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When I talk to students, I sometimes advise them, “Follow your curiosity and do things that keep you awake at night.”

Most of us know people who’ve pulled all-nighters in pursuit of a discovery — whether the discovery involved a scientific experiment, a search through a library archive, or a creative endeavor in art, performance or music.

The pursuit of discoveries keeps us up at night because discoveries have the power to change our conception of the world. Many truths trace their roots to a person or group that observed an experimental result that didn’t fit with the existing paradigm. Rather than succumbing to self-doubt, these individuals repeated experiments, explored every hypothesis, and spent many a late night until they confirmed they had indeed discovered something new. And then they had to convince the world.

Discoveries often take years to gain acceptance. Galileo’s confirmation that the Earth travels around the Sun did not happen overnight but rather built on precedents from Copernicus and the ancient Greeks. Charles Darwin gathered data for decades before finally publishing his theory of evolution. The Austrian physicist Ludwig Boltzmann in the late 19th century brilliantly connected the world of atoms and molecules to the tangible, continuum world of our everyday experience, at a time when the very existence of atoms was the subject of heated controversy.

Yet once acceptance occurs, it becomes hard to imagine any other paradigm. When Princeton psychology researcher and Nobel laureate Daniel Kahneman, the Eugene Higgins Professor of Psychology, Emeritus, and a professor of psychology and public affairs, emeritus, demonstrated that humans are not always rational actors when it comes to decision making, the discovery confounded economists. Today, knowledge of behavioral science is considered essential for public policymaking.

In these pages, you’ll read about many discoveries, big and small, in the natural sciences, engineering, social sciences and the humanities. For many discoveries, it is too soon to tell what the impact will be. But they all have the potential to inspire us to create, dream, resist doubting our ideas, and do something that we don’t mind losing a night of sleep over. I hope that this issue of *Discovery: Research at Princeton* inspires you to do things that keep you up at night.
PRINCETON RESEARCHERS will have an integral role in the Simons Observatory, a new astronomy facility in South America recently established with a $38.4 million grant from the Simons Foundation. The observatory will investigate cosmic microwave background (CMB) radiation to better understand the physics of the Big Bang, the nature of dark energy and dark matter, the properties of neutrinos, and the formation of structure in the universe.

The project is a collaboration between Princeton, the University of California-San Diego, the University of California-Berkeley, the University of Pennsylvania and the Lawrence Berkeley National Laboratory, all of which will provide financial support. The Heising-Simons Foundation will provide an additional $1.7 million of support. The observatory will be located in Chile’s Atacama Desert, a longtime site for astronomy and CMB research because of its elevation and near absence of precipitation.

The project manager for the Simons Observatory will be located at Princeton, and Princeton faculty also will oversee the development, design, testing and manufacture of many of the observatory’s camera components.

Suzanne Staggs, Princeton’s project lead for the observatory and the Henry DeWolf Smyth Professor of Physics, said the mission of the Simons Observatory builds on the University’s long history of advancing the understanding of the CMB. Princeton faculty members Lyman Page, the James S. McDonnell Distinguished University Professor in Physics and department chair, and David Spergel, the Charles A. Young Professor of Astronomy on the Class of 1897 Foundation, also will participate in the Simons Observatory.

–By Staff
Princeton Research Day highlights student and early-career work

**MORE THAN 150** undergraduates, graduate students and postdoctoral researchers presented their work at the first Princeton Research Day held May 5, 2016.

The event highlighted research from the natural sciences, engineering, social sciences, humanities and the arts in formats including talks, poster presentations, performances, art exhibitions and digital presentations — all designed with the general public in mind.

“It’s a wonderful cross section of the research enterprise at Princeton,” said Dean for Research Pablo Debenedetti, the Class of 1950 Professor in Engineering and Applied Science, and professor of chemical and biological engineering.

In all, Princeton Research Day presented an important opportunity for undergraduates, said Dean of the College Jill Dolan, the Annan Professor in English and professor of theater in the Lewis Center for the Arts.

“Princeton is one of the very few universities in the world where undergraduate students are encouraged to do the kind of original research that every single undergraduate on this campus does,” Dolan said. “So taking the opportunity at the end of the year to do a major public event in which students can present that work is groundbreaking.”

Princeton Research Day was a collaborative initiative between the offices of the dean of the college, dean of the faculty, dean of the graduate school and the dean for research. The second Princeton Research Day is scheduled for May 11, 2017. —By Michael Hotchkiss

Students explore sustainable building with bamboo

Russell Archer and Lu Lu, who both majored in civil and environmental engineering, partnered with a group in Colombia to analyze and design a bamboo canopy that is sustainable and strong. View the video at discovery.princeton.edu.

**LAST FALL,** two undergraduates approached Sigrid Adriaenssens, an associate professor of civil and environmental engineering, about working together on their senior-thesis projects, from different angles.

Lu Lu, who is from Chongqing, China, wanted to work on sustainable construction with a focus on design and digital modeling. Russell Archer, who is from East Orange, New Jersey, wanted to physically test building materials. Adriaenssens served as the adviser for both students, who graduated in 2016.

With the help of a graduate student in Adriaenssens’ lab, the seniors identified a partner, the Administrative Department of Environmental Management (DAGMA), in Cali, Colombia. The students and the group collaborated on a project involving bamboo architecture and construction — the entrance canopy to a park to be used by schoolchildren.

Bamboo grows quickly and is lightweight but strong. It has been used as a building material for centuries, but little engineering analysis has been done on it. Lu focused on the structural form of the canopy, and Archer analyzed the effectiveness of the fishmouth joints used in the designs.

Last March, with funding from the School of Engineering and Applied Science, they traveled to Cali to meet with the DAGMA architects and engineers, share their results, and inform the design and construction of the bamboo canopy.

“I couldn’t have imagined I would be traveling to Colombia,” said Archer, who plans to pursue a master’s degree in structural engineering. “I’m really impressed by the breadth of the entire project.”

“I really enjoyed this project because engineering is not only hard-core science — you calculate something but that’s it,” Lu said. “There’s a very strong social component.”

—By the Office of Communications

Watch participants from across the Princeton campus prepare, present and reflect on the University’s first Princeton Research Day at discovery.princeton.edu.
ELECTRONS DART within and between atoms far too quickly for current imaging techniques to observe their motion. To capture fast-moving objects without a blur, a photographer can use a camera flash to light up a scene for an instant. Julia Mikhailova, an assistant professor of mechanical and aerospace engineering, hopes to capture electron motion in a similar way, but her camera flash must last only a few attoseconds — just millionths of a trillionth of a second.

Mikhailova and her team use lasers and plasmas, which are collections of charged particles, to create attosecond pulses of light. “With these pulses one can observe the action inside atoms and molecules,” Mikhailova said. These observations could help researchers predict electron behavior, leading to a better understanding of everything from chemical reactions to superconductivity.

Lasers cannot by themselves produce such brief pulses. Instead, scientists scatter high-powered laser light off a stream of gas. Too much energy from the laser, however, can strip the electrons in the gas from their atoms to make a plasma that no longer scatters light in the right way.

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Mikhailova and her team, with funding from the National Science Foundation, are taking a different approach. Instead of using a gas target, they aim a much higher-powered laser at a solid glass disc, creating a dense plasma at its surface. The laser light — an oscillating electromagnetic field — accelerates the electrons in the plasma toward nearly the speed of light. At these speeds, Newton’s physics breaks down and relativity takes over, causing the release of light in the form of attosecond pulses.

To improve the technique, Matthew Edwards, a graduate student in Mikhailova’s lab, ran simulations of plasma-laser interactions on Princeton’s TIGRESS high-performance computer cluster. The results, published Sept. 16, 2016, in the journal *Physical Review Letters*, showed that mixing laser light with light at harmonic frequencies — which are multiples of the original laser’s frequency — increases the efficiency of the process.

In a paper published Feb. 24, 2016, in the journal *Physical Review A*, the researchers proposed an extremely efficient two-target system: the first target generates light with harmonic frequencies, which hits the second target to generate attosecond pulses. With such powerful pulses, a new domain becomes visible, Mikhailova said. “We may be able to really see what the electron is doing as it ‘orbits’ in the atom.” —By Bennett McIntosh

Exploring collective interactions of matter and antimatter

STRIP AWAY ELECTRONS FROM THEIR ATOMS and you get a plasma — a collection of negatively charged electrons and positively charged ions. But at high energies around compact cosmic objects such as black holes, quasars and pulsars, curious plasmas may form that, instead of ions, contain positrons, the antimatter counterparts of electrons.

Scientists are searching for ways of distinguishing this type of plasma from others, both in astrophysical environments and in laboratories on Earth. Julia Mikhailova, an assistant professor of mechanical and aerospace engineering, and Matthew Edwards, a graduate student in her lab, together with Professor of Astrophysical Sciences Nathaniel Fisch, found that, contrary to earlier claims, an electron-positron plasma would scatter some wavelengths of light surprisingly intensely via a process called Brillouin scattering.

This fundamental insight into the unusual behavior of matter-antimatter plasmas, published in the journal *Physical Review Letters* Jan. 8, 2016, may help to find such plasmas in space, or validate methods for creating them in the lab. The work was funded in part by the National Science Foundation and the National Nuclear Security Administration.

—By Bennett McIntosh
In cells, self-destructive behavior suggests strategy for fighting cancer

SOMETIMES, TO SURVIVE, our cells destroy their own ribonucleic acid (RNA), the part of our genetic instruction code that helps turn genes into proteins. Cells do this as part of the first line of defense against pathogens and damage. New research suggests how this mechanism could form the basis of a strategy against cancer.

The mechanism is part of the body’s innate immune system, which kicks into gear minutes after infection. The innate immune system holds pathogens at bay for the critical few days needed to make antibodies.

One of the mysterious weapons in the innate immune system is an enzyme called RNase L that chops up strands of RNA, an intermediate step between genes and their final products, proteins. Because viruses lack the machinery to make copies of themselves to spread infection, they hijack a cell’s reproductive technology and force it to make viral RNA and proteins. To fight back, the body sends RNase L. (The “ase” is a common ending for enzymes, and the “L” is for latent, because RNase L lies in wait for infection or damage signals.)

RNase L chops up the viral RNA, but it also shears the body’s own RNA. This self-mutilation is necessary for good health. Mice that lack RNase L are obese, diabetic and have signs of inflammation.

“This cleavage of the cell’s own RNA has a protective function. It does not always kill the cell, but when it does it eliminates only damaged or infected cells, which repairs the tissue. It ultimately means animals survive better,” said Alexei Korennykh, an associate professor of molecular biology. His lab was the first to solve the crystal structure of human RNase L, a result they published in the journal Science March 14, 2014.

Korennykh’s research is funded by the National Institutes of Health, the Sidney Kimmel Foundation, the Burroughs Wellcome Fund and the Vallee Foundation.

With the 3-D structure in hand, Korennykh and his team turned to the question of how RNase L works. Korennykh wondered if RNase L chops up every RNA that comes along, or just certain ones. To find out, the researchers sequenced every piece of RNA made in a typical human cell and evaluated them to see which ones were susceptible to RNase L.

What they found surprised them. RNase L chops up RNA strands that govern the rapid division of cells, as well as how well cells stick to each other. These two activities — when cells proliferate and attach themselves in new locations — are two of the key steps in the spread of cancer. They published the findings Dec. 29, 2015, in the Proceedings of the National Academy of Sciences.

The link between RNase L and cancer made sense because RNase L mutations are common in individuals from families with a hereditary predisposition for prostate cancer, Korennykh said. The team is exploring how to turn this discovery into a strategy for inhibiting cancer’s spread using small drug-like molecules to boost RNase L’s activity against cell proliferation and attachment.

“We really stumbled on this approach very unexpectedly,” Korennykh said. “Often the best experiments are the ones where you didn’t get the results you expected.”

–By Catherine Zandonella

Julia Mikhailova and her research team scatter high-powered lasers off a stream of gas to produce pulses of light that last only a few attoseconds — just millionths of a trillionth of a second. These ultrafast pulses can reveal the behavior of electrons, which move far too quickly to be captured by conventional imaging techniques.
Cuban literature and culture are focus of

**Planet/Cuba**

**RACHEL PRICE**, an associate professor of Spanish and Portuguese who also is affiliated with the Program in Media and Modernity, joined Princeton in 2009. Her scholarship focuses on culture, media, poetics, empire and ecocriticism in Latin American, Caribbean and, particularly, Cuban literature.

In her book *Planet/Cuba* (2015, Verso Books), Price addresses contemporary literature as well as conceptual, digital and visual art from Cuba that engages questions of environmental crisis, new media, and new forms of labor and leisure.

**What inspired you to write this book?**

I wanted to think about the many positions Cuba has occupied in its own imagination and for the rest of the world. Cuban history has always been inescapably global — it was shaped by empires, by massive slave trade, and by sitting at the junction of international trade routes.

Both because of and despite this, Cuba is often discussed as singular; sometimes as a theme park, or as a world apart, as a kind of “Planet Cuba.” By introducing the slash [in the title], I also wanted to call attention to the indissociable relation between Cuba and the planet.

**The book has a strong emphasis on ecology. How are artists addressing issues of climate change and issues such as the impact of deforestation in Cuba?**

So much of life in Cuba, like anywhere on the planet, is deeply marked by an engagement with the environment. In cities, where food security is an issue; in the countryside, where drought is an increasing problem and where invasive species restore nitrates to land worn out by sugar but also thwart agriculture; and in the water, where fishing is diminished.

Artists and writers engage ecological questions both on the local and global scales. To give just a few examples, they may make humorous video art about the failures of agricultural reform in Cuba, create installations (“environments”) that involve living trees, or write speculative fiction — another term for science fiction — that imagines mass migrations caused by ever-increasing hurricanes in the Caribbean.

**How does art-making in Cuba reflect issues of surveillance and state security?**

Artists use a variety of approaches: hacking into systems of transmission and rebroadcasting information; creating exhibits that force viewers to participate unwittingly in being surveilled; producing video-game art that simulates a famous Panopticon prison [such as Cuba’s Presidio Modelo]; and so on.

What interested me in particular was the way that art references the particularities of Cuba’s network of vigilance, but goes beyond it to comment on — or intervene into — the more pervasive global systems of surveillance, both state and corporate, in which we all participate.

—By Jamie Saxon

Rachel Price explores how Cuban artists are addressing themes such as the environment, deindustrialization, state surveillance and economic change. Pictured: Humberto Díaz’s *Afluente No. 1*, 2009. Installation: Ford Maverick ’74, concrete, paint.
Exploring the emergence of Cuban consumerism

DENNISSE CALLE FOUND THE TOPIC for her senior thesis along a Havana street in the back of a stall that sells pirated movies and music. Cubans pay the equivalent of a few dollars, insert a flash drive into the computer at the back of the stall, and get access to El Paquete — a weekly, one-terabyte compilation of popular TV shows, movies, music, computer and phone apps, and advertisements that serves as an offline Netflix, YouTube, Craigslist and more in a country where internet access is slow and expensive. Calle, a sociology major at Princeton, spent two weeks in January doing research in Cuba and interviewed 50 users and distributors of El Paquete — which means "The Package" — to learn about the service and the way it fits into the lives of everyday Cubans.

"I focus on how El Paquete is transforming how people view themselves as consumers," Calle said. "This is one of the first forms of consumer culture that is being normalized in Cuba, in part because it’s cheap and easy to pass around."

The origins of El Paquete, which began around 2008, are unclear, as is the identity of the people behind it. El Paquete is widely available — either distributed door to door using a portable hard drive or from central locations like the stall where Calle discovered it — despite existing in a sort of legal gray area in Cuba. It offers an alternative to state-controlled Cuban television, which broadcasts only 10 channels of news and sedate fare to most residents.

Many of the TV shows and movies — generally subtitled in Spanish — come from the United States, along with the United Kingdom and Spain. Competition shows such as "The Voice" and "Cake Wars" are popular, as are South Korean soap operas. Calle, who is originally from Ecuador and moved to Trenton, New Jersey, also looked beyond the content to explore how El Paquete is changing the way people see themselves. "I think it’s reflective of what’s happening in Cuba, moving from a state that is very controlling to one that is allowing capitalism to emerge into the nation and its culture," she said.

Calle’s research and analysis are impressive, said her adviser, Patricia Fernandez-Kelly, a senior lecturer in sociology. "It’s really a study about identity," Fernandez-Kelly said. "Not just personal identity but national identity."

What’s ahead for El Paquete in Cuba, which has been working to ease tensions with the United States? Calle predicts El Paquete will survive even if Cubans gain broader access to the internet — in part because it is so inexpensive and easily shared.

—By Michael Hotchkiss
Bias in the machine: Internet algorithms reinforce harmful stereotypes

THE ARTIFICIAL-INTELLIGENCE (AI) SYSTEMS that suggest our search terms and otherwise determine what we see online rely on data that can be biased against women and racial and religious groups, according to a study led by researchers in Princeton’s Center for Information Technology and Policy (CITP).

As machine learning and AI algorithms become more ubiquitous, this phenomenon could inadvertently cement and amplify bias that is already present in our society or a user’s mind, according to the study, which was led by Arvind Narayanan, an assistant professor of computer science. The paper was posted in August 2016 on the preprint server arXiv.

The team found that the algorithms tended to associate domestic words more with women than men, and associated negative terms with the elderly and certain races and religions. “For just about every kind of bias that’s been documented in people, including gender stereotypes and racial prejudice, we were able to replicate it in today’s machine-learning models,” said Narayanan, who worked with CITP postdoctoral research associate Aylin Caliskan-Islam and Joanna Bryson, a professor of computer science at the University of Bath and a visiting scholar at CITP.

Machine-learning algorithms build models of language by exploring how words are used in context — for example, by combing all of Wikipedia or gigabytes of news clippings. Each time the model learns a word, it gives that word a series of geometric coordinates that correspond to a position in a many-dimensional constellation of words. Words that are frequently found near each other are given nearby coordinates, and the positions reflect the words’ meanings.

Biases develop as a result of the positions of these words. If the text used to train the model more often associates “doctor” with words relating to men, ambition and medicine, while linking “nurse” to words related to women, nurturing and medicine, the model would come to assume that “nurse” is feminine, possibly even the feminine version of the masculine “doctor.”

To measure biases in algorithm results, the researchers adapted a test long used to reveal implicit bias in human subjects, the Implicit Association Test, for use on the language models. The human version of the test measures how long it takes a subject to associate words such as “evil” or “beautiful” with names and faces of people from different demographics. Thanks to the geometric model of language that machine-learning algorithms use, their biases can actually be measured more directly by simply finding the distance between the name of a group and positive, negative or stereotypical words.

Such biases can have very real effects. For example, in 2013 researchers at Harvard University led by Latanya Sweeney noted that African American-sounding names were far more likely to be paired with ads for arrest records. Such experiences could lead to unintentional discrimination when, say, a potential employer searches the internet for an applicant’s name.

“AI is no better and no worse than we are,” Bryson said. “However, we can continue to learn, but the machine learning for an AI program might be turned off, freezing it in a prejudiced state.”

If we can measure this bias, however, Narayanan said, we can take steps to mitigate it. This could mean mathematically correcting a language model’s bias or simply being aware of the algorithms’ faults — and our own.

–By Bennett McIntosh
The literature of madness
and how it shaped
modern psychiatry

IN 1890, THE RUSSIAN PHYSICIAN and writer Anton Chekhov traveled across Siberia to document the lives of prisoners sentenced to a remote penal colony on Sakhalin Island. The visit inspired not only a nonfiction exposé but also several works of fiction, including a famous short story, “Ward Number Six,” about the ill-fated friendship of a doctor and a paranoid patient in a rural Russian institution.

Science and medicine often provide the inspiration for literature, but graduate student Cate Reilly notes that the reverse also can be true. In an effort to establish psychiatry as a legitimate medical science, German physicians in the period from the 1890s to the late 1920s created a standardized terminology, one that eventually formed the basis of our present-day diagnostic manual of mental illness. Reilly, a doctoral student in comparative literature, is exploring how the literary descriptions of mental disorders by Russian and German-language fiction writers contributed to the science of mental illness in ways that stay with us today.

“The story that hasn’t been told is about the birth of these terms and how literature influenced the development of our current international classification system for mental disorders,” Reilly said. “This was all happening at a time of tremendous exchanges between psychiatrists in Germany and Russia. Those nations’ creative writers, some of whom were doctor-physicians like Chekhov, were involved in and contributed to this classification system.”

Reilly was inspired to explore this interdisciplinary area in part by modern debates over the extent to which definitions of pathologies are shaped by culture. At one time, mental illnesses included homosexuality and “indigenous psychopathology,” a diagnosis given by French physicians to native Algerians to justify their subjugation. “Once you have the standardization of these terms, then you start to see their abuse for purposes of power,” Reilly said.

Reilly explores how psychiatry and literature influenced each other during this critical time by citing works by Chekhov, Russian playwright Nikolai Evreinov, and German-language authors Rainer Maria Rilke and Alfred Döblin. For example, Evreinov’s dramas drew themes from German psychology and the anatomical-imaging technologies available during the 1880s and 1890s. Döblin’s 1924 “true-crime” novella, Two Girlfriends Commit Murder by Poisoning, about a court case involving lesbians who plotted to kill their husbands, featured pages of pseudoscientific diagrams to explain the women’s mental states.

“When creative writers influence what happens in psychiatry, it is not so much the case of a specific work of literature influencing a single term or definition, but the opening of a space for experimentation in how mental illness is characterized,” Reilly said.

–By Catherine Zandonella
IT IS SPRINGTIME in the Makira-Masoala peninsula of northeastern Madagascar, and the lychee trees are in full fruit. I sit crouched with my research team in camping chairs as dusk settles, our eyes intent on Rousettus madagascariensis, one of three species of endemic Malagasy fruit bat. The fox-faced bats flit deftly amongst the leafy branches, dodging our nets as they search out juicy pink fruits for their evening meal.

Our quiet vigil is interrupted by the arrival of a whistling gray-haired man from the nearby village who carries a net strung on a pole in one hand and a garish yellow plastic fuel can in the other. With a nod to us, he strides up to a neighboring tree and expertly scoops five of the feasting bats, pins the net to the ground with a bare hand, and coaxes the bats one-by-one into his yellow can. Mission accomplished, he straightens up with a wink and turns back home, rattling his can of bats in time to his whistle as he walks.

“Handehe hihinina andrehy izy?” I ask my Malagasy colleagues in astonishment. Is he going to eat the bats? Laughing at my horror, they nod in affirmation.

Bats as reservoirs
I study zoonotic diseases, infections that transmit from wildlife to humans, as a graduate student in Princeton’s Department of Ecology and Evolutionary Biology. Bats are native reservoir hosts — meaning they host viruses without getting sick — for a number of the world’s most dangerous human diseases, including rabies, Ebola and SARS. I want to understand how bats host these viruses without getting sick and what factors contribute to the viruses’ spillover to human populations.

A lot of my work involves building mathematical models to understand disease. When I started graduate school, I barely understood what a “model” was. Four years later, I recognize that a model is simply a representation of reality.
— it can be physical, like a model of the solar system; experimental, like a mouse that a scientist infects to monitor disease progression; or mathematical, like the equations we use to describe disease transmission in my field of disease ecology.

The goal is to build simple models that still adequately represent reality. One of my professors, Bryan Grenfell, once told me, “If you apply a complex model to a complex system, then you have two things that you don’t understand.” If we can understand our models, then we can learn by observing the differences between these models and the more complex reality.

In disease ecology, our simple models are mathematical equations that class all potential disease hosts — bats, in my research — into three categories: (1) susceptible to infection; (2) currently infected; or (3) recovered from infection and now immune. We use our equations to predict how the proportion of hosts within each category changes over time, and then we collect data to determine whether our predictions match reality.

Remote corners
One of the ideas we are testing is whether bats are fundamentally different from other mammals in their capacity for resisting or tolerating viral infections. I build models depicting the spread of infected cells within individual bats and explore the physiological processes that might allow a bat cell to host a replicating virus without experiencing the cellular damage that causes the host to feel sick.

In the lab, I grow layers of bat cells, infect them with virus, and monitor cell-to-cell viral spread. Then I compare these data with what is predicted in my models. If the data match the model, then maybe the mechanism for disease mitigation that I chose for my model also is the one used in real life.

At a population level, bat-virus transmission, including spillover, peaks in the winter, and we want to know why. I build population-level transmission models that incorporate different seasonal pathways to cause winter infections, then I try to match those models to data.

Collecting field data is hard — I spend years trekking to remote corners of Madagascar, mastering obscure Malagasy dialects, and rigging complex pulley systems out of nets, fishing lines and carabiners.

At the end of it all, like the man in Makira-Masoala, I catch a few bats. Instead of cooking them for dinner, however, I use fine-gauge needles, cryogenic vials and sterile swabs to collect their blood and other bodily fluids before I let them go. I haul the fluids in vats of liquid nitrogen to the laboratories of the Pasteur Institute of Madagascar in the capital city of Antananarivo. From there, samples are shipped to collaborators in London, Berlin, New York and Washington, D.C., while others remain in-country. My collaborators and I perform a variety of tests on these transported fluids to ascertain whether the bats were susceptible, infected or recovered from infection at the time of sampling.

When all is said and done, the results are sometimes difficult to interpret. Science is a gradual process, and the goal is to always narrow the window of possible hypotheses at least a little bit.

For me, science is a recognition of, as John Steinbeck put it, “how man is related to the whole thing.” I’m still trying to understand how humans fit into the zoonotic cycle of disease. I’m nearing the end of my Ph.D., but I have enough questions to keep me going for a lifetime.

Cara Brook is a fifth-year doctoral student. Her advisers are Andrew Dobson, professor of ecology and evolutionary biology; Bryan Grenfell, the Kathryn Briger and Sarah Fenton Professor of Ecology and Evolutionary Biology and Public Affairs; Andrea Graham, associate professor of ecology and evolutionary biology; and C. Jessica Metcalf, assistant professor of ecology and evolutionary biology and public affairs. Brook’s research is funded by the National Science Foundation, the National Geographic Society and PIVOT, a Madagascar-based health care nongovernmental society.
THE COLDEST SPOT on the Princeton campus is a cluster of a few thousand atoms suspended above a table in Waseem Bakr’s laboratory. When trapped in a lattice of intersecting lasers at just millionths of a degree above absolute zero — and roughly one-millionth the density of air — atoms become very still, enabling Bakr, an assistant professor of physics, to study them through a microscope.

At these frigid temperatures and ultralow densities, atoms begin to act very strangely. They function less like individual particles and instead behave like waves that blur and overlap, losing their individual identity and trading the physics of the everyday world for the laws of quantum mechanics. The resulting state, known as a degenerate Fermi gas, can yield insights into new states of matter that someday may lead to applications such as superconductors and quantum computers.

Bakr uses a system of lasers and magnetic fields to cool and trap the ultracold atoms in a crystal-like lattice made from light. He then manipulates and observes the atoms using a quantum-gas microscope, a device that he helped invent during his graduate studies with Markus Greiner at Harvard University, and further improved when he was a postdoctoral researcher with Martin Zwierlein at the Massachusetts Institute of Technology.

“We use lasers to create artificial crystals in which we place these quantum-mechanical atoms where the spacing between atoms is 10,000 times larger than what you find in real crystals,”
Assistant Professor Waseem Bakr and his team of students and postdoctoral researchers use a system of lasers and magnets to cool and slow down the movement of atoms, enabling the exploration of fundamental physics that could someday lead to applications such as superconductors and quantum computers.

Bakr said, “We are essentially engineering the behaviors of atoms using light.”

Bakr and his team first heat a block of lithium to 800 degrees Fahrenheit to liberate individual atoms that then fly into a long tube. There, the particles collide head-on with a laser beam pointed in the opposite direction, which rapidly slows and cools them. The atoms then flow into a chamber where the intersection of several laser beams creates an electromagnetic field that confines the atoms in an “optical trap.” The trap allows the fastest-moving (and warmest) atoms to escape, further cooling the ultracold gas. The resulting cluster of atoms, Bakr said, is “the coldest stuff you can find in the universe.”

Using the microscope, Bakr can agitate a single atom to watch the disturbance propagate, or he can rearrange the entire system to simulate a different material. “If I decide I want to study graphene today,” he said, “I can arrange my lasers to make a graphene-like lattice, and suddenly the physics that I’m looking at are very different.” This precise control could hold the key to another advance, he said. “If you have 1,000 atoms, and you have control over every single atom and their interactions, these are the basic building blocks of a quantum computer,” Bakr said.

Bakr and his team are using ultracold atoms to study the behavior of superfluids with imbalanced spin populations. In a paper published in
As an undergraduate, Joseph Scherrer (pictured), Class of 2016, built a laser system with classmate Adam Bowman, Class of 2017, to separate a nucleus’ positive charge from its electron’s negative charge, creating a new form of matter with quantum properties.

When they joined Assistant Professor of Physics Waseem Bakr’s lab in the spring of 2014, Scherrer and Bowman had little experience in optics or quantum physics. Their task was to convince lithium atoms to enter a state of matter known as the Rydberg state. In this state, each atom has a very high-energy electron located far from the atom’s nucleus. The separation of the electron’s negative charge from the nucleus’ positive charge creates a dipole, like a magnet’s north and south poles.

To give the electrons the right amount of energy to create the Rydberg state, Scherrer and Bowman hit the atoms with two carefully tuned lasers, first blue and then red. To prove that the lithium atoms had indeed entered the Rydberg state, the two researchers needed a way to detect them. They trawled the scientific literature for a sensitive enough detection method, and eventually implemented a technique called electromagnetically induced transparency. With this technique, the Rydberg atoms interfere with the absorbance of certain wavelengths of light, so if the gas is transparent in those wavelengths, the Rydberg atoms are present.

The undergraduates designed and built the device independently, Bakr said. “I wasn’t planning on starting this, and suddenly it grew into a whole project, largely due to their efforts,” he said.

“It was a turning point in our scientific development,” said Scherrer, who graduated in 2016 with a degree in physics. “For me, it was a realization of what you can do with quantum optics.” Scherrer was awarded a Fulbright grant to join a team in Munich, Germany, where he is building electron microscopes to image the brain. He will next head to the Massachusetts Institute of Technology to pursue a Ph.D. in physics.

Bowman, a physics major in the Class of 2017, continues to study the physics of electronically interesting materials, and spent his junior year and the summer of 2016 working on a new project with Ali Yazdani, Princeton’s Class of 1909 Professor of Physics. There, Bowman built a device that works like an inkjet printer for atoms to print superconductors layer-by-layer.

—By Bennett McIntosh
Behind the curtain: Scandal, tragedy, art and politics at the Bolshoi

By Jamie Saxon

ON THE NIGHT OF JAN. 17, 2013, a hooded assailant approached Sergey Filin, artistic director of the Bolshoi Theater Ballet, and flung battery acid in his face. The crime made international headlines and stunned a community of artists known for elegance rather than violence.

Some months later at a gala at the Kremlin, Simon Morrison, a professor of music and an expert on 20th-century Russian and Soviet music and ballet, met Filin, who had undergone numerous operations in Germany and had lost all of his sight in one eye.

“You could still see the scars on his neck from the acid,” Morrison said. “He wore these dark wraparound glasses and had an attendant with him administering drops. It was horrific, deeply macabre.”

Morrison’s encounter with Filin inspired him to explore whether the Bolshoi — a symbol of Russia presented to the world as a great cultural
Professor of Music Simon Morrison explores how the Bolshoi Ballet was used throughout history as a political tool. Pictured is Joseph Stalin (fourth from right), former leader of the Soviet Union, attending the Bolshoi in the mid-1930s.

icon — had been roiled by these types of scandals in the past, and what that said about the institution historically and politically. He wrote a piece about the attack for the London Review of Books, prompting a literary agent to suggest that he write a book about the incident.

Morrison knew that the story of the attack, despite its tragedy, would not on its own have a lot of traction or depth as a book. He had to get into the history of the organization, explore the archives and talk with other scholars. To learn more about how art and politics intersect at the Bolshoi, Morrison began an intensive three-year research process.

The result is a richly detailed account of the crown jewel of Russian culture, considered an emblem of power by the government since its founding in 1776, according to Morrison. “It is a tale about the kind of negative pressures that lead to the creation of great art,” he said. “One of the morals of the story is that in the Soviet experience there’s something about immense censorship, repression and threat that leads to the production of masterpieces. The Bolshoi has been burned and rebuilt and almost liquidated numerous times, yet has produced some of the world’s greatest ballets, including Swan Lake.”

A member of the Princeton faculty since 1998, Morrison has been diving deep into the Moscow archives — once with mittens on his fingers — for nearly two decades and knows them well. He also knows the art of “gentle pestering” often required to access them. Morrison earned his Ph.D. in music history from Princeton in 1997, and his previous works include Russian Opera and the Symbolist Movement, The People’s Artist: Prokofiev’s Soviet Years, and Lina and Serge: The Love and Wars of Lina Prokofiev, a biography of Prokofiev’s first wife.

His research for Bolshoi Confidential took him into the small theater museum at the Bolshoi and the immense theater and dance archives in the Bakhрушin Museum as well as the Russian State Archive of Literature and Art and the Russian State Archive of Social Political History, which houses the records of the Central Committee (the operating division of the Stalinist government in the Kremlin), among others. He also enlisted the help of freelance archivist Ilya Magin, whom he said was indispensable for researching the Imperial era in the St. Petersburg archives. In addition, Morrison conversed with dance critics and historians in Moscow “who have lived and breathed ballet all their lives.” He even wrangled an invitation to spend the day at the dacha, or country house, of Yuri Grigorovich, ballet master from the Khrushchev-Brezhnev era into the 1990s, now almost 90.

Among the gems Morrison uncovered was an enormous box of bureaucratic correspondence about the search for a real donkey for the ballet Don Quixote, created by the famous choreographer Marius Petipa. During the ballet’s first run in St. Petersburg in 1869-70, a female donkey was borrowed from a nearby vaudeville show. “This poor thing had a heart attack and died on the stage during a rehearsal,” said Morrison, who read the long veterinary report. In Moscow, the Bolshoi used a male donkey from the Moscow Zoo. “This donkey was trotted in with its minder from the zoo to the theater every day for the show and there was a budget for ‘treats in the form of bread and oats’ for the donkey. To the present day in Moscow, they use a donkey in Don Quixote,” he said.

Throughout its storied past and to this day, the Bolshoi — the theater and its eponymous ballet company, arguably the finest in the world — has been indelibly controlled by the government — culture and politics, performers and bureaucrats, forever entwined. For example, the iconic Soviet ballet of the late 1920s, The Red
In his new book, *Bolshoi Confidential: Secrets of the Russian Ballet from the Rule of the Tsars to Today* (W.W. Norton & Company, 2016), Professor of Music Simon Morrison weaves a richly detailed account of the Bolshoi Ballet from its origins in 1776 under Catherine the Great through its glorious history as a cradle for high art, political intrigue and shocking scandal.

But still the Bolshoi Ballet goes on. In late May, Pavel Dmitrichenko, the dancer who was convicted of and imprisoned for organizing the attack against Sergey Filin, was released on bail having served only half his sentence. “He now wants to dance again at the Bolshoi,” Morrison said. “If he does, which I think is 50-50 at this point, he may well be performing in the ballet that he was performing in when he was convicted, which is *Ivan the Terrible*. If that happens, the perverse ironies pile up because Ivan the Terrible is rumored to have blinded the architects of St. Basil’s Cathedral on Red Square to ensure that they never again built anything as beautiful. Dmitrichenko’s rehabilitation is so implausible that it is almost guaranteed of happening. Ballet is like that.”

**Poppy**, a tale of Soviet sailors who are detained in China, is about the Stalinist regime’s involvement in the rise of Communist China. “The Central Committee decided when and how this ballet would be produced and performed in 1927,” Morrison said.

The Bolshoi, with more than 2,000 seats, was a kind of political convention center during the Soviet period, Morrison said, and was used for the signing of the Soviet Constitution in 1935. After the Revolution, Vladimir Lenin gave speeches there.

In 2005, at the start of its most recent renovation — which took six years and cost $680 million — the theater was gutted and boxes of ancient materials were found in the basement and attic. Soldiers were brought in to move the materials into the administrative building next door. “There is always that connection between arts and the government,” Morrison said. “The Bolshoi is a national treasure.”

While once accessible to people of all classes with affordable tickets in the Soviet era, today the Bolshoi is no longer “the people’s house,” Morrison said. Tickets can cost as much as $500. “It’s a kind of playground for the petrol-ruble crowd in that way in which oligarchs now control so much of the culture in Russia, much of it eroded into popularized entertainment.”

Elizaveta Gerdt, one of the few ballerinas who did not leave Russia after the Soviets took over, instructs Bolshoi ballet dancers Maya Plisetskaya and Vladimir Preobrazhensky in 1947.
Discovery: Research at Princeton

PRINCETON RESEARCHERS UNLOCK THE POTENTIAL OF LIGHT TO PERFORM PREVIOUSLY IMPOSSIBLE FEATS

By Bennett McIntosh
Late at night in Princeton’s Frick Chemistry Laboratory, blue LED lights work overtime to catalyze new chemical reactions. The method, developed largely at Princeton, involves using light and a catalyst to join molecules that normally would not react with each other. The technique is already being used in industry to create medicines, solvents, plastics and other products.
One hundred years ago, Italian chemist Giacomo Ciamician predicted a future society that would run on sunlight.

In a paper presented in 1912 to an international meeting of chemists in New York City, he foresaw a future of vibrant desert communities under “a forest of glass tubes and greenhouses of all sizes” where light-driven chemical reactions would produce not just energy but also wondrous medicines and materials.

Ciamician’s vision has not yet arrived, but a handful of Princeton researchers have succeeded with one part of his legacy: they are harnessing light to perform previously impossible feats of chemistry. In Princeton’s Frick Chemistry Laboratory, blue LED lamps cast light on flask after flask of gently stirring chemicals that are reacting in ways they never have before to create tomorrow’s medicines, solvents, dyes and other industrial chemicals.

The leader in this emerging field is David MacMillan, who arrived in Princeton’s chemistry department in 2006. He was intrigued by the potential for using light to coax new chemical reactions. Like most chemists, he’d spent years learning the rules that govern the interactions of elements such as carbon, oxygen and hydrogen, and then using those rules to fashion new molecules. Could light help change these rules and catalyze reactions that have resisted previous attempts at manipulation?

Changing the rules
The idea for using light as a catalyst had been explored since Ciamician’s time with limited success. Light can excite a molecule to kick loose one or more of its electrons, creating free radicals that are extremely reactive and readily form new bonds with one another. However, most chemists did not think this process could be controlled precisely enough to make a wide variety of precision molecules.

But that changed in the summer of 2007. MacMillan and postdoctoral researcher David Nicewicz were working on a tough problem. The two scientists wanted to create chemical bonds between one group of atoms, called bromocarbonyls, and another group, known as aldehydes. “It was one of those longstanding challenges in the field,” MacMillan said. “It was one of those reactions that was really useful for making new medicines, but nobody knew how to do it.”

Nicewicz had found a recipe that worked, but it involved using ultraviolet (UV) light. This high-energy form of light causes sunburn by damaging the molecules in the skin, and it also damaged the molecules in the reaction mixture, making the recipe Nicewicz had discovered less useful. MacMillan, who is Princeton’s James S. McDonnell Distinguished University Professor of Chemistry, asked Nicewicz to investigate how to do the transformation without UV light.

Nicewicz recalled some experiments that he’d seen as a graduate student at the University of North Carolina-Chapel Hill. Researchers led by chemistry professor Malcom Forbes had split water into oxygen and hydrogen fuel using visible light and a special molecule, a catalyst containing a metal called...
Abigail Doyle is one of a handful of Princeton professors to quickly adapt the use of blue LED light and photoredox catalysis to rewrite the rules of organic chemistry. Drug companies have taken notice.

Abigail Doyle is one of the fastest-adopted chemistries I’ve seen. A couple of months after we published, we were visiting pharmaceutical companies and many of them were using this chemistry.”

Abigail Doyle
Associate Professor of Chemistry

ruthenium. The approach was known as “photoredox catalysis” because particles of light, or photons, propel the exchange of electrons in a process called oxidation-reduction, or “redox” for short.

Visible light is lower in energy than ultraviolet light, so Nicewicz and MacMillan reasoned that the approach might work without damaging the molecules. Indeed, when the researchers added a ruthenium catalyst to the reaction mixture and placed the flask under an ordinary household fluorescent lightbulb, the two scientists were astounded to see the reaction work almost perfectly the first time. “More times than not, the reaction you draw on the board never works,” Nicewicz said. Instead, the reaction produced astonishing amounts of linked molecules with high purity. “I knew right away it was a fantastic result,” he said.

With support from the National Institutes of Health, MacMillan and Nicewicz spent the next year showing that the reaction was useful for many different types of bromocarbonyls and aldehydes, results that the team published in *Science* in October 2008. Research in the lab quickly expanded beyond this single reaction, and each new reaction hinted at a powerful shift in the rules of organic chemistry. “It just took off like gangbusters,” MacMillan said. “As time goes on you start to realize that there are nine or 10 different things that it can do that you didn’t think of.”

**Old catalysts, new tricks**

At the time that Nicewicz and MacMillan were making their discovery, chemistry professor Tehshik Yoon and his team at the University of Wisconsin-Madison found that combining the ruthenium catalyst with light produced a different chemical reaction. They published their work in 2008 in the *Journal of the American Chemical Society* the same day MacMillan’s paper appeared in *Science*. Within a year of MacMillan publishing his paper, Corey Stephenson, a University of Michigan chemistry professor, and his team found yet another photoredox-based reaction.

With these demonstrations of the versatility of photoredox catalysts, other chemists quickly joined the search for new reactions. About 20 photoredox catalysts were already available for purchase from chemical catalogs due to previous research on water-splitting and energy storage, so researchers could skip the months-long process of building catalysts. However, by designing and tailoring new catalysts, the chemists unlocked the potential to use light to drive numerous new reactions, and today there are more than 400 photoredox catalysts available.

The secret to these catalysts’ ability to drive specific reactions lies in their design. The catalysts consist of a central atom, often a metal atom such as ruthenium or iridium, surrounded by a halo of other atoms. Light frees an electron from the central atom, and the atoms surrounding the center act as a sort of channel that ushers the freed electrons toward the specific atoms that the chemists want to join.

One scientist who became intrigued with the power of photoredox catalysts was Abigail Doyle, a Princeton associate professor of chemistry. Doyle, whose work is funded by the National Institutes of Health, uses nickel to help join two molecules. In 2014, she was searching for a way to conduct a reaction that had long eluded other scientists. She wanted to find a catalyst that could make perhaps the most common bond in organic chemistry — between carbon and hydrogen — reactive enough to couple to another molecule. Perhaps a photocatalyst could make a reactive free radical, allowing her to then bring in a nickel catalyst to attach the carbon-carbon bond.
Unbeknownst to Doyle, the MacMillan lab had recently turned their attention to combining photoredox and nickel catalysts on a similar reaction, coupling molecules at the site of a carboxylate group, a common arrangement of atoms found in biological molecules from vinegar to proteins.

Given the similarities in their findings, the MacMillan and Doyle labs decided to combine their respective expertise in nickel and photoredox chemistry. Together, the teams found a photocatalyst based on the metal iridium that worked with nickel to carry out both coupling reactions — at the carbon-hydrogen bond and at the carboxylate group. Their collaborative paper, published in Science July 25, 2014, showed the extent of photoredox catalysis’ power to couple molecules with these common features.

The ability to combine molecules using natural features such as the carbon-hydrogen bond or the carboxylate group makes photoredox chemistry extremely useful. Often, chemists have to significantly modify a natural molecule to make it reactive enough to easily link to another molecule. One popular reaction — which earned a Nobel Prize in 2010 — requires several steps before two molecules can be linked. Skipping all these steps means a far easier and cheaper reaction — and one that is rapidly being applied.

“It’s one of the fastest-adopted chemistries I’ve seen,” Doyle said. “A couple of months after we published, we were visiting pharmaceutical companies and many of them were using this chemistry.”

The search for new drugs often involves testing vast libraries of molecules for ones that interact with a biological target, like trying thousands of keys to see which ones open a door. Pharmaceutical companies leap at the chance to quickly and cheaply make many more kinds of molecules for their libraries.

Merck & Co., Inc., a pharmaceutical company with research labs in the Princeton area, was one of the first companies to become interested in using the new approach — and in funding MacMillan’s research. The company donated $5 million to start Princeton’s Merck Center for Catalysis in 2006, and recently announced another $5 million in continued research funding.

In addition to aiding drug discovery, photoredox-catalyzed reactions can produce new or less-expensive fine chemicals for flavorings, perfumes and pesticides, as well as plastic-like polymer materials. And the techniques keep getting cheaper. MacMillan published a paper June 23, 2016, in Science showing that with the aid of a photoredox catalyst, a widely used reaction to make carbon-nitrogen bonds can be carried out with nickel instead of palladium. Because nickel is thousands of times cheaper than palladium, companies hoping to use the reaction were contacting MacMillan before the paper was even published.

“IT just took off like gangbusters. As time goes on you start to realize that there are nine or 10 different things that it can do that you didn’t think of.”

David MacMillan
James S. McDonnell Distinguished University Professor of Chemistry

Spreading the light
Doyle has continued to explore photoredox chemistry, as have other Princeton faculty members, including two new assistant professors, Robert Knowles and Todd Hyster.

Hyster combines photoredox catalysis with reactions inspired by biology. Drugs often function by fitting in a protein like a hand fits in a glove. But just as placing a left hand in a right glove results in a poor fit, inserting a left-handed molecule into a protein designed for a right-handed molecule will give poor results. Many catalysts produce both the intended product and its mirror image, but by combining photoredox catalysts with artificial proteins, Hyster is finding reactions that can make that distinction.

Hyster, who arrived at Princeton in summer 2015, was drawn to Princeton’s chemistry department in part because of the opportunities to share knowledge and experience with other groups researching photoredox catalysis. “The department is quite collegial, so there’s no barrier when talking to colleagues about projects that are broadly similar,” he said.

Students from different labs chat about their work over lunch, teaching and learning informally — and formally, as the labs encourage collaboration and sharing expertise, said Emily Corcoran, a postdoctoral researcher who works with MacMillan. When Corcoran was trying to determine exactly how one of her reactions worked, she was able to consult with students in Knowles’ lab who had experience using sensitive magnetic measurements to find free radicals in the reaction mixture.

“If you have a question, you can just walk down the hall and ask,” Corcoran said. “That really pushes all the labs forward at a faster pace.”

A bright future
After the graduate students go home at night, the blue LEDs continue to drive new chemical reactions and new discoveries. “This is really just the beginning,” Doyle said.

Hyster thinks that within a few years, manufacturers may take advantage of photoredox chemistry to produce biological chemicals — such as insulin and the malaria drug artemisinin — to meet human needs. For his part, MacMillan envisions zero-waste chemical plants in the Nevada desert, driven not by fossil fuels but by the sun.

MacMillan’s vision echoes that of the original photochemist, Ciamician. The Italian’s optimistic vision of a sunlit future is brighter than ever.
ROBERT CAVA PULLS A LONG CURVED steel blade from its ornate sheath, revealing a rippling pattern of light and dark metal. The sword is a Japanese katana made from steel of such legendary strength and sharpness that it was said to be able to cut a hair as it fell to the ground.

In his office where the shelves are lined with mineral samples and crystal structures, Cava, Princeton’s Russell Wellman Moore Professor of Chemistry, recounts the sword’s role in his destiny. He’d entered the Massachusetts Institute of Technology (MIT) wanting to study applied physics. “Someone at MIT interpreted ‘applied physics’ as being about materials science,” he said. “So, I ended up in a freshman seminar about samurai swords.”

Samurai swords derive their mythic properties from distinctive arrangements of iron and carbon atoms, Cava learned. His fascination with the atomic structure of the ancient metal turned into a career arranging atoms into materials for a more modern age: batteries, superconductors and materials with strange and exotic properties that could become the basis for future electronic devices.

In the 1970s, when Cava was a student, these technologies were far off in the future. Captivated by the science of materials, Cava stayed at MIT to earn his Ph.D. in ceramics. “Now I know how to make toilet bowls,” Cava quipped. In fact, ceramics have a wide range of electrical properties that make them useful in computers, televisions and communications devices. After graduation and a postdoctoral fellowship at the National Bureau of Standards, Cava took a job at Bell Laboratories, the research arm of the then-dominant AT&T telephone company.

Renowned for hiring the best and giving its researchers intellectual freedom, Bell Labs was at the time brimming with new ideas. “Collaborations were built by sitting with random people in the cafeteria,” Cava recalled. One day in 1986, one of these collaborators invited Cava to a seminar on high-temperature superconductors, which were newly discovered materials that conducted electricity with no energy loss, but required less of the expensive refrigeration conventional superconductors needed.

Sitting in the seminar, Cava contemplated how the atoms in the new materials could be arranged to improve their performance. “I went back to the lab and four days later I had made a better superconductor,” he said. He would co-author more than 30 papers on superconductors in 1987 alone. One
former colleague, Bertram Batlogg, now at the Swiss Federal Institute of Technology in Zurich (ETH Zurich), recalled being so excited about one discovery that they wrote the paper in one night, fueled by “European-strength coffee and fresh home-baked cornbread.”

In 1996, as AT&T broke up and spun off Bell Labs, Cava moved to Princeton, where he established a reputation of being able to weave physicists’ dreams into exotic new materials. When his collaborators in the Department of Physics come to him with theoretical predictions, he can often make a material that exhibits the desired properties. Some of the new materials he has conjured are topological insulators, materials that act like superconductors on their surface but conduct no electricity at all under the surface. “It is dark magic,” said B. Andrei Bernevig, a Princeton professor of physics and a frequent collaborator of Cava’s.

Cava is more understated in explaining what he calls his “chemical intuition.” The properties of a material depend as much upon the geometrical arrangement of its atoms as on the specific kinds of atoms. Cava approaches designing a new material first by finding the right geometry — how many other atoms of each kind should each atom connect to, and in which orientations — and then finding the right atoms to fit this geometry. All the while, he bounces ideas off his students and collaborators. “In the end, science is very personal,” Cava said.

The move to Princeton from Bell Labs brought more than new collaborators and projects. “At Princeton, I have to be more than a scientist,” Cava said. He had to become a teacher and, often, a performer, to engage the 100-plus students in his first-year general chemistry course.

To share the inspiration he has felt every day since his first materials-science class, Cava peppers his lessons with references to ancient alchemists and demonstrations of the power of their discoveries. Slicing a pumpkin — often adorned with a Harvard cap — with his Samurai sword is perhaps the tamest demonstration. “He’s always blowing something up, or lighting something on fire,” said Marisa Sanders, a Ph.D. student in Cava’s lab.

The antics cross over to his lab, where the lab rules encourage taking experimental risks, and where he can sometimes be spotted walking the lab in a Darth Vader costume, which he wears when he administers final exams to, as he puts it, “relieve some of the students’ tension.” He is a patient teacher, willing to sit for hours with students to work through a difficult problem or an unexpected result.

But, especially in materials chemistry, such logical teaching only goes so far. The most harebrained ideas will either succeed or teach in their failure, according to Cava. “If he thinks something is not going to work, he won’t tell you not to do it,” said Elizabeth Seibel, a doctoral student in Cava’s lab. “But he might make a bet with you.”

When Cava isn’t conjuring crystals, he pursues his first scientific love, astronomy. Growing up on Long Island during the 1960s Space Race, Cava swapped his model-train set for another student’s home-built telescope just to get a good look at the moon. Now his students laugh at him for having so many telescopes in his garage that there is no room for a car. “I love to sit under the night sky and appreciate how beautiful the universe is,” he said. He shares this love with others, setting up a telescope outside the chemistry building to share eclipses and solar flares with colleagues and students. “It’s something that a bunch of us from the lab really look forward to,” Seibel said.

Beyond his passions for chemistry and astronomy, Cava hopes his mentorship and example help his students find something they love to do. “You have to be passionate about something,” he said. “In the end, you don’t want to look back and think, ‘I didn’t do anything with my life.’”

He certainly will not have to worry about that.
Innovations in building materials, design, water systems and power grids are helping to make cities more livable, say researchers in Princeton’s School of Engineering and Applied Science

By Bennett McIntosh
Cities. They sprawl and tangle, juxtaposing ancient public squares and glistening skyscrapers. They provide homes for half of humanity, and economic and cultural centers for the rest.

It has taken us thousands of years to build today’s urban centers, and yet, they’re expected to double in land-area in just the next few decades. “Half the urban infrastructure we will be using in 2050 has not yet been built,” said Elie Bou-Zeid, a Princeton associate professor of civil and environmental engineering.

Though this growth is inevitable, the way these cities will expand is not. Rather than repeat the sprawling and uncoordinated development patterns of the past, researchers like Bou-Zeid and others in Princeton’s School of Engineering and Applied Science are exploring new ways to build urban infrastructures to serve our growing population, changing civilization and warming planet.

These intelligent cities will require buildings that heat and cool themselves on a limited energy budget. They’ll require bridges and other infrastructure built with the flexibility to adapt to a changing global climate and rising sea levels. And they’ll require innovations in the networks that supply cities with water and energy. These ideas — from new building materials to continent-spanning electrical grids — have the potential to shift urban development away from the present-day jumble of strip malls, suburbs and shantytowns toward the resilient cities of the future.

Clever buildings
The basic unit of these smarter, resilient cities is the intelligent building. Assistant Professor Forrest Meggers, who has a background in architecture and engineering, has a number of plans for making buildings smarter about how they heat and cool their indoor spaces. Often these heating and cooling systems involve water, which readily absorbs heat that is then shed through evaporation.

In one structure called the Thermoheliodome, the interior is coated with mirrors at odd angles to reflect heat toward water-cooled pipes. In another, the interior cools itself with evaporation through an external membrane that traps liquid water while allowing water vapor to escape. By demonstrating the effectiveness of these innovative ideas, Meggers, who has a joint appointment in the School of Architecture and the Andlinger Center for Energy and the Environment, hopes to show other architects that it is possible to make more effective and more attractive heating and cooling systems.

Meggers’ structures take advantage of two different ways heat is transferred: It can be carried by molecules of warm air or water, or it can radiate like light directly from surface to surface. Thermometers, which measure air temperature, don’t capture the effects that radiative heating and cooling can have on a building’s occupants, so Meggers developed a radiative heat-sensing camera. About the size of a thermostat, the camera captures a 360-degree view that researchers can use to build a 3-D model of the radiative surfaces in any room.

To investigate urban radiant-heat exchanges, Meggers’ students took similar devices to New York City, about 50 miles northeast of Princeton. The resulting thermal photographs enabled them to see how heat lingers in alleyways and clusters around window-mounted air conditioners. By seeing the heat, architects and engineers can improve their designs for optimal energy efficiency.

Optimal cooling is the goal of one project that Meggers collaborated on with Dorit Aviv, who earned her master’s degree in architecture in 2013 and is now a doctoral student at Princeton. The building is called the Cool Oculus and is designed to keep cool in the desert heat through a combination of evaporation and shifting shape. The researchers built the Cool Oculus as a prototype on the Princeton campus, and have secured a grant from the New York-based Tides Foundation to build a full-scale model and measure its capabilities.

During a hot day, mist flows into the Oculus’ central chimney and evaporates to cool the air within,
which sinks as a refreshing breeze into the building. Meanwhile, the structure’s foundation absorbs excess heat, which it releases at night when the chimney widens to expose the foundation to the cool night sky. Combined, these effects can turn 100-degree desert heat into a comfortable 75 degrees.

Like forms in nature, engineering professor Sigrid Adriaenssens’ structures often show striking curves, from spiraling earthen garden walls and arching steel footbridges, to shell-shaped pavilions that keep out direct sunlight while admitting scattered light and breezes.

**Inspired by nature**
The Oculus moves on a daily cycle, but Sigrid Adriaenssens, an associate professor of civil and environmental engineering, has designed structures whose real-time response to heat is built into the material itself. In a transparent case above her desk, Adriaenssens displays three structures that could pass for the leaves of a cyborg Venus flytrap. They each are made of white translucent shells curving off a central metallic strut.

The resemblance to a flytrap is not coincidental. Adriaenssens designed the structures with inspiration from the waterwheel plant, an aquatic cousin of the flytrap. This shape allows the entire structure to open or close in response to a small movement of the central strut. The strut, in turn, is made of two metals that expand differently when heated, so the shell expands significantly with a small increase in temperature. Adriaenssens envisions that these shells, which were developed with funding from the Andlinger Center for Energy and the Environment, could cover a building’s entire façade. On hot days, the shells would expand and block heat from streaming in through the windows.

Structures like these, which make clever use of materials and their form, will be the key to affordable and efficient structures in future cities, according to Adriaenssens. To make these structures, Adriaens-

**Water world**
Where does the water that surges around Adriaenssens’ barriers go? Where does the water that cools Meggers’ buildings come from? To plan something as complex as a future city’s water system requires not just understanding the interactions between structures like these, but understanding how the structures and the people affect each other. Such an undertaking requires cooperation between researchers from many different fields, and an understanding of the successes and failings of many different cities, according to Bou-Zeid.

Bou-Zeid first grew interested in cities when he was a mechanical engineering undergraduate at the American University of Beirut in Lebanon. “I thought I would be designing racecars or airplanes, but environmental problems that involve the interaction of humans with their surroundings are more interesting,” he said. During his graduate and postdoctoral studies, Bou-Zeid investigated how cities — with their skyscraper-created wind canyons and their innumerable sources of heat and steam — fundamentally alter the movement of air around them.

Bou-Zeid is interested in how this airflow affects an invisible but critical part of cities’ water systems: evaporation. Before a city is built, water evaporates out of plants and earth, cooling the area. But in built-up areas, dark asphalt absorbs heat. Water flows off impermeable pavement into storm systems before it has the chance to evaporate and take heat away with it, trapping heat in the buildings and the streets. This trapped heat can warm cities by 10 to 15 degrees Fahrenheit higher than the surrounding countryside. The so-called urban heat island raises energy consumption and contributes to climate change as we burn fossil fuels to cool ourselves.
Parks, greenbelts and green roofs covered in plants can solve this problem by encouraging cooling through evaporation, Bou-Zeid said. But it is not as simple as planting trees: While Baltimore’s greenbelts have cooled it significantly, drier cities like Denver and Phoenix may be better off saving water by cooling with traditional air conditioning. “How do you compare the value of a gallon of water and a kilowatt-hour of energy in different cities?” Bou-Zeid asked.

Bou-Zeid’s attempts to answer this question, and similar studies by other researchers in every aspect of the water cycle, led to the formation of the Urban Water Innovation Network. The Network, supported by a five-year grant from the National Science Foundation, includes engineers, architects and social scientists from 14 institutions who are studying how six American cities interact with water. Bou-Zeid, Princeton’s team lead for the network, is working with colleagues at the University of Maryland and Arizona State University to create software that will model everything water can do in a city. Such software could be used to predict the benefit of new water projects while accounting for local climate and geology.

The wildest possible experiments
To ensure that the urban landscape is accurately represented in such simulations, professor James Smith is leading a team of researchers from five universities in the network to produce extremely accurate maps of the rainfall and flooding in each of the cities. For Smith, the William and Edna Macaleer Professor of Engineering and Applied Science and professor of civil and environmental engineering, such studies of real cities are the only way to understand urbanization’s present and future effects.
You must accept urban expansion — you have to work with it.

Elie Bou-Zeid
Associate Professor of Civil and Environmental Engineering

It’s not the first time Bou-Zeid has worked to make small, efficient changes to cities. Simply painting black roofs white so that they reflect more light keeps buildings cooler and saves energy and money.

New York City has implemented this idea via their °CoolRoofs program, through which thousands of volunteers have painted roofs white since 2009. These efforts provided Bou-Zeid with more data than he could ever have achieved in a laboratory. He is using data from this experiment in conjunction with his models of urban air and heat flow to determine the cost and energy savings of painting roofs white.

Networks and grids
Painting roofs white is a relatively easy modification to make to a city, but other modifications require a new way of thinking. Our cities are already in need of upgrades to electricity supply and delivery systems. Going forward, our electricity will increasingly come from renewable sources such as solar and wind power, which, while better for the environment, can vary due to wind shifts and cloud cover.

With renewable energy making up only about 10 percent of power production in the United States, this variability is not yet an issue, said Warren Powell, a professor of operations research and financial engineering who studies networks such as electrical grids and transportation systems. “But I see us hitting problems at about 20 percent renewables,” Powell said.

This variability makes it hard to fully replace coal, the traditional workhorse of electricity generation, and natural-gas turbines, which can be ramped up quickly. “When the dust clears in 40 years, we’re still going to have some fossil energy,” Powell said. While large, efficient batteries could store wind and solar power and release it as needed, the marginal cost of battery storage increases as more batteries are added to the grid. “It is going to be hard to fight this curve,” he said.

Changes in how the power grid operates could help. Powell recently began a project in Brazil, where a drought has cut into Brazil’s heavy dependence on hydroelectric power. Powell has begun working with a group of Brazilian power companies to study strategies for managing the variability from the influx of wind power. Because of wind’s variability, this is not simply a matter of replacing one power source with another. Instead, Powell will be supervising the development of Brazil’s first grid model that can closely simulate the variability of wind. This model will be used to develop robust management policies and energy portfolios that would help Brazil optimize an energy system that depends heavily on wind and solar.
New technologies deployed smartly will help, Powell said. For example, self-driving electrical vehicles can decrease congestion in dense cities and lend their batteries to the electrical grid, selling power when the city needs it most and recharging overnight from the grid’s excess capacity.

Ultimately, these changes in technologies and policy must work within the economic and social constraints of existing cities. Failing to understand and anticipate urban changes and growth leads to not just bad policy, but unenforceable policy, Bou-Zeid said. If a city tries to prevent urban growth, for example, by limiting new housing, the city will often still grow, but in unregulated and unhealthy shantytowns on the periphery. “You must accept urban expansion — you have to work with it,” Bou-Zeid said.

But the size and inertia of cities is an opportunity, too, Meggers said. “Cities have the power to make a change.”

If researchers and policymakers at Princeton and in cities around the world can collaborate, making clever use of form, physics and interacting components as a part of urban planning, then that change will be a positive one. ♦

Resilient cities require resilient power grids. Professor Warren Powell is designing smart models that optimize the use of wind and solar power despite variability due to wind shifts and cloud cover.
BETTER LIVING THROUGH BEHAVIORAL SCIENCE

How the psychology of human behavior is helping tackle society’s biggest problems

By Wendy Plump
**SUPOSE** someone approaches you on the street with the following proposition: You can receive either cash on the spot or a much larger contribution to your retirement account that likely will yield far more in the future. Do you choose the instant cash, or go with the retirement account?

The answer tells a lot about how people think, and about how public policymakers think people think. Most people, it turns out, would choose the instant cash. Most policymakers, at least until somewhat recently, would have said that people would select the higher long-term payout of the retirement account.

Over the past two decades, policy planners from the Oval Office to the middle-school principal’s office have become aware that people often do not behave rationally, nor even in their own best interests. Understanding why people act as they do is the basis of the growing discipline of behavioral science, which is helping shape policies that tackle society’s biggest problems, from financial planning to public health.

“IT is remarkable how little effort has been made to understand human behavior in policy circles,” said Eldar Shafir, the Class of 1987 Professor in Behavioral Science and Public Policy and a leader in this field of research. “Policy depends upon people doing things that the policymakers expect them to do. Yet, there has been almost no attempt to understand what people actually do, what they can do and what they want to do.”

Shafir has been working to change that along with colleagues at Princeton’s Woodrow Wilson School of Public and International Affairs. Wilson School researchers are exploring the behavioral aspects of policies that combat poverty, school bullying, discrimination and many other issues.

The idea that psychology is essential for good public policy can be traced back 100 years to American economist John Maurice Clark at Columbia University, according to Shafir. “Clark pointed out that any time you design policy, you have to understand psychology,” Shafir said. “If you don’t, your policy design and implementation will often be flawed.”

This may sound like common sense, but in the past, psychology rarely had a place at the policy table, said Daniel Kahneman, Princeton’s Eugene Higgins Professor of Psychology, Emeritus, and professor of psychology and public affairs, emeritus, and a pioneer in the field. Instead, two disciplines — economics and law — were the wells from which policymakers drew almost exclusively.

Kahneman’s work is credited with improving economic analyses by including insights from psychology, especially on human judgment and decision making under uncertainty. The citation for his 2002 Nobel Prize in Economic Sciences lauds him for “laying the foundation for a new field of research.”

Yet, Kahneman is uncomfortable taking credit for the field’s progress. Instead, he cites economist Richard Thaler of the University of Chicago. Thaler and Harvard University Law School’s Cass Sunstein co-authored a 2008 book titled, *Nudge: Improving Decisions about Health, Wealth and Happiness*, that ushered applied behavioral science into the public consciousness.

The book brought attention to concepts such as how to present choices to people in ways that provide a gentle prod toward making good decisions. For example, automatically enrolling new employees in a retirement-savings program and allowing them to opt out, rather than encouraging employees to opt in to the program, dramatically increases the number of people who save for retirement.

These and other insights are backed up by extensive studies of how people actually behave and make decisions in given situations. A number of Princeton researchers are involved in research in behavioral science that has direct implications for public policy.

**Stopping schoolyard conflict**

Early in her career, Elizabeth Levy Paluck became interested in how social norms can influence people’s behavior. In post-genocide Rwanda, she found that a media campaign to help reduce prejudice and violence drew much of its success from its emphasis on changing people’s definition of acceptable and desired behavior.

“I study social norms — informal laws that are created and enforced by people,” said Paluck, professor of psychology and public affairs in the Wilson School. “How do people in a community figure out what these laws are, and how to follow them? One theory is that we look to the behavior of certain peers for cues as to what we should be doing.”

Paluck and colleagues wondered whether highly influential students could have an outsized impact on the social norms and behaviors of other students in a school setting. They designed an intervention called the Roots program that was aimed at reducing school bullying and conflict by convincing influential students to practice positive behaviors, with the goal of reaching wider networks of peers.

With colleagues at Rutgers and Yale universities, Paluck tested this approach in a study conducted at 56 middle schools throughout New Jersey. The researchers asked students to report who they socialized with on a regular basis — both in person and online — and then used the data to identify the most connected students.

The analysis identified students who were leaders among their specific peer groups, not just those who were the most popular overall. The researchers
encouraged this small set of students to take a public stand against bullying at their schools. Would these “social referents” be able to spread social change?

Paluck and her collaborators found that middle schools that instituted Roots experienced a 30 percent reduction in reported “conflict incidents,” a finding the researchers published Jan. 4, 2016, in the journal *Proceedings of the National Academy of Sciences*. The results suggest that behavior-change campaigns may be made more effective when they harness networks of influence to change societal norms.

Funding for the project came from the William T. Grant Foundation’s Scholars Program, the Canadian Institute for Advanced Research, Princeton’s Educational Research Section, the Russell Sage Foundation, the National Science Foundation and the Spencer Foundation.

**Combating scarcity**

For his research on poverty, Shafir studies the impact that deprivation has on an individual’s ability to focus intellectual energy on life tasks. His work touches on the age-old question regarding the causes and effects of poverty: Are people poor because they are not capable, or are they not capable because they are poor?

Shafir and his team have found that poor people are often quite good at making short-term decisions about how to spend money. But the continual pressure to make ends meet can create an oppressive cognitive load on the individual, leaving little bandwidth for other tasks, including long-term planning.

This situation is compounded by the fact that small but unexpected expenses, such as a car-repair bill, can have much larger consequences for poor people than for middle-class individuals who have some slack in their monthly budget. Shafir and co-author Sendhil Mullainathan of Harvard explored research on poverty in their 2013 book, *Scarcity: Why Having Too Little Means So Much*. They challenge the common societal perception that poverty is the result of personal failings and recast it as the outcome of a chronic lack of resources, be it money, transportation and housing, or even time.

Understanding the drivers of behavior among the poor can guide policies that help reduce the stresses and challenges associated with poverty, Shafir said. For example, if a fast-food company were to hand out employee work schedules further in advance — as opposed to the 48-hour timeframe it typically uses — then parents would be able to dedicate fewer cognitive resources to the constant management of childcare concerns, leaving them with more resources to devote to other aspects in their lives, including their job performance.

**Counteracting stereotypes**

Since she came to Princeton 16 years ago, Susan Fiske, the Eugene Higgins Professor of Psychology and professor of psychology and public affairs, has been researching issues of bias, discrimination and stereotypes.

One area of study involves exploring our perceptions of people as “warm and trustworthy” and “competent” at what they do. Middle-class individuals get high ratings on both counts, while homeless people and undocumented immigrants score low on both counts. Older people are seen as trustworthy but not competent, and rich people are seen as competent but not trustworthy.

In a study published earlier this year, Fiske and graduate student Jillian Swencionis reported that people in the workplace try to appear more competent by acting cold when dealing with their superiors, while superiors play up their warmth when dealing with subordinates. Supervisors and subordinates engage in these behaviors both to disprove stereotypes about themselves and to match what they think about the other person.

Recognizing these warmth-competence tradeoffs in interactions between employees of different ranks could help improve communications within organizations. The study was published in the *Journal of Experimental Social Psychology* in May 2016. Swencionis was funded in part by the National Science Foundation.

“People automatically categorize other people by race and gender and age,” Fiske said. “They do this without intention, so it’s not about evil motivation when people act on these associations. It’s kind of a default. As a result, people and organizations have to engage in extraordinary efforts to counteract that proclivity.”

No matter how groundbreaking the research,
it is useless to public policy unless it is available to people in a position to implement it. So, Fiske started the journal *Policy Insights from the Behavioral and Brain Sciences* a few years ago. The journal is affiliated with the Federation of Associations in Behavioral & Brain Sciences, which does education and advocacy work. Fiske has been the federation’s president and serves on its executive committee.

**Bringing policy into the 21st century**

In September 2015, President Barack Obama signed an executive order directing federal agencies to draw on emerging research from the field of behavioral science when crafting policies. Obama described the directive as a way to “bring our government into the 21st century.”

Researchers at the Wilson School and in Princeton’s Department of Psychology are helping lead the application of behavioral science to policymaking through their work in government, at think tanks and nongovernmental organizations, and at schools and institutions. The growing demand for these skills led Shafir and several colleagues to cofound ideas42, a nonprofit company devoted to creating behaviorally informed solutions to societal problems.

The Wilson School also is home to a new center launched in spring 2015 and led by Shafir that is focused on applied behavioral science research. In the fall of 2016, the Kahneman-Treisman Center for Behavioral Science & Public Policy launched its inaugural symposium. The center has more than 45 affiliated faculty members, including Alin Coman and Johannes Haushofer, both assistant professors of psychology and public affairs in the Wilson School. The center also has members from 11 departments across campus, including such diverse fields as geosciences, human values, philosophy and African American studies.

“It’s an exciting time,” Fiske said. “I’m a child of the ’60s and ’70s. So for me to be able to have an influence with data on policy is really a dream come true. We wanted to make the world a better place. It’s not so clear that we did, but there’s progress on several fronts.”
A 1970s program aimed at helping low-income urban and minority residents become homeowners led to predatory lending and mass foreclosures, found Keeanga-Yamahtta Taylor, an assistant professor of African American studies.

The subprime-mortgage crisis is nothing new, at least for America’s poor urban communities. In the late 1960s, the United States government, reeling from violent civil-rights protests, enacted a plan to encourage homeownership among poor and low-income residents, most of whom were African American. But the program, a partnership between public agencies and private enterprise, quickly became rife with corruption. The result was eerily prescient of the recent housing crisis.

Keeanga-Yamahtta Taylor, a Princeton assistant professor of African American studies, became fascinated by this little-remembered era as a graduate student. She was living in Chicago and was already a fierce proponent of social justice — she attended her first demonstration at age 16, in support of women’s reproductive rights. She has brought that tradition of activism to her position at Princeton where, within a year of being hired, she wrote her first book, touching on how structural inequalities embedded in American society and its institutions have fueled the Black Lives Matter movement. The book, *From #BlackLivesMatter to Black Liberation* (Haymarket Books, 2016), received the 2016 Lannan Foundation Freedom Award for an Especially Notable Book.

The fact that inequality continues to permeate society some 60 years after the dismantling of discriminatory laws comes as no surprise to Taylor. As a student in the 1990s at a predominantly black high school in Buffalo, New York, she recalls being told by a white teacher that the students “would all be on welfare” if they didn’t learn to respect authority. During a parent-teacher conference, the teacher threatened to call the police to remove her father, who was a university professor.

Although she enrolled in college directly after high school, Taylor was restless, and after a year, she dropped out and moved to New York City to pursue writing. She continued to demonstrate against social injustice, protesting police brutality in the city. A relationship led her to move to Chicago where she and her partner joined efforts to repeal the death penalty.

A turning point for Taylor came in 2000 when these efforts paid off: Illinois’ governor placed a moratorium on executions. “It was an important moment for me because I saw the results that can happen when people advocate for change,” she said. At 29, she decided to finish her undergraduate degree and enrolled at Northeastern Illinois University in a program for returning adult students.

Taylor already knew she wanted to study housing disparities and race when she entered graduate
school at Northwestern University. "I was fascinated by how rigidly segregated Chicago is," Taylor said. "The black areas stretch for miles, and you can walk for blocks without seeing a white person."

Through her work as a community organizer, Taylor had learned about the housing policies that shaped segregation in Chicago and the nation. The government's post-World War II emphasis on homeownership favored purchases in newly built suburbs. Many black families could not afford to buy in the new suburbs, and those that could endured blatant discrimination from realtors. The government considered urban areas to be "high-risk," so these areas didn't qualify for federally insured loans, a policy Taylor described in her doctoral dissertation as "racial judgments cloaked in the garb of objective economic analysis."

The civil unrest of the 1960s brought attention to the crisis of dilapidated and unsafe housing in urban America. In response, President Lyndon B. Johnson in 1968 announced that the government would extend its pro-home buying policy — including federally insured loans — to low-income purchasers. The hope was that a new cadre of urban residents, spurred by the pride of homeownership, would fix up neglected dwellings and catalyze urban renewal from within.

The new program would accomplish this through the creation of a "federally chartered private, profit-making housing partnership." Under the program, called Section 235, the private sector would provide the real estate agents, appraisers, mortgage brokers and financing, while the Department of Housing and Urban Development (HUD) would oversee the process.

Flaws emerged almost from the outset. One was that the responsibility for vetting a potential homeowner's creditworthiness fell to parties that had little stake in making sure people could afford the loans. Traditional banks and savings-and-loans stayed away from the new borrowers — they were considered too risky. Instead, a new type of lender, the mortgage broker, stepped in and began to pool loans that were resold as investments known as mortgage-backed securities.

By 1971, new infractions had surfaced. Owners found that the homes had more than cosmetic problems, including "faulty plumbing, leaky roofs, cracked plaster, faulty and inadequate wiring, rotten wood in the floors, staircases and porches, lack of insulation and faulty heating units," according to a HUD report. "About one-quarter were in such poor condition that investigators concluded that they should have never been insured," wrote Taylor in her dissertation.

It emerged that real estate speculators were buying cheap and uninhabitable properties and quickly “flipping” them for sale under the Section 235 program. A HUD internal report found that real estate agents, property appraisers and mortgage brokers colluded to artificially inflate prices for buyers. “No-doc” loans — issued without checking income statements and other documents — were common because lenders stood to make more money when a borrower defaulted due to the federal insurance payout. The report called attention to the biased attitudes of HUD officials toward the potential homeowners, suggesting that race played a role in letting the abuse happen.

The program came to an end in 1973 when President Richard M. Nixon declared a moratorium on subsidized housing programs, citing the corruption and disarray. A new narrative emerged that enabled the government to distance itself from programs to help provide homeownership in the inner cities: Poor people were too irresponsible to own homes and to revitalize their own communities.

This new narrative ignored the evidence — documented in HUD reports, hearings before Congress and major newspapers — that property speculators, real estate agents, appraisers and mortgage brokers lured poor and predominantly African American people into buying homes they could not afford. By mid-1975, the foreclosures were mounting. Foreclosure rates were seven times higher in the low-income housing programs than they were in the conventional home-lending market. According to newspaper reports, the government had paid more than $4 billion in insurance claims since the start of the program.

Yet, few people were indicted or censured for these failings, Taylor found. One reason...
was the close relationship between the private sector and HUD. According to a government report, the president of the Mortgage Bankers Association had personally helped write HUD regulations.

In archives held at the Hoover Institution at Stanford University, Taylor found the personal correspondence of Carla Hills, HUD director during the mid-1970s. The files were a treasure trove — an insight into what HUD officials were thinking during the height of the scandal. What Taylor found surprised her.

“There was a reluctance to discipline lenders and private-sector companies because of the fear that too much regulation would discourage participation in HUD programs,” Taylor said. “There also was a discussion of HUD employees’ concerns that they would be risking their ability to get jobs in the private sector. It was a surprise to me to find an open, written discussion of these issues.”

This and other evidence has helped inform Taylor’s viewpoint that private enterprise has no business shaping or implementing public policies. “In my opinion, those two spheres are very different,” she said. “Private enterprise is about making profits, while the public sector was created to protect the public’s welfare. As my work shows, public-private partnerships have a history, and this history should be included in the discussion about the best approaches to providing necessities such as water, healthcare, education or housing.”

Taylor earned her doctorate and published her dissertation, “Race for Profit: Black Housing and the Urban Crisis in the 1970s,” in 2013. She began as a faculty member at Princeton the following year, and she continues her work as an activist through her writing, lectures and community involvement. She is now writing a book about her housing research.

Her combination of high-quality research and her drive to bring her findings to the broader public are needed to make sure past policy mistakes are not repeated, said Taylor’s Ph.D. adviser, Martha Biondi, a professor of African American studies and history at Northwestern University.

“Questions around finance and lending have been critically important in our own recent recession, and Keeanga brings a sharp historical lens to an issue that has been forgotten and neglected in most histories of the 1970s,” Biondi said. “In a society that celebrates homeownership, Keeanga’s work is a cautionary tale about the ways in which homeownership can be used to exploit poor and working-class communities.”

Taylor’s work underscores the importance of research in shaping public policy, said Eddie Glaude Jr., Princeton’s William S. Tod Professor of Religion and African American Studies and the chair of the Department of African American Studies.

“Keeanga’s work reveals in really powerful ways the unintended consequences of these public-private partnerships to solve the crisis of housing for low- and moderate-income families,” Glaude said. “You come away from reading her work with not only a sense of the disaster that that decision was, but also the importance of understanding its social and historical overtones.”

Taylor’s research on structural discrimination in housing, combined with her ongoing work as an activist, led her to consider how Americans can move beyond inequality to build a society where people are treated fairly and not on the basis of racial stereotypes, a topic she tackles in From #BlackLivesMatter to Black Liberation.

“The Civil Rights Movement addressed legal discrimination, but it also revealed that the problems confronting African Americans were not just Jim Crow laws — they were the practices and customs of racial discrimination that weren’t written in law, that were found in real estate or banking or employment,” Taylor said. “The outcome has been that African Americans suffer disproportionately in the areas that determine the quality of one’s life.”

The Black Lives Matter movement has brought much-needed awareness to the structural and institutional forms of racism in American society, she said. “We’ve become accustomed to thinking of racism as acts by individuals. But putting the blame on the individual suggests that racism can be overcome by education alone.”

Instead, Taylor reminds us that throughout history racism has been used as a way for the powerful to control others for material gain — and it is still used that way. “Unless you address the way society is organized, you won’t dismantle that power structure,” Taylor said. “Patterns, unless actively undone, replicate themselves.

“Knowledge alone will not reverse this.”
Welcome to the Universe: An Astrophysical Tour

Authors: Neil deGrasse Tyson, director of the Hayden Planetarium at the American Museum of Natural History and a former visiting research scientist at Princeton; Michael Strauss, Princeton professor of astrophysical sciences; and J. Richard Gott, Princeton professor of astrophysical sciences, emeritus

Publisher: Princeton University Press, 2016

Welcome to the Universe is a guided tour of the cosmos by three of today’s leading astrophysicists. Inspired by the enormously popular introductory astronomy course that Neil deGrasse Tyson, Michael Strauss and J. Richard Gott taught together at Princeton, this book covers it all — from planets, stars and galaxies to black holes, wormholes and time travel.

Describing the latest discoveries in astrophysics, the informative and entertaining narrative propels you from our home solar system to the outermost frontiers of space. How do stars live and die? Why did Pluto lose its planetary status? What are the prospects of intelligent life elsewhere in the universe? How did the universe begin? Why is it expanding and why is its expansion accelerating? Is our universe alone or part of an infinite multiverse? Answering these and many other questions, the authors open our eyes to the wonders of the cosmos, sharing their knowledge of how the universe works.

Breathtaking in scope and stunningly illustrated throughout, Welcome to the Universe is for those who hunger for insights into our evolving universe.

Postcolonial Modernism: Art and Decolonization in Twentieth-Century Nigeria

Author: Chika Okeke-Agulu, Princeton associate professor of art and archaeology and African American studies

Publisher: Duke University Press, 2016

Written by one of the foremost scholars of African art and featuring 129 color images, Postcolonial Modernism chronicles the emergence of artistic modernism in Nigeria in the heady years surrounding political independence in 1960, before the outbreak of civil war in 1967. Chika Okeke-Agulu traces the artistic, intellectual and critical networks in several Nigerian cities. Zaria is particularly important, because it was there, at the Nigerian College of Arts, Science and Technology, that a group of students formed the Art Society and inaugurated postcolonial modernism in Nigeria. As Okeke-Agulu explains, their works show both a deep connection with local artistic traditions and the stylistic sophistication that we have come to associate with 20th-century modernist practices. He explores how these young Nigerian artists were inspired by the rhetoric and ideologies of decolonization and nationalism in the early- and mid-20th century and, later, by advocates of Négritude and pan-Africanism. They translated the experiences of decolonization into a distinctive “postcolonial modernism” that has continued to inform the work of major Nigerian artists.

Bitcoin and Cryptocurrency Technologies: A Comprehensive Introduction

Authors: Arvind Narayanan, Princeton assistant professor of computer science; Joseph Bonneau, postdoctoral researcher at Stanford University; Edward Felten, Princeton Robert E. Kahn Professor of Computer Science and Public Affairs; Andrew Miller, assistant professor at the University of Illinois-Urbana-Champaign; and Steven Goldfeder, Princeton Ph.D. student in computer science

Publisher: Princeton University Press, 2016

Bitcoin and Cryptocurrency Technologies provides a comprehensive introduction to the revolutionary yet often misunderstood new technologies of digital currency. How do bitcoins and their blockchain actually work? How secure are your bitcoins? How anonymous are their users? Can cryptocurrencies be regulated? These are some of the many questions this book answers. It begins by tracing the history and development of bitcoin and cryptocurrencies, and then gives the conceptual and practical foundations you need to engineer secure software that interacts with the bitcoin network as well as to integrate ideas from bitcoin into your own projects. Topics include decentralization, mining, the politics of bitcoin, altcoins and the cryptocurrency ecosystem, the future of bitcoin, and more.
On March 29, 1516, the city council of Venice issued a decree forcing Jews to live in a closed quarter, il geto — named for the copper foundry that once occupied the area. The term stuck, and soon began its long and consequential history. In this sweeping account, Mitchell Duneier traces the idea of the ghetto from its beginnings in the 16th century and its revival by the Nazis to the present day. We meet pioneering black thinkers such as Horace Cayton, a graduate student whose work on the South Side of Chicago established a new paradigm for thinking about Northern racism and black poverty in the 1940s. We learn how the psychologist Kenneth Clark subsequently linked the slum conditions in Harlem with black powerlessness in the civil rights era, and we follow the controversy over Daniel Patrick Moynihan’s report on the black family. We see how the sociologist William Julius Wilson refocused the debate on urban America as the country retreated from racially specific remedies, and how the education reformer Geoffrey Canada sought to transform the lives of inner-city children in the ghetto.

By expertly resurrecting the history of the ghetto from Venice to the present, Duneier’s Ghetto provides a remarkable new understanding of an age-old concept. He concludes that if we are to understand today’s ghettos, the Jewish and black ghettos of the past should not be forgotten.

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**The China Challenge:**

**Shaping the Choices of a Rising Power**

Author: Thomas J. Christensen, Princeton William P. Boswell Professor of World Politics of Peace and War

Publisher: W.W. Norton, Paperback, 2016

Many see China as a rival superpower to the United States and imagine the country’s rise to be a threat to U.S. leadership in Asia and beyond. Drawing on decades of scholarship and experience as a senior diplomat, Thomas J. Christensen argues against this zero-sum vision. Instead, he describes a new paradigm in which the real challenge lies in dissuading China from regional aggression while encouraging the country to contribute to the global order.

*The China Challenge* shows why China is nowhere near powerful enough to be considered a global “peer competitor” of the United States, but it is already strong enough to destabilize East Asia and to influence economic and political affairs worldwide. Despite China’s impressive achievements, the Chinese Communist Party faces enormous challenges. Christensen shows how nationalism and the threat of domestic instability influence the party’s decisions on issues like maritime-sovereignty disputes, global financial management, control of the internet, climate change, and policies toward Taiwan and Hong Kong.

Analyzing U.S.-China policy since the end of the Cold War, Christensen articulates a balanced strategic approach that explains why we should aim not to block China’s rise but rather to help shape its choices so as to deter regional aggression and encourage China’s active participation in international initiatives that benefit both nations.

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**The Euro and the Battle of Ideas**

Authors: Markus Brunnermeier, Princeton Edwards S. Sanford Professor of Economics; Harold James, Princeton Claude and Lore Kelly Professor in European Studies; and Jean-Pierre Landau, associate professor of economics at SciencesPo, Paris

Publisher: Princeton University Press, 2016

Why is Europe’s great monetary endeavor, the euro, in trouble? A string of economic difficulties in Greece, Ireland, Spain, Italy and other eurozone nations has left observers wondering whether the currency union can survive. In this book, Markus Brunnermeier, Harold James and Jean-Pierre Landau argue that the core problem with the euro lies in the philosophical differences between the founding countries of the eurozone, particularly Germany and France. But the authors also show how these seemingly incompatible differences can be reconciled to ensure Europe’s survival.

As the authors demonstrate, Germany, a federal state with strong regional governments, saw the Maastricht Treaty, the framework for the euro, as a set of rules. France, on the other hand, with a more centralized system of government, saw the framework as flexible, to be overseen by governments. The authors discuss how the troubles faced by the euro have led its member states to focus on national, as opposed to collective, responses, a reaction explained by the resurgence of the battle of economic ideas: rules vs. discretion, liability vs. solidarity, solvency vs. liquidity, austerity vs. stimulus.

Weaving together economic analysis and historical reflection, *The Euro and the Battle of Ideas* provides a forensic investigation and a road map for Europe’s future.
Roberto Car, the Ralph W. *31 Dornte Professor in Chemistry, was recognized for his innovative research by the American Chemical Society (ACS) during a ceremony March 15, 2016. He received the ACS Award in Theoretical Chemistry for the “depth, originality and scientific significance” of his work.

Car’s research explores materials at the level of atoms and electrons. He uses theoretical tools and numerical simulations to gain insight into the chemical and physical processes underlying chemical reactions. While Car’s research is theoretical and fundamental, his discoveries may have technological implications that can aid in the design of new materials and devices with desirable properties. Car, who is a professor of chemistry and the Princeton Institute for the Science and Technology of Materials, is known for the invention of an *ab initio* molecular-dynamics method with Italian physicist Michele Parrinello that is now a standard tool for molecular simulation. The method has been applied to a variety of problems in condensed matter and chemical physics, materials science, geosciences, chemistry and biochemistry.
Michael Celia, Theodora Shelton Pitney Professor of Environmental Studies, professor of civil and environmental engineering (2016)

National Academy of Inventors H. Vincent Poor, Michael Henry Strater University Professor of Electrical Engineering (2015)


Igor Klebanov, Eugene Higgins Professor of Physics (2016)

Simons Foundation Fellowship Shou-Wu Zhang, professor of mathematics (2016)

NATIONAL DISTINCTIONS FOR EARLY CAREER RESEARCHERS

Air Force Office of Scientific Research Young Investigator Award Waseem Bakr, assistant professor of physics (2016)

Marcus Hultmark, assistant professor of mechanical and aerospace engineering (2016)

Alfred P. Sloan Foundation Research Fellowship Stefanos Aretakis, assistant professor of mathematics (2016)

José Avalos, assistant professor of chemical and biological engineering and the Andlinger Center for Energy and the Environment (2016)

Barbara Engelhardt, assistant professor of computer science (2016)

Mariangela Lisanti, assistant professor of physics (2016)

Benjamin Moll, assistant professor of economics and international affairs (2016)

Defense Advanced Research Projects Agency (DARPA) Young Faculty Award Barry Rand, assistant professor of electrical engineering and the Andlinger Center for Energy and the Environment (2015)

Department of Energy Office of Science Early Career Research Award Egemen Kolemen, assistant professor of mechanical and aerospace engineering and the Andlinger Center for Energy and the Environment (2016)

The Gruber Foundation Rosalind Franklin Young Investigator Award Carolyn “Lindy” McBride, assistant professor of ecology and evolutionary biology and the Princeton Neuroscience Institute (2016)

National Institutes of Health Director’s New Innovator Award Mohamed Abou Donia, assistant professor of molecular biology (2015)

Mohammad Seyedsayamdost, assistant professor of chemistry (2015)

National Science Foundation Early Career Development Award Emmanuel Abbe, assistant professor of electrical engineering and applied and computational mathematics (2016)

Amir Ali Ahmadi, assistant professor of operations research and financial engineering (2016)

Adam Marcus, assistant professor of mathematics and applied and computational mathematics (2016)

Prateek Mittal, assistant professor of electrical engineering (2016)

Office of Naval Research Young Investigator Award Barry Rand, assistant professor of electrical engineering and the Andlinger Center for Energy and the Environment (2016)

Jane Cox, senior lecturer in theater in the Lewis Center for the Arts and director of the Program in Theater, was presented with the Ruth Morley Design Award from the League of Professional Theatre Women on May 3, 2016. The annual award recognizes leading female designers working in theater and film. Cox is an award-winning lighting designer and has been a lecturer at Princeton since 2007. Her recent projects include Hamlet, starring English actor Benedict Cumberbatch and directed by Lyndsey Turner, and the new musical Amelie, directed by Pam MacKinnon. She received a 2016 Drama Desk Award nomination for her lighting design on the Broadway revival of The Color Purple.
Paul Chirik, the Edwards S. Sanford Professor of Chemistry, was among five recipients nationwide of the 2016 Presidential Green Chemistry Challenge Awards presented by the U.S. Environmental Protection Agency. Chirik was recognized for discovering a new class of catalysts that produce silicones without using hard-to-obtain platinum, which could dramatically reduce the mining of ore and reduce costs, greenhouse-gas emissions and waste. The winners were recognized during a ceremony June 13, 2016.
GUGGENHEIM FELLOWSHIPS awarded

Two faculty members and a visiting lecturer have received 2016 fellowships from the John Simon Guggenheim Memorial Foundation in recognition of their excellence in scholarship or creative work. The fellowships were awarded to Daniel Garber, the A. Watson Armour, Ill, University Professor of Philosophy, for his project, How Philosophy Became Modern in the 17th Century; Juri Seo, assistant professor of music, for music composition; and Raphael Xavier, a visiting lecturer in dance and the Lewis Center for the Arts, for choreography.

Garber researches the history of philosophy and the history of science in the early modern period, especially the questions of what is considered philosophy and what is considered science, and how that has changed over time. He is the author of numerous works on the science and philosophy of Galileo Galilei, René Descartes, Francis Bacon, Isaac Newton and others.

Seo is a composer and pianist who writes music that is unified and fluid but also complex in structure. She brings influences from music of the past century into her compositions, which are serious and humorous, lyrical and violent, and use fast-changing dynamics. She has earned many composition honors and joined the Princeton faculty in fall 2014.

A hip-hop practitioner since 1983, Xavier is a choreographer with a profound understanding of movement, sound and musicality. In addition to his success at integrating hip-hop styles into dance theater, he has created an approach to dance that helps with physical healing and makes movement accessible to any body type. His artistic work also includes photography, film and music.
Marina Rustow, the Khedouri A. Zilkha Professor of Jewish Civilization in the Near East and professor of Near Eastern studies and history, has been awarded a 2015 MacArthur Fellowship.

Rustow is among 24 scientists, artists, scholars and activists who will each receive $625,000 no-strings-attached grants over a five-year period from the John D. and Catherine T. MacArthur Foundation. The MacArthur Fellows Program awards unrestricted fellowships to talented individuals who have shown originality and dedication in their creative pursuits and a capacity for self-direction.

Rustow’s area of specialization is the medieval Middle East, particularly texts from the Cairo Geniza, a cache of more than 300,000 folio pages of legal documents, letters and literary materials that span more than a millennium and were preserved in an Egyptian synagogue. In its announcement, the MacArthur Foundation cited Rustow for research on the Geniza texts “that shed new light on Jewish life and on the broader society of the medieval Middle East. Rustow’s approach to this archive goes beyond decoding documents, in itself a formidable task, to questioning the relationship between subjects and medieval states and asking what that relationship tells us about power and the negotiation of religious boundaries.”

MARINA RUSTOW, historian of the medieval Middle East, wins MacArthur Fellowship

Louis Comfort Tiffany Foundation
Pam Lins, lecturer in visual arts and the Lewis Center for the Arts: 2015 Louis Comfort Tiffany Award

Mershon Center for International Security Studies at Ohio State University
Keren Yarhi-Milo, assistant professor of politics and international affairs: 2014 Edgar S. Furniss Book Award

Mikhail Prokhorov Foundation and Academic Studies Press
Ekaterina Pravilova, professor of history: 2015 Historia Nova Prize

Modern Language Association
Lital Levy, associate professor of comparative literature: 2014 First Book Prize

National Academy of Sciences
Sergio Verdu, Eugene Higgins Professor of Electrical Engineering: 2016 Award for Scientific Reviewing

National Institutes of Health
Zemer Gitai, Edwin Grant Conklin Professor of Biology, professor of molecular biology: 2015 Pioneer Award
Coleen Murphy, professor of molecular biology and the Lewis-Sigler Institute for Integrative Genomics: 2015 Pioneer Award

New York Public Library
Dorothy and Lewis B. Cullman Center for Scholars and Writers
Michael Reynolds, associate professor of Near Eastern studies: 2016 Cullman Center Fellow

Northwestern University
Jonas Kollár, Donner Professor of Science, professor of mathematics: 2016 Frederic Esser Nemmers Mathematics Prize

Society for Classical Studies
Joshua Billings, assistant professor of classics: 2015 Charles J. Goodwin Award of Merit

Society for Industrial and Applied Mathematics
Yannis Kevrekidis, Pomeroy and Betty Perry Smith Professor in Engineering, professor of chemical and biological engineering: 2016 W.T. and Idalia Reid Prize

Susan G. Komen Foundation
Yibin Kang, Warner-Lambert/Parke-Davis Professor of Molecular Biology: 2016 Komen Scholar

University of Maryland A. James Clark School of Engineering
Naomi Leonard, Edwin S. Wilsey Professor of Mechanical and Aerospace Engineering: 2015 Innovation Hall of Fame

INTERNATIONAL PRIZES AND DISTINCTIONS

Academy of Athens
Yannis Kevrekidis, Pomeroy and Betty Perry Smith Professor in Engineering, professor of chemical and biological engineering: 2016 Corresponding Member

American Academy in Rome
David Reinfurt, lecturer in visual arts and the Lewis Center for the Arts: 2016 Rome Prize in Design

Barcelona City Council
Ricardo Piglia, Walter S. Carpenter Professor of Language, Literature and Civilization of Spain, Emeritus, professor of Spanish and Portuguese languages and cultures, emeritus: 2015 Premio Ciutat de Barcelona for Literature in the Castilian Language
Simon Levin, the James S. McDonnell Distinguished University Professor in Ecology and Evolutionary Biology, received a National Medal of Science, the nation’s highest scientific honor. Levin was honored at a White House ceremony in early 2016 along with eight fellow Medal of Science recipients, and eight recipients of the National Medal of Technology and Innovation.

Levin focuses his research on complexity, particularly how large-scale patterns — such as at the ecosystem level — are maintained by small-scale behavioral and evolutionary factors at the level of individual organisms. His work uses observational data and mathematical models to explore topics such as biological diversity, the evolution of structure and organization, and the management of public goods and shared resources. While primarily related to ecology, Levin’s work also has analyzed conservation, financial and economic systems, and the dynamics of infectious diseases and antibiotic resistance.
**Sponsored Research Projects**

$200.8\text{ M}$

Princeton University campus expenditures\(^1\)

$106.4\text{ M}$

U.S. Department of Energy’s Princeton Plasma Physics Laboratory (PPPL) allocation\(^2\)

235

Projects supported by foundation funding

62

Projects supported by industry funding

1,433

Total sponsored research projects

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**Technology Licensing Activities**

100

Invention disclosures received

25

Patents issued

172

Patent applications filed

25

Technologies licensed

$131\text{ M}$

Gross royalty proceeds\(^3\)

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**Funding Sources for Sponsored Research Activities (Campus)**

- **National Institutes of Health**: 23% ($26.1\text{ M})
- **National Science Foundation**: 11% ($22.5\text{ M})
- **U.S. Department of Defense**: 13% ($26.1\text{ M})
- **Foundations**: 29% ($57.2\text{ M})
- **Industry**: 7% ($16.9\text{ M})
- **Other**: 3% ($4.7\text{ M})
- **Other Government**: 6% ($10.2\text{ M})
- **National Aeronautics and Space Administration**: 5% ($8.4\text{ M})
- **National Institutes of Health**: 3% ($4.7\text{ M})

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1Expenditures for the fiscal year July 1-June 30.
2Amount allocated for the fiscal year Oct. 1-Sept. 30. This funding level does not include an allocation of $21.9\text{ M}$ for infrastructure improvement or pass through procurements related to ITER, an international fusion program.

395 percent of this amount is from royalty payments from a cancer drug, Alimta\textsuperscript{TM}, which almost entirely cease in 2016.
Race for profits
Research on the 1970s urban housing crisis exposes a familiar history

PHOTO BY SAMEER KHAN/FOTOBUDDY

PHOTO BY DENISE APPLEWHITE

ILLUSTRATION BY MATILDA LUK

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Bright future
Princeton researchers unlock the potential of light to perform previously impossible feats

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Resilient, smart, adaptable
CITIES

32
Better living
through behavioral science

A leader in organic and plastic electronics, Professor Yueh-Lin (Lynn) Loo is the director of Princeton’s Andlinger Center for Energy and the Environment. The center supports research, education, corporate partnerships and outreach aimed at scientific, technological and policy solutions to today’s environmental and energy challenges.

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Bright future
Resilient, smart cities
Better living
Race for profits