are simply American." D

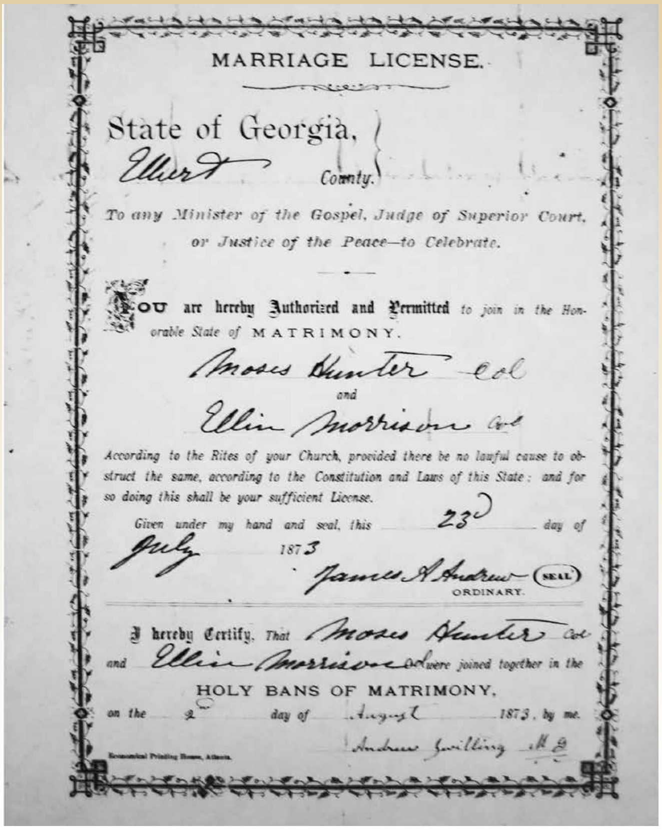
The more than 600 pages of documents, maps, videos and essays are available at slavery.princeton.edu.

Bound in wedlock

Professor of history explores slavery's shackles on black families

By Tera Hunter

ELBERT COUNTY MARRIAGE BOOK, IMAGE COURTESY OF BRUCE HUNTER



MARRIAGE LICENSE.

State of Georgia,
Elbert County.

To any Minister of the Gospel, Judge of Superior Court, or Justice of the Peace—to Celebrate.

You are hereby Authorized and Permitted to join in the Honorable State of MATRIMONY.

Moses Hunter col

and

Ellin Morrison col

According to the Rites of your Church, provided there be no lawful cause to obstruct the same, according to the Constitution and Laws of this State: and for so doing this shall be your sufficient License.

Given under my hand and seal, this 23d day of July 1873

James A Andrew (SEAL)
ORDINARY.

I hereby Certify, That Moses Hunter col and Ellin Morrison col were joined together in the HOLY BANS OF MATRIMONY, on the 2 day of August 1873, by me.

Andrew Gwilling M G

Marriage certificate of the great-great-grandparents of Tera Hunter, professor of history and African American studies.

For her new book, **Bound in Wedlock: Slave and Free Black Marriage in the Nineteenth Century** *(Harvard University Press, 2017), Tera Hunter, a professor of history and African American studies, meticulously researched court records, legal documents and personal diaries to illustrate the constraints that slavery placed on intimate relationships. In this article she talks about the very personal side of her research and the importance of this chapter of history in understanding American society today.*

I HAVE A COPY OF THE MARRIAGE certificate of my great-great-grandparents, Ellen and Moses Hunter, from 1873. They were both enslaved, freed and then married during Reconstruction. I posted the document on my bulletin board, which served as a source of inspiration as I researched slave and free black marriage in the years before and after the Civil War. Their marriage was the first among my direct paternal ancestors, and they were the first non-interracial couple in my paternal lineage after arriving in the New World. It became increasingly clear how much my own family history was evocative of the larger history that I was researching.

I was especially drawn to documents that I found from the period of Reconstruction, which demonstrated the depth of feelings and the challenges that former slaves faced in reconstituting their family ties after slavery ended. These records are tremendously rich, and they raised a lot of interesting questions that could not be easily answered by focusing on the period following emancipation alone. To fully understand post-slavery marriage and family, I needed to trace these relations over the entire 19th century.

One of the topics I explored was how marriage was not an inviolable union between two people but an institution defined and controlled by the superior relationship of master to slave. Women have literally borne many of slavery's burdens not just as laborers but also as the literal reproducers of capital that enriched slave owners, making them among the wealthiest people on the planet. Exploiting women's sexuality and denying legal rights to marriage, maternity and paternity were inextricably linked to preserving slavery as a profitable, permanent, inheritable system of labor.

Christianity was closely tied to supporting and rationalizing this system of labor, with little dissent from mainstream clergy or laypersons. Despite the fact that marriage was held as one of the most important sacraments of Christianity, in the United States the Church supported the property rights of masters above all else. Readers are often shocked to learn such facts about the complicity of their own faith traditions.

My research on free blacks produced some surprises. I do not think historians have fully captured the extremity of the constraints faced by African Americans who were either born free or born into slavery and later freed. We certainly have not paid adequate attention to the repercussions that they faced in building and sustaining their marriages and families. Slaves could not marry legally in the South, but neither was legal marriage guaranteed to free blacks. Their relationships were even more compromised when they were married to slaves because they were reduced to their enslaved spouse's lack of standing in society and the law. In some cases, they even voluntarily submitted to (re)enslavement just to keep their families together, as laws were passed to evict newly manumitted free people in the South.

Free black couples faced constraints above the Mason-Dixon Line as well, which is probably more surprising to people who are less familiar with slavery in the North. For example, New York state passed a law that supported slave marriage. But slaves were required to get the consent of owners first, and, in practice, the law did not guarantee that their relationships were respected as legally inviolable.

My research on marriage allowed me to examine the internal lives of African Americans. The existing scholarship on black families was preoccupied with whether or not they conformed to the nuclear structure and gender norms of male-headed households. This led to a very limited view of both the internal values and meaning of marriage to African Americans and also the external constraints that they faced in creating and sustaining these relationships.

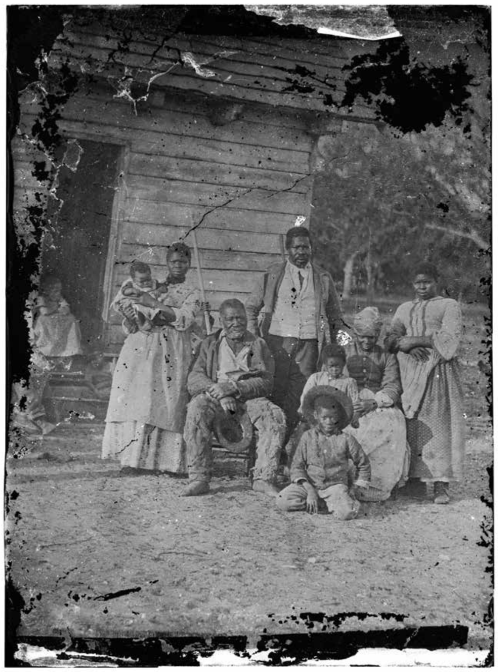


PHOTO BY TIMOTHY H. O'SULLIVAN, COURTESY OF THE LIBRARY OF CONGRESS

Marriage between slaves was discouraged or illegal; individuals could be sold away from their spouses at any time. This photo, taken in 1862, is of an extended family of slaves on a plantation in Beaufort, South Carolina.

Debates about the status of black families in the 21st century have often invoked the legacy of slavery. In the epilogue to the book, I scrutinize and challenge the misinformed assumptions articulated by both liberal and conservative scholars, commentators and political pundits regarding the impact of slavery on marriage and family today. Despite centuries of degradation, adult African Americans were nearly universally married by the turn of the 20th century, only decades after legalization. That pattern would begin to change post-World War II, and marriage rates began a downward slope to the point now that most African Americans are not married. There are many factors that explain this, but slavery is not one of them. We need to look to factors in the 20th and 21st centuries.

I hope that my work contributes to deepening the knowledge of the history of slavery and its consequences for American society and for African American lives. We cannot fully appreciate how the nation has come to be what it is without the knowledge of how slavery and freedom were intertwined. We cannot fully understand the harms done to African Americans without accounting for how they impacted marriages and family.

African Americans have always been creative, resourceful and practical in building meaningful relationships. There is "a great black river" along an enduring freedom struggle, as historian Vincent Harding wrote. We keep going back to the future.

And yet, despite the distinct disabilities that black families suffered under, there is a long legacy of stigmatizing the bonds they created, of using the failure to meet dominant societal norms as a barometer to judge black fitness for civilization and citizenship negatively. No matter what period of history, black families are always judged to be deficient as compared to whites, with little regard for the systems that structure those inequities.

We need to understand those patterns and the legacies that are continually replicated with each iteration of the seemingly forward movement toward greater freedom and justice. D

Let it

the ideas, the creativity, the findings, the impacts, the benefits to society

THE RESEARCHERS in Princeton's Complex Fluids laboratory are sometimes inspired by a cup of coffee or a permanent marker.

Such everyday items may seem like odd subjects of inquiry in a lab known for its cutting-edge research, but in fact the coffee — a latte actually — acts as a model system to study pattern formation in liquids, which could lead to applications in food science, and the permanent markers may suggest ways to transfer patterns of micro-fabricated electronics from one surface to another.

These seemingly unconnected experiments are tied together by the study of fluids and how they move and change in space and over time. At the head of the lab is Howard Stone, a professor in the School of Engineering and Applied Science, whose mentorship of graduate students and postdoctoral researchers has led to a multitude of papers on topics that have the potential to address societal problems, from coping with climate change to purifying water using the technology that adds fizz to soda.

"I encourage the members of my lab to do things that excite them, things they're very curious about," said Stone, Princeton's Donald R. Dixon '69 and Elizabeth W. Dixon Professor and chair of the Department of Mechanical and Aerospace Engineering. "It is a little different than how other groups sometimes run, and in part that's because I'm not focused on trying to solve only one problem. Instead I am serious about seeking new understanding as well as potential applications."

Stone's lab attracts students and postdoctoral researchers from around the world, with backgrounds ranging from chemistry and math to physics and engineering. These scholars combine their talents with a lot of energy, laboratory camaraderie and a spirit of exploration, turning creativity into results that have the potential to make a difference in areas such as health and the environment.

Using gelatin to study fracking

Ching-Yao Lai recalls the first time she heard the term "fracking" as a newly arrived graduate student from Taiwan five years ago. "I had absolutely no idea what that was," she said. She soon became immersed in studying hydraulic fracturing, which involves injecting high-pressure liquids into underground rock to generate fractures that allow oil and gas to come to the surface. But the liquid can also bring contaminants — such as brine, naturally occurring radioactive material and metals — into contact with underground drinking water sources.

"It's very important to know how fast a fracture grows and how far it can go," Lai said. To study this, she uses a substance that bears little overt resemblance to rock: a block of gelatin.

Gelatin mimics the brittle and elastic properties of rocks, and it is convenient in other ways. It is transparent, so Lai and her co-investigators can see what happens to the liquid and where it goes.

To model fracking in the cube of gelatin, the researchers poke cracks in the springy solid to represent the fissures and faults in the Earth. Then they push mineral oil through the cracks and, while shining a green light on

flow

By Yasemin Saplakoglu

PHOTO BY SAMEER A. KHAN/FOTOBUDDY

In the laboratory led by Howard Stone, a professor in the School of Engineering and Applied Science, the flow of creativity among the postdoctoral researchers, graduate students and undergraduates leads to findings with the potential to benefit society.

the block to illuminate the spread of the oil, take photos for later measurements of the size and extent of the cracks.

With this experimental system, Lai and colleagues are exploring what happens to liquid injected into the gelatin. Some of the questions are why not all of the injected liquid comes back to the surface, and how much fluid gets trapped in various types of fractures.

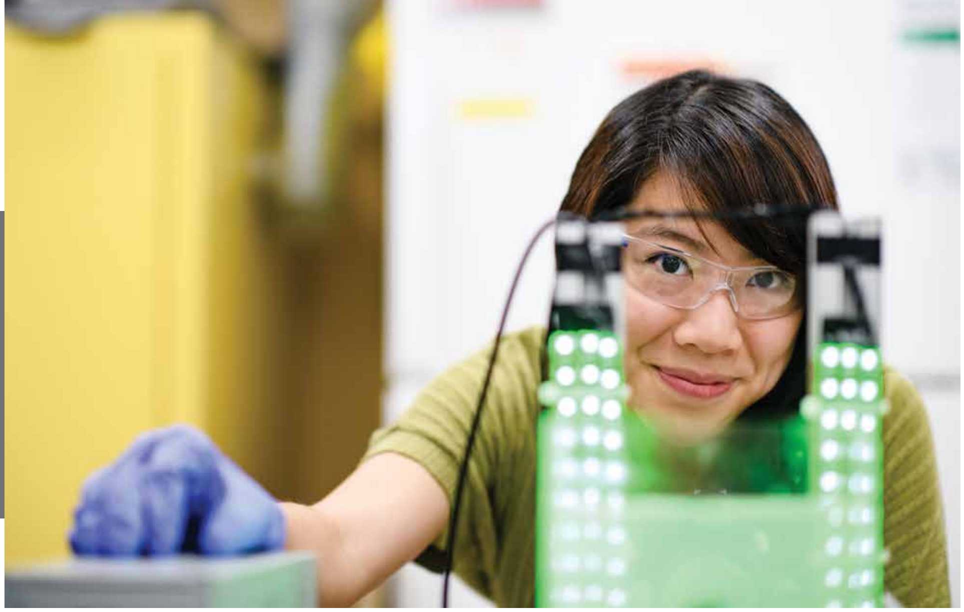
One of their next areas of study involves an entirely different type of liquid — foam. Lai is exploring whether foam could be use in place of today's high-pressure liquids. Foam uses 90 percent less water and may be less likely to travel to groundwater sources.

Tangled fibers for wound healing

At the next lab bench over, Janine Nunes holds a vial of tiny polymer fibers that could someday become wound-healing bandages or provide scaffolding for repairing damaged tissues in the body. Nunes is developing liquids that solidify into small fibers. These fibers could be injected into a damaged part of the body where they then tangle to provide a scaffold on which cells can regrow.

Nunes, an associate research scholar, makes the slender fibers using a device that works sort of like a pasta maker and that fits in the palm of her hand. She injects a polymer liquid into a slender pipe. Then, by sending pulses of ultraviolet light into the device, she converts the light-sensitive liquid into a hair-thin, solid fiber.

By changing the duration of light pulses, Nunes can control the shapes of the fibers. She and Antonio Perazzo, a



A block of gelatin mimics the brittle and elastic properties of rocks, making it a convenient model for graduate student Ching-Yao Lai to use when studying how fluids spread underground during hydraulic fracturing for the extraction of gas and oil.

PHOTO BY SAMEER A. KHAN/FOTOBUDDY

postdoctoral research associate, found that longer fibers are more likely to entangle, creating a semisolid gel, while the shorter fibers stay suspended in the liquid.

The microfluidic device produces one fiber at a time, but the team plans to improve the process to churn out many fibers at once. She is also exploring what would happen if she mixes in ingredients that make the gel degradable, to make tissue scaffolding or internal bandages that can biodegrade when they are no longer needed.

Arctic ice bridges

Outside the glass doors of the lab, postdoctoral research associate Bhargav Rallabandi sits across from a whiteboard filled with geometrical figures and equations, the evidence of a day in the life of a theorist. Rallabandi's latest project is a theoretical model of the formation of Arctic ice bridges.

Ice bridges form when chunks of ice, flowing through a narrow strait between two bodies of land, form a clog. The bridges can prevent ice from flowing south and melting due to warmer temperatures, and may also enable polar bears to reach their hunting grounds.

Using pen and paper, and later, computer simulations, Rallabandi calculated the critical thickness, wind speed and ice compactness necessary for ice bridges to form. The team found that the formation of ice bridges can be understood as a balance between wind stresses that drive motion and frictional stresses in the ice that resist motion. These frictional stresses arise from the motion of ice floes relative to each other and to the land boundaries of the strait. The results were published earlier this year in the journal *Physical Review Letters*.

"This gives you a way to think about what factors we need to measure in the Arctic to predict ice bridge formation," Rallabandi said. Now that he figured out how ice bridges form, he plans to tackle the other side of the question: How do they break up?

Barista science

When Nan Xue joined the lab as a new graduate student last year, the first thing he did was buy a coffee machine, and it wasn't to stay awake. He needed to brew a lot of the stuff for his studies on how two liquids — in this case, coffee and milk — can settle into layers. What he finds could have applications for food science or improving personal care products.

The idea for the study originated with the observation that pouring hot coffee into warm milk leads to the formation of layers that are progressively darker from the top of the cup to the bottom. "In the beginning, we thought maybe this was something related to the oil particles in the milk or the foam," said Xue. "That was totally wrong."

PHOTO BY SAMEER A. KHAN/FOTOBUDDY

Janine Nunes, an associate research scholar, develops liquids that solidify into fibers for applications in wound healing. Such a liquid could be injected into the body, where it could solidify into a scaffold on which cells can regrow.

Coffee is less dense than milk, so, in the absence of stirring, it normally floats atop the milk. Making a latte, however, involves pouring hot coffee into a cup of warm milk, forcing coffee to the bottom where it slowly separates into regions of different coffee-to-milk ratios. The liquid at the exterior of the cup is slightly cooler than the liquid in the interior, and cooler liquids are denser, so this liquid sinks until it is stopped by a section of denser coffee-milk. Over several minutes, these processes lead to the formation of layers.

Xue found that a large factor dictating the layering was speed. When he poured the coffee quickly into the milk, the layers formed, but when he poured slowly, no layering occurred. Xue and his colleagues developed a model system to show how the layers form, and they are now exploring the effects of volume, speed and density differences on the pattern formations. The team has also created a material that gels to form a solid containing these layers.

Writing on water

The layered lattes are not the only example of an everyday observation that became a research question. Sepideh Khodaparast, a postdoctoral research associate, was working with bacteria when she noticed something curious.

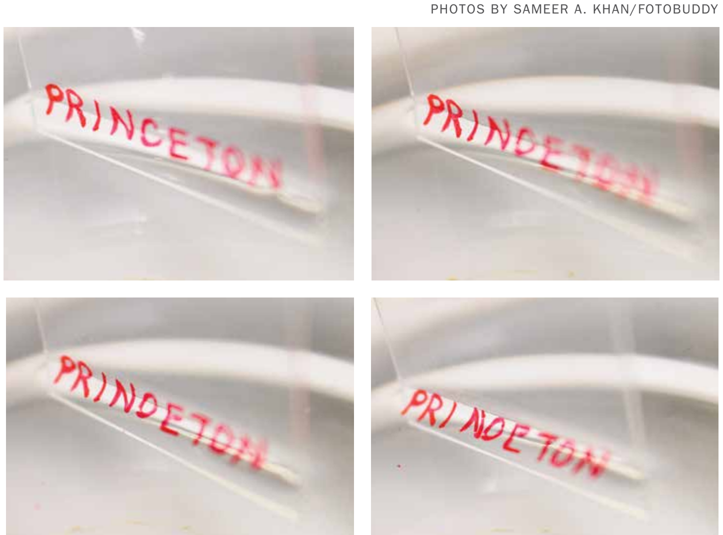
Khodaparast was studying the slimy bacterial films that adhere to surfaces and can contaminate medical tubing, stents and implants. In her primary research, she investigates how the interfaces between air and water, such as those that occur in bubbles, can be harnessed to remove pathogenic bacterial cells from different surfaces. She has found that bubbles are highly effective at preventing the formation of more mature layers of bacteria.

One day she was trying to remove bacteria from a glass surface, which was labeled with permanent marker ink, when she observed that, under the right conditions, dipping the slides in water caused the ink to slip off the slides and onto the surface of the water with the words intact.

PHOTO BY SAMEER A. KHAN/FOTOBUDDY

Graduate student Nan Xue studies how two fluids — in this case, coffee and milk — settle into layers. The results could have applications for food science or improving personal care products.

PHOTOS BY SAMEER A. KHAN/FOTOBUDDY



Under the right conditions, dipping slides in water caused permanent ink to slip off the slides and into the water.

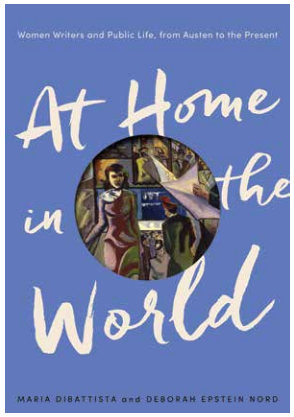
With further investigation, Khodaparast and François Boulogne, a former postdoctoral researcher who is now at Paris Saclay University in France, found that when they quickly dipped the glass into a tub of water, the words did not peel off. But if they did it slowly, the words slid off and floated on the water. “This mechanism could be useful for removing water-resistant stains and transferring thin elastic films, patterned with microfabricated electronics, from one surface to another,” Khodaparast said.

The broad range of inquiry in the lab has produced numerous technologies with the potential to benefit society. Early this year, the group published a study showing that carbon dioxide gas — the substance that gives soda its fizz — can remove contaminating particles from water, suggesting a low-cost, low-energy water treatment system.

“You could potentially use this to clean water from a pond or river that has bacteria and dirt particles,” said Sangwoo Shin, who performed the research as a postdoctoral researcher in the laboratory and is now an assistant professor of mechanical engineering at the University of Hawaii at Manoa. The study was published earlier this year in *Nature Communications*.

By bringing together talent from around the globe in the form of postdoctoral fellows, graduate students and undergraduates, and letting the ideas flow, Stone and the Complex Fluids Group are making new discoveries while also probing deeply to understand fundamentals. As mentor to this diverse team of early-career scientists and engineers, Stone is modest when it comes to taking credit for their accomplishments. Instead, he said, “I am incredibly lucky to work with such smart, talented, hard-working and kind people.” D

BOOKS



At Home in the World: Women Writers and Public Life, from Austen to the Present

Maria DiBattista, *Charles Barnwell Straut Class of 1923 Professor of English, professor of English and comparative literature;* *and* **Deborah Epstein Nord**, *Woodrow Wilson Professor of Literature and professor of English*

Princeton University Press, February 2017

In a bold and sweeping reevaluation of the past two centuries of women's writing, *At Home in the World* argues that this body of work has been defined less by domestic concerns than by an active engagement with the most pressing issues of public life: from class and religious divisions, slavery, warfare and labor unrest to democracy, tyranny, globalism and the clash of cultures. In this new literary history, Maria DiBattista and Deborah Epstein Nord contend that even the most seemingly traditional works by English-language women writers redefine the domestic sphere in ways that incorporate the concerns of public life.

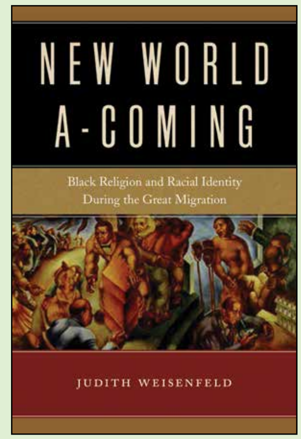
The book explores works by a wide range of writers, including canonical figures such as Jane Austen, Charlotte Brontë and George Eliot; neglected or marginalized writers like Mary Antin and Martha Gellhorn; and recent and contemporary figures, including Nadine Gordimer and Jhumpa Lahiri. DiBattista and Nord show how these writers dramatize tensions between home and the wider world through recurrent themes of sailing forth, escape, exploration, dissent and emigration. The result is an enlightening reinterpretation of women's writing from the early 19th century to the present day.

New World A-Coming: Black Religion and Racial Identity During the Great Migration

Judith Weisenfeld, *the Agate Brown and George L. Collord Professor of Religion*

New York University Press, February 2017

When Joseph Nathaniel Beckles registered for the draft in the 1942, he rejected the racial categories presented to him and persuaded the registrar to cross out the check mark she had placed next to Negro and substitute "Ethiopian Hebrew." "God did not make us Negroes," declared religious leaders in black communities of the early-20th-century urban North. They insisted that so-called Negroes are, in reality, Ethiopian Hebrews, Asiatic Muslims or raceless children of God. Rejecting conventional American racial classification, many black Southern migrants and immigrants from the Caribbean embraced these alternative visions of black history, racial identity and collective future, thereby reshaping the black religious and racial landscape.



Focusing on the Moorish Science Temple, the Nation of Islam, Father Divine's Peace Mission Movement and a number of congregations of Ethiopian Hebrews, Judith Weisenfeld draws on extensive archival research and incorporates a rich array of sources to highlight the experiences of average members. The book demonstrates that the efforts by members of these movements to contest conventional racial categorization contributed to broader discussions in black America about the nature of racial identity and the collective future of black people that still resonate today.

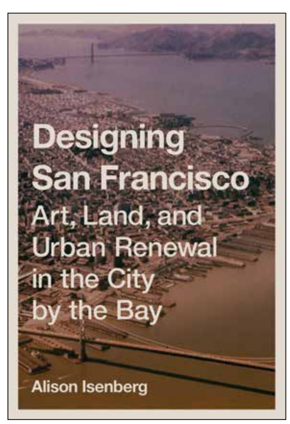
Designing San Francisco: Art, Land and Urban Renewal in the City by the Bay

Alison Isenberg, *professor of history*

Princeton University Press, September 2017

Designing San Francisco is the previously untold story of the formative postwar decades when U.S. cities took their modern shape amid clashing visions of the future. In this pathbreaking and richly illustrated book, Alison Isenberg shifts the focus from architects and city planners — those most often hailed in histories of urban development and design — to the unsung artists, activists and others who played pivotal roles in rebuilding San Francisco between the 1940s and the 1970s.

Previous accounts of midcentury urban renewal have focused on the opposing terms set down by Robert Moses and Jane Jacobs — put simply, development versus preservation — and have followed New York City models. Now Isenberg turns our attention west to colorful, pioneering and contentious San Francisco, where unexpectedly fierce battles were waged over iconic private and public projects like Ghirardelli Square, Golden Gateway and the Transamerica Pyramid.



Isenberg explores how centrally engaged arts professionals brought new ideas to city, regional and national planning and shaped novel projects across urban, suburban and rural borders. An evocative portrait of one of the world's great cities, *Designing San Francisco* provides a new paradigm for understanding past and present struggles to define the urban future.

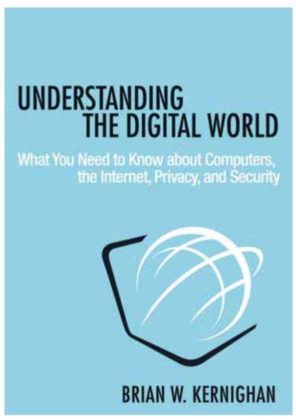
Understanding the Digital World: What You Need to Know about Computers, the Internet, Privacy and Security

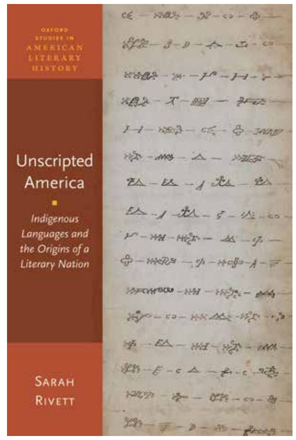
Brian Kernighan, *professor of computer science*

Princeton University Press, January 2017

Computers are everywhere. Some of them are highly visible, in laptops, tablets, cellphones and smart watches. But most are invisible, like those in appliances, cars, medical equipment, transportation systems, power grids and weapons. We never see the myriad computers that quietly collect, share and sometimes leak vast amounts of personal data about us. Through computers, governments and companies increasingly monitor what we do. Social networks and advertisers know far more about us than we should be comfortable with, using information we freely give them. Criminals have all-too-easy access to our data.

Understanding the Digital World explains how computer hardware, software, networks and systems work. Topics include how computers are built and how they compute; what programming is and why it is difficult; how the internet and the web operate; and how all of these affect our security, privacy, property and other important social, political and economic issues. *Understanding the Digital World* is a must-read for all who want to know more about computers and communications. It explains, precisely and carefully, not only how they operate but also how they influence our daily lives, in terms anyone can understand, no matter what their experience and knowledge of technology.





Unscripted America: Indigenous Languages and the Origins of a Literary Nation

Sarah Rivett, *associate professor of English and American studies*

Oxford University Press, October 2017

In 1664, French Jesuit Louis Nicolas arrived in Quebec. Upon first hearing Ojibwe, Nicolas observed that he had encountered the most barbaric language in the world — but after listening to and studying approximately 15 Algonquian languages over a 10-year period, he wrote that he had "discovered all of the secrets of the most beautiful languages in the universe."

Unscripted America is a study of how colonists in North America struggled to understand, translate and interpret Native American languages, and the significance of these languages for theological and cosmological issues such as the origins of Amerindian populations, their relationship to Eurasian and Biblical peoples, and the origins of language itself. Through a close analysis of previously overlooked texts, *Unscripted America* places American Indian languages within transatlantic intellectual history, while also demonstrating how American letters emerged in the 1810s through 1830s via a complex and hitherto unexplored engagement with the legacies and aesthetic possibilities of indigenous words.

By examining the foundation of the literary nation through language, writing and literacy, *Unscripted America* revisits common conceptions regarding "early America" and its origins to demonstrate how the understanding of America developed out of a steadfast connection to American Indians, both past and present.

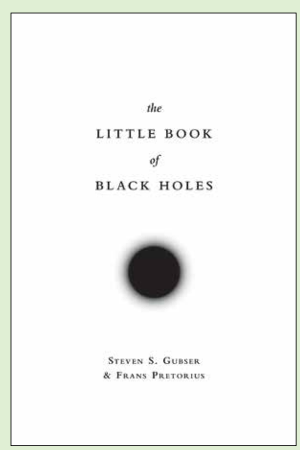
The Little Book of Black Holes

Steven Gubser and Frans Pretorius, *professors of physics*

Princeton University Press, October 2017

Black holes, predicted by Albert Einstein's general theory of relativity more than a century ago, have long intrigued scientists and the public with their bizarre and fantastical properties. Although Einstein understood that black holes were mathematical solutions to his equations, he never accepted their physical reality — a viewpoint many shared. This all changed in the 1960s and 1970s, when a deeper conceptual understanding of black holes developed. Black holes have since been the subject of intense research — and the physics governing how they behave and affect their surroundings is stranger and more mind-bending than any fiction.

This book describes black holes both as astrophysical objects and theoretical "laboratories" in which physicists can test their understanding of gravitational, quantum and thermal physics. The authors describe the decades-long quest to observe the universe in gravitational waves, which recently resulted in the LIGO observatories' detection of the distinctive gravitational wave "chirp" of two colliding black holes — the first direct observation of black holes' existence. The work was awarded the 2017 Nobel Prize in Physics. *The Little Book of Black Holes* takes readers deep into the mysterious heart of the subject, offering rare clarity of insight into the physics that makes black holes simple yet destructive manifestations of geometric destiny.



SELECTED FACULTY HONORS

MEMBERSHIPS AND FELLOWSHIPS

American Academy of Arts and Sciences: Fellow

Michael Aizenman, professor of physics and mathematics (2017)

Manjul Bhargava, Brandon Fradd, Class of 1983, Professor of Mathematics (2017)

Anne Case, Alexander Stewart 1886 Professor of Economics and Public Affairs, Emeritus (2017)

Dalton Conley, Henry Putnam University Professor in Sociology (2017)

Yannis Kevrekidis, Pomeroy and Betty Perry Smith Professor in Engineering, Emeritus, professor of chemical and biological engineering and applied and computational mathematics, emeritus, and senior scholar (2017)

Eldar Shafir, Class of 1987 Professor in Behavioral Science and Public Policy, professor of psychology and public affairs (2017)

Suzanne Staggs, Henry DeWolf Smyth Professor of Physics (2017)

Elke Weber, Gerhard R. Andlinger Professor in Energy and the Environment, professor of psychology and public affairs, Woodrow Wilson School (2016)

American Academy of Arts and Sciences: Foreign Honorary Member

Peter Schäfer, Ronald O. Perelman Professor of Jewish Studies, Emeritus, professor of religion, emeritus, and senior scholar (2017)

American Association for the Advancement of Science: Fellow

Edward Groth, professor of physics, emeritus (2016)

Yibin Kang, Warner-Lambert/Parke-Davis Professor of Molecular Biology (2016)

Eric Wood, Susan Dod Brown Professor of Civil and Environmental Engineering (2016)

American Philosophical Society: Member

Orley Ashenfelter, Joseph Douglas Green 1895 Professor of Economics (2017)

Anne Case, Alexander Stewart 1886 Professor of Economics and Public Affairs, Emeritus (2017)

American Society of Civil Engineers, Structural Engineering Institute: Fellow

Maria Garlock, professor of civil and environmental engineering (2017)

Association for Computing Machinery: Fellow

Nick Feamster, professor of computer science (2016)

European Molecular Biology Organization (EMBO): Member

Michael Levine, Anthony B. Evnin '62 Professor in Genomics, professor of molecular biology and the Lewis-Sigler Institute for Integrative Genomics (2017)

National Academy of Medicine: Member

Bonnie Bassler, Squibb Professor in Molecular Biology (2016)

National Academy of Sciences: Foreign Associate

F. Duncan Haldane, Sherman Fairchild University Professor of Physics (2017)

National Academy of Sciences: Member

David Huse, Cyrus Fogg Brackett Professor of Physics (2017)

Society for Mathematical Biology: Fellow

Simon Levin, James S. McDonnell Distinguished University Professor in Ecology and Evolutionary Biology (2017)

PHOTO BY DAVID KELLY CROW

EMILY CARTER awarded Langmuir Prize in Chemical Physics

Emily Carter, dean of the School of Engineering and Applied Science, has been named the recipient of the 2017 Irving Langmuir Prize in Chemical Physics of the American Physical Society.

The prize recognizes Carter's achievements in "the development of rigorous, *ab initio* methods such as embedding techniques and orbital free density functional theory, and their application to modeling the electronic structure of large systems, including solid materials, and charge transfer phenomena between molecules and surfaces."

Carter is the Gerhard R. Andlinger Professor in Energy and the Environment and a professor of mechanical and aerospace engineering and applied and computational mathematics. Prior to becoming dean, Carter served as the founding director of the Andlinger Center for Energy and the Environment.

Society of American Historians: Member
Regina Kunzel, Doris Stevens Professor in Women's Studies, history, and the Program in Gender and Sexuality Studies (2017)

Julian Zelizer, Malcolm Stevenson Forbes, Class of 1941 Professor of History and Public Affairs, Woodrow Wilson School (2017)

Society of Experimental Psychologists: Fellow
Susan Fiske, Eugene Higgins Professor of Psychology, professor of psychology and public affairs (2017)

NATIONAL DISTINCTIONS FOR EARLY CAREER RESEARCHERS

Alfred P. Sloan Foundation: Research Fellowship
Amir Ali Ahmadi, assistant professor of operations research and financial engineering (2017)

Nathalie de Leon, assistant professor of electrical engineering (2017)

Matthew Kunz, assistant professor of astrophysical sciences (2017)

Han Liu, assistant professor of operations research and financial engineering (2017)

Silviu Pufu, assistant professor of physics (2017)

Nicholas Sheridan, assistant professor of mathematics (2017)

American Institute of Chemical Engineers: Owens Corning Early Career Award
Rodney Priestley, associate professor of chemical and biological engineering (2017)

Camille and Henry Dreyfus Foundation: Teacher-Scholar Award
Robert Knowles, professor of chemistry (2017)

David and Lucile Packard Foundation: Fellowship for Early Career Scientists
Waseem Bakr, assistant professor of physics (2016)

Ecological Society of America: Early Career Fellow
Corina Tarnita, assistant professor of ecology and evolutionary biology (2017)

Howard Hughes Medical Institute: Faculty Scholar
Mala Murthy, associate professor of molecular biology and the Princeton Neuroscience Institute (2016)

Celeste Nelson, professor of chemical and biological engineering (2016)

Howard Hughes Medical Institute-Simons Foundation: Faculty Scholar
Clifford Brangwynne, assistant professor of chemical and biological engineering (2016)

Martin Jonikas, assistant professor of molecular biology (2016)

Coleen Murphy, professor of molecular biology and the Lewis-Sigler Institute for Integrative Genomics (2016)

National Institutes of Health: New Innovator Award
Sabine Petry, assistant professor of molecular biology (2016)

Jared Toettcher, assistant professor of molecular biology (2017)

National Science Foundation: Alan T. Waterman Award
John Pardon, professor of mathematics (2017)

National Science Foundation: Early Career Development (CAREER) Award
Bradley Carrow, assistant professor of chemistry (2017)

John Higgins, assistant professor of geosciences (2017)

Marcus Hultmark, assistant professor of mechanical and aerospace engineering (2017)

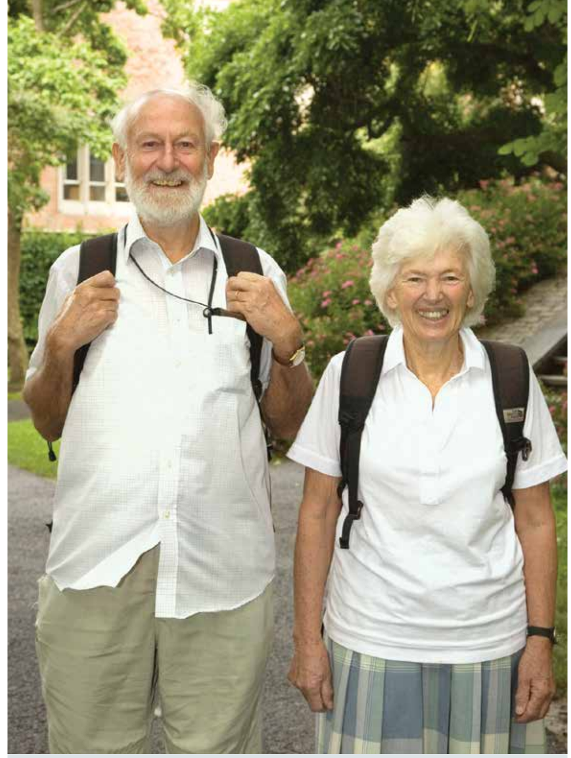


PHOTO BY DENISE APPLEWHITE

PETER AND ROSEMARY GRANT receive Royal Medal in Biology

Peter Grant, the Class of 1877 Professor of Zoology, Emeritus, and professor of ecology and evolutionary biology, emeritus, and B. Rosemary Grant, senior research biologist, emeritus, and a senior biologist in the Department of Ecology and Evolutionary Biology, have been named recipients of the Royal Medal in Biology. The Grants' legendary explorations of the group of 18 bird species known as Darwin's finches that populate the Galápagos island of Daphne Major — which is in an entirely natural state unaffected by humans — over four decades have produced an array of dazzling insights into evolutionary theory.

The biologists are the first husband-and-wife team to be given the award and the first recipients in population biology.

The Royal Society of London stated that the Grants received the Royal Medal "for their research on the ecology and evolution of Darwin's finches on the Galápagos, demonstrating that natural selection occurs frequently and that evolution is rapid as a result."

Ning Lin, assistant professor of civil and environmental engineering (2017)

Arvind Narayanan, assistant professor of computer science (2017)

Ben Raphael, professor of computer science (2016)

Allan Sly, professor of mathematics (2017)

PHOTO BY MARK CZAJKOWSKI

Historian of religion **ELAINE PAGELS** awarded National Humanities Medal

Elaine Pagels, an authority on the religions of late antiquity and the author of *The Gnostic Gospels* and *Beyond Belief: The Secret Gospel of Thomas*, received the 2015 National Humanities Medal. The announcement was made by the White House. The medal was conferred by President Barack Obama at a ceremony at the White House on Sept. 22, 2016.

The medal honors an individual or organization whose work has deepened the nation's understanding of the human experience, broadened citizens' engagement with history and literature, or helped preserve and expand Americans' access to cultural resources. Pagels was among 12 recipients of the award.

The official citation for the award honored Pagels, who is the Harrington Spear Paine Foundation Professor of Religion, "for her exploration of faith and its traditions. Through her study of ancient manuscripts and other scholarly work, she has generated new interest and dialogue about our contemporary search for knowledge and meaning."

Vlad Vicol, assistant professor of mathematics (2017)

Mengdi Wang, assistant professor of operations research and financial engineering (2017)

Claire White, assistant professor of civil and environmental engineering and the Andlinger Center for Energy and the Environment (2016)

Pew Charitable Trusts: Scholar in the Biomedical Sciences
Mohamed Abou Donia, assistant professor of molecular biology (2017)

José Avalos, assistant professor of chemical and biological engineering and the Andlinger Center for Energy and the Environment (2017)

U.S. Air Force Office of Scientific Research: Young Investigator Award
Nathalie de Leon, assistant professor of electrical engineering (2016)

U.S. Navy Office of Naval Research: Young Investigator Program Award
Kaushik Sengupta, assistant professor of electrical engineering (2017)

PRIZES AND DISTINCTIONS

African Studies Association
Chika Okeke-Agulu, associate professor of art and archaeology and African American studies: *2016 Melville J. Herskovits Prize*

American Academy of Political and Social Science
Alan Krueger, Lynn Bendheim Thoman, Class of 1976, and Robert Bendheim, Class of 1937, Professor in Economics and Public Policy, Woodrow Wilson School: *2017 Daniel Patrick Moynihan Prize*

American Chemical Society
Salvatore Torquato, professor of chemistry and the Princeton Institute for the Science and Technology of Materials: *2017 Joel Henry Hildebrand Award in Theoretical and Experimental Chemistry of Liquids*

American Economic Association
Cecilia Rouse, dean of the Woodrow Wilson School, Lawrence and Shirley Katzman and Lewis and Anna Ernst Professor in the Economics of Education, professor of economics and public affairs, Woodrow Wilson School: *2016 Carolyn Shaw Bell Award*

American Geophysical Union
Gabriel Vecchi, professor of geosciences and the Princeton Environmental Institute: *2017 Atmospheric Sciences Ascent Award*

American Physical Society
Howard Stone, Donald R. Dixon '69 and Elizabeth W. Dixon Professor of Mechanical and Aerospace Engineering: *2016 Fluid Dynamics Prize*

American Psychological Association
Susan Fiske, Eugene Higgins Professor of Psychology, professor of psychology and public affairs: *2016 Award for Distinguished Service to Psychological Science*

Association for Computer Aided Design in Architecture
Elizabeth Diller, professor of architecture: *2016 ACADIA Lifetime Achievement Award*

Breakthrough Prize Foundation
Simone Giombi, assistant professor of physics: *2017 New Horizons Prize in Fundamental Physics*

Frans Pretorius, professor of physics: *2017 New Horizons Prize in Fundamental Physics*

Columbia University Lamont-Doherty Earth Observatory
S. George Philander, Knox Taylor Professor of Geosciences, Emeritus: *2017 Vetlesen Prize*

Federation of American Societies for Experimental Biology
Bonnie Bassler, Squibb Professor in Molecular Biology: *2016 Excellence in Science Award*

Fusion Power Associates
Stefan Gerhardt, principal research physicist: *2016 Excellence in Fusion Engineering Award*

Eight win **GUGGENHEIM FELLOWSHIPS**

Eight Princeton faculty members have received 2017 Guggenheim Fellowships — they are among 173 fellowships from a group of almost 3,000 applicants awarded on the basis of prior achievement and exceptional promise.

The recipients are (in order of the photos below): Claudia Rankine, visiting professor of creative writing and the Lewis Center for the Arts, for poetry; B. Andrei Bernevig, professor of physics, who focuses on quantum condensed-matter physics; Linda Colley, the Shelby M.C. Davis 1958 Professor of History, for a forthcoming book on how rising levels of conflict after 1750 fostered the worldwide spread of new constitutions; Phil Klay, lecturer in creative writing and the Lewis Center for the Arts, for fiction; Aaron Landsman, lecturer in theater and the Lewis Center for the Arts, for drama and performance art; Fiona Maazel, lecturer in creative writing and the Lewis Center for the Arts, for fiction; Mark Beissinger, the Henry W. Putnam Professor of Politics, for a project that concerns how revolution as a mode of regime change has evolved globally over the past century; and Stacy Wolf, professor of theater in the Lewis Center for the Arts, for her forthcoming book, *Beyond Broadway: Four Seasons of Amateur Musical Theatre in the U.S.*

Harvard University John F. Kennedy School of Government
Markus Prior, professor of politics and public affairs, Woodrow Wilson School: *2016 Joan Shorenstein Fellowship*

Institute of Classical Studies
Joshua Katz, Cotsen Professor in the Humanities, professor of classics: *2017 Dorothy Tarrant Fellowship*

Institute of Electrical and Electronics Engineers
H. Vincent Poor, Michael Henry Strater University Professor of Electrical Engineering: 2017 *Alexander Graham Bell Medal*

Materials Research Society
Robert Cava, Russell Wellman Moore Professor of Chemistry: *2016 Materials Research Society Medal*

National Endowment for the Humanities
Amy Borovoy, associate professor of East Asian studies: *2016 Fellowship for Advanced Research*

Lara Harb, assistant professor of East Asian studies: *2016 Fellowship for University Teachers*

Anna Shields, professor of East Asian studies: *2016 Fellowship for University Teachers*

Nigel Smith, William and Annie S. Paton Foundation Professor of Ancient and Modern Literature, professor of English: *2017 Folger Institute Fellowship*

National Humanities Center
Tera Hunter, professor of history and African American studies: *2017 Birkelund Fellowship*

Sara Poor, associate professor of German: *2017 NEH Fellowship, Josephus Daniels Fellowship of the Research Triangle Foundation*

PHOTO CREDITS FROM LEFT TO RIGHT:
TOP ROW: JOHN LUCAS, RICHARD SODEN, PETER HURLEY, HANNAH DUNPHY
BOTTOM ROW: DAVID BROWN, NINA KATCHADOURIAN, DENISE APPLEWHITE, JILL DOLAN

PHOTO BY DENISE APPLEWHITE

TRACY K. SMITH
named U.S. Poet Laureate

Tracy K. Smith has been named the Library of Congress's 22nd Poet Laureate Consultant in Poetry, for 2017-18. Smith is the Roger S. Berlind '52 Professor in the Humanities and a professor of creative writing in the Lewis Center for the Arts.

Smith is the author of three books of poetry: *Life on Mars* (2011); *Duende* (2007), winner of the 2006 James Laughlin Award and the 2008 Essence Literary Award; and *The Body's Question* (2003), winner of the Cave Canem Poetry Prize. Smith is also the author of a memoir, *Ordinary Light* (2015), a finalist for the 2015 National Book Award in nonfiction and selected as a notable book by *The New York Times* and *The Washington Post*.

The Library of Congress Poetry and Literature Center is the home of the Poet Laureate Consultant in Poetry, a position that has existed since 1936. During their terms, poet laureates seek to raise the national consciousness to a greater appreciation of the reading and writing of poetry.

National Institutes of Health
Uri Hasson, professor of psychology and the Princeton Neuroscience Institute: *2016 Pioneer Award*

Joshua Rabinowitz, professor of chemistry and the Lewis-Sigler Institute for Integrative Genomics: *2016 Pioneer Award*

New York Dance and Performance League
Rebecca Lazier, senior lecturer in dance in the Lewis Center for the Arts: *2016 Bessie Award for Outstanding Musical Composition/Sound Design*

Daniel Trueman, professor of music: *2016 Bessie Award for Outstanding Musical Composition/Sound Design*

PEN/Faulkner Foundation
Jhumpa Lahiri, professor of creative writing in the Lewis Center for the Arts: *2017 Award for Excellence in the Short Story*

Society for Risk Analysis
Elke Weber, Gerhard R. Andlinger Professor in Energy and the Environment, professor of psychology and public affairs, Woodrow Wilson School: *2016 Distinguished Achievement Award*

U.S. Navy
Christopher L. Eisgruber, president of the University, Laurance S. Rockefeller Professor of Public Affairs in the Woodrow Wilson School and the University Center for Human Values: *2017 Distinguished Public Service Award*

INTERNATIONAL PRIZES AND DISTINCTIONS

Academia Europaea
Michael Aizenman, professor of physics and mathematics: *2016 Foreign Member*

Alexander von Humboldt Foundation and the Max Planck Society
Bonnie Bassler, Squibb Professor in Molecular Biology: *2016 Max Planck Research Award*

Anglo-Hellenic League
Marc Domingo Gygax, professor of classics: *2017 Runciman Award*

Bernoulli Society for Mathematical Statistics and Probability
Allan Sly, professor of mathematics: *2016 Doeblin Prize*

Bogliasco Foundation
Stacy Wolf, professor of theater in the Lewis Center for the Arts: *2017 Fellowship*

British Academy
Denis Feeney, Giger Professor of Latin, professor of classics: *2016 Corresponding Fellow*

Commonwealth of Australia
Philip Pettit, Laurance S. Rockefeller University Professor of Politics and the University Center for Human Values: *2017 Companion of the Order of Australia*

Government of France
Florent Massé, senior lecturer in French and Italian: *2017 Chevalier dans l'Ordre des Arts et des Lettres*

Government of Italy
Jhumpa Lahiri, professor of creative writing in the Lewis Center for the Arts: *2017 Cavaliere Ordine al Merito della Repubblica Italiana*

Indian Academy of Sciences
Manjul Bhargava, Brandon Fradd, Class of 1983, Professor of Mathematics: *2017 Honorary Fellow of the Indian Academy of Sciences*

Institution of Chemical Engineers
Pablo Debenedetti, Dean for Research, Class of 1950 Professor in Engineering and Applied Science, professor of chemical and biological engineering: *2016 Guggenheim Medal*

Kurchatov Institute - Institute of Theoretical and Experimental Physics
Curtis Callan, James S. McDonnell Distinguished University Professor of Physics: *2016 Pomeranchuk Prize*

Igor Klebanov, Eugene Higgins Professor of Physics: *2017 Pomeranchuk Prize*

National Academy of Engineering of Korea
H. Vincent Poor, Michael Henry Strater University Professor of Electrical Engineering: *2017 Foreign Member*

National Academy of Sciences of Korea
H. Vincent Poor, Michael Henry Strater University Professor of Electrical Engineering: *2017 Honorary Member*

Royal Society
Jo Dunkley, professor of physics and astrophysical sciences: *2016 Rosalind Franklin Award and Lecture*

Andrew Wiles (Sir), James S. McDonnell Distinguished University Professor of Mathematics, Emeritus: *2017 Copley Medal*

Royal Swedish Academy of Sciences
F. Duncan Haldane, Sherman Fairchild University Professor of Physics: *2016 Nobel Prize in Physics*

Shaw Prize Foundation
János Kollár, Donner Professor of Science, professor of mathematics: *2017 Shaw Prize in Mathematical Sciences*

Society for Applied Anthropology
Douglas Massey, Henry G. Bryant Professor of Sociology and Public Affairs, Woodrow Wilson School: *2018 Bronislaw Malinowski Award*

Swiss Chemical Society
Robert Knowles, professor of chemistry: *2017 Grammaticakis-Neumann Prize*

Additional faculty honors can be found at discovery.princeton.edu.

PHOTO BY WILLIAM CROW

CHARLES FEFFERMAN awarded 2017 Wolf Prize in Mathematics

Charles Fefferman, the Herbert E. Jones, Jr ’43 University Professor of Mathematics, has been selected to receive the 2017 Wolf Prize in Mathematics awarded by the Wolf Foundation in Israel. Fefferman, whose focus is on mathematical analysis, was honored for his “major contributions to several fields, including several complex variables, partial differential equations and subelliptic problems,” according to the prize citation from the Wolf Foundation.

Bestowed annually since 1978, the Wolf Prize is one of the most prestigious awards in mathematics. Fefferman, who shares the prize with Richard Schoen of Stanford University, is one of numerous Princeton faculty and alumni to receive the prize. He received his Ph.D. from Princeton in 1969 at the age of 20 and joined Princeton’s faculty in 1973.

Fefferman’s work earned him the Fields Medal in 1978, which honors outstanding mathematicians under the age of 40. In 1976, he was the inaugural recipient of the National Science Foundation’s Alan T. Waterman Award, the nation’s highest honorary award for early-career scientists and engineers.

RESEARCH BY THE NUMBERS

FISCAL YEAR 2017

Sponsored Research Projects

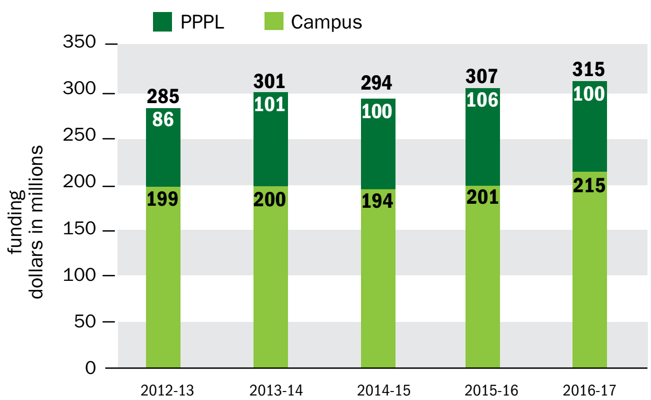
$215.2 M
Princeton University campus expenditures[1]

$100.2 M
U.S. Department of Energy's Princeton Plasma Physics Laboratory (PPPL) allocation[2]

241
Projects supported by foundation funding

67
Projects supported by industry funding

1,433
Total sponsored research projects



[1]Expenditures for the fiscal year July 1–June 30
[2]Amount allocated for the fiscal year Oct. 1–Sept. 30. This funding level does not include pass-through procurements related to ITER, an international fusion experiment.

Technology Licensing Activities

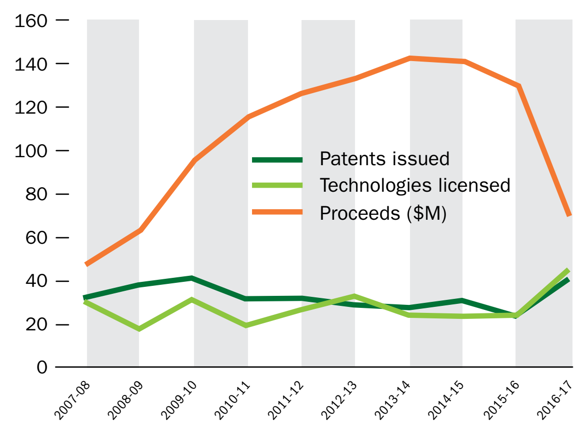
90
Invention disclosures received

41
Patents issued

160
Patent applications filed

45
Technologies licensed

$70 M
Gross royalty proceeds[3]



[3] 89 percent of this amount is from royalty payments from a cancer drug, Alimta™, which ceased in fiscal year 2017.

Funding Sources for Sponsored Research Activities (Campus)

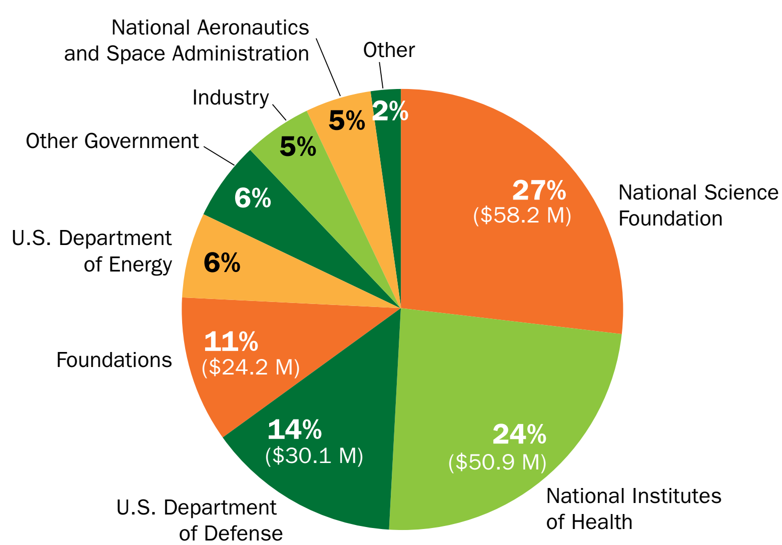


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PHOTO BY DAVID KELLY CROW

Professor Margaret Martonosi is a leader in computer architecture and mobile computing, with a particular focus on power-efficient systems. She is the Hugh Trumbull Adams '35 Professor of Computer Science and director of Princeton's Keller Center for Innovation in Engineering Education. The Keller Center's broad portfolio includes efforts on engineering education, design thinking and entrepreneurship through classes and programs. "Whether in technology, design, entrepreneurship or leadership, the Keller Center's goal is to support students and faculty in translating aspirations to meaningful impact," Martonosi said. "Our goal is to educate the leaders of our technology-driven society to solve critical societal challenges."

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The new 22-acre Lewis Arts complex dramatically expands the space for innovation and creativity in the arts at Princeton. The complex includes the Wallace Theater, a performance space with all-LED lighting.

PHOTO BY DENISE APPLEWHITE