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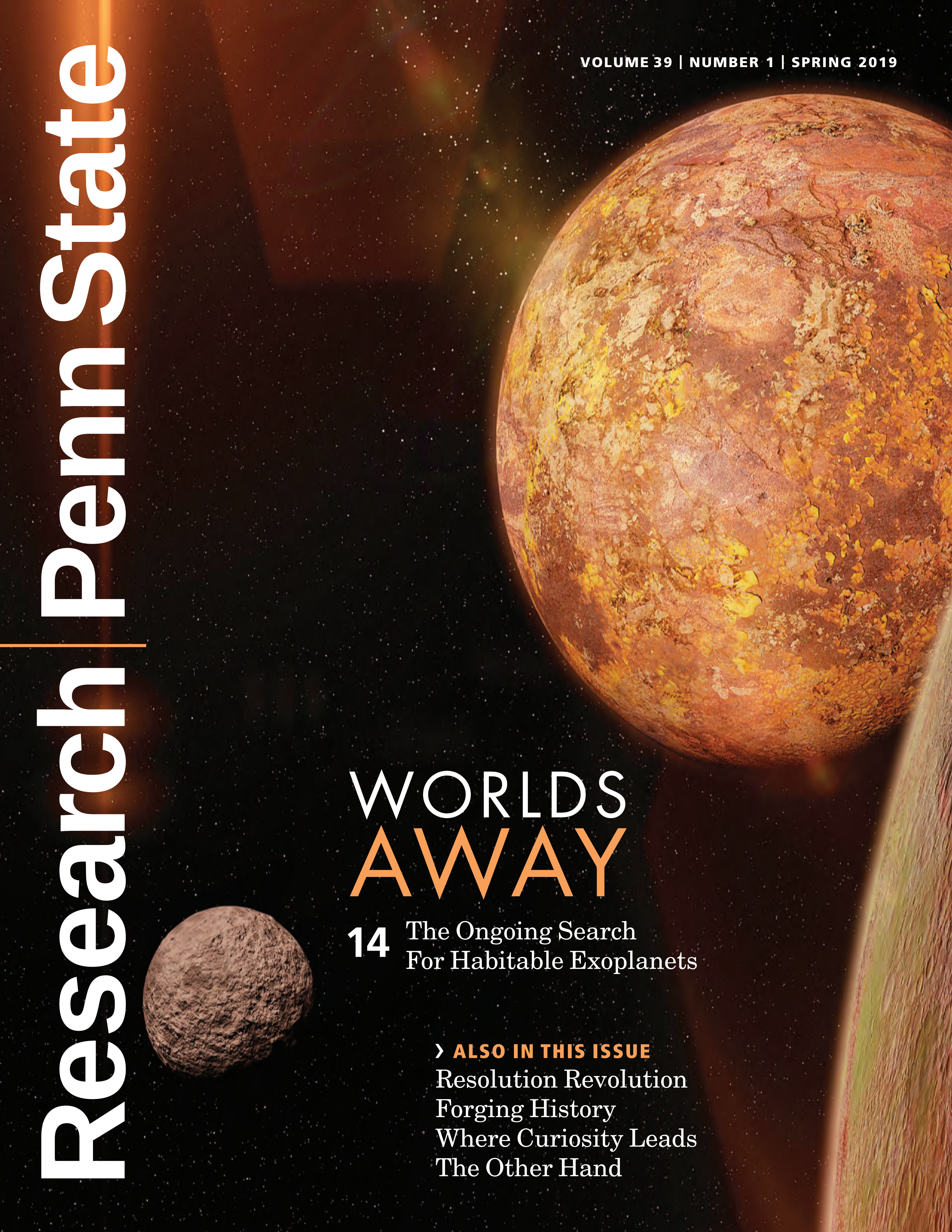

WORLDS AWAY

› ALSO IN THIS ISSUE

Expect the Unexpected

One of the joys of research, like any creative endeavor, is the chance to follow your curiosity wherever it may lead. What a thrill when that path, however winding, ends up in a place you never dreamed of, with impacts far beyond what you imagined!

This issue of *Research/Penn State* is full of winding pathways and unexpected discoveries. Most obvious is the case of Jeff Catchmark, who was well along in a career as an optical engineer when he quit the telecomm industry and came to Penn State. Retooling himself as a biological engineer, he set out to find an eco-friendly alternative to styrofoam. The biofoam he invented with Dr. Scott Armen of the College of Medicine, while not so well-suited to making cups, holds real promise as a biodegradable dressing for surgical and battlefield wounds.

Robert Sainburg was an occupational therapist who, frustrated with the lack of science behind standard practice, decided to become a neuroscientist. Sainburg's enduring fascination with how the brain controls movement led him to explore the phenomenon of handedness, and from there to important discoveries that could lead to more effective treatments for stroke patients.

Similar surprises have delighted Ann Killebrew and the "experimental archeologists" working at Tel Akko, a site of ancient industry, as well as the cosmos-scouring team of astrophysicists at our Center for Exoplanets and Habitable Worlds. And no one yet knows what worlds may come into focus for investigators using our powerful new cryo EM microscope.

These stories and many others are unfolding every day as Penn State researchers follow their curiosity toward unexpected discoveries and surprising solutions to the complex problems that face our world.

Neil A. Sharkey
Vice President for Research

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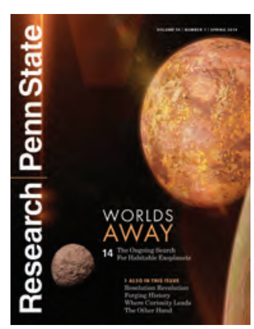

ON THE COVER:
Researchers at the Center for Exoplanets and Habitable Worlds are deploying powerful new tools in the search for what's out there, and in the process learning a lot about how planetary systems form. See story, page 14.

(Getty Images/ dottedhippo)

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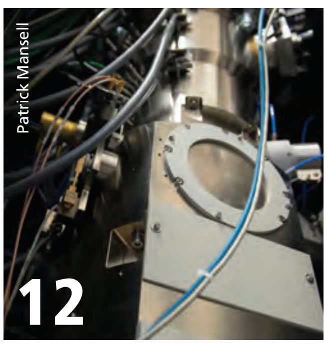
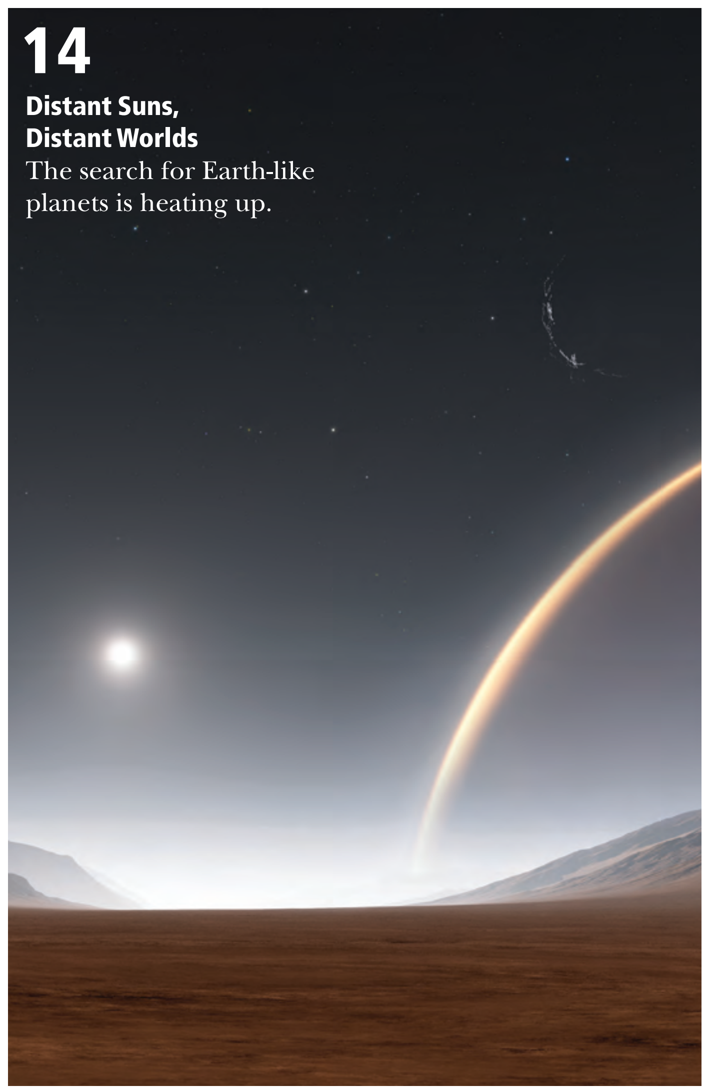


Patrick Mansell



›› Better Questions→ Better Answers

Healthcare providers use screening questions to detect patients who may be at risk for developing Alzheimer's disease, but those questions may be unclear or may trigger emotional responses that lead to inaccurate answers.

"When we ask people questions, we assume that they see the questions the same way we do," says Jacqueline Mogle, assistant professor of nursing. "However, that clearly isn't the case. What we might see as a straightforward question—like 'Do you have problems with your memory?'—may mean something very different for older adults. Right now it isn't clear how they are deciding to answer the question."

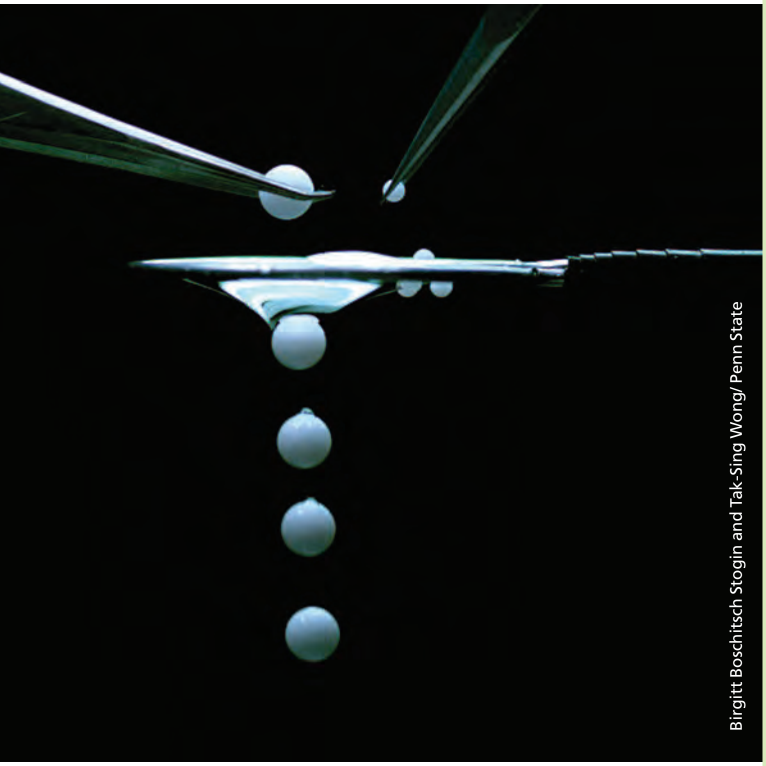
To identify such biases in screening questions, the researchers worked with 49 older adults in central Pennsylvania who did not have dementia. Each was asked several questions commonly used to screen for Alzheimer's disease. Then they were asked follow-up questions about how and why they answered the way they did.

The study identified 13 types of problems in the screening questions. The two most common were vagueness and an assumption that the participant's behavior or experience is always the same—that a person who has trouble remembering the day of the week today *always* struggles to do so, for example. Some questions, such as asking the participant to rate their memory compared to others, tended to provoke an emotional response.

Nikki Hill, assistant professor of nursing, says the results will help clinicians and researchers ask better questions and better interpret patient responses.

—KATIE BOHN

Getty Images/ wildpixel



Birgitt Boschitsch Stogin and Tak-Sing Wong/ Penn State

Time-lapse image shows the "reverse filter" as it lets a larger object pass through but catches a smaller object.

Small Catch

It's straight out of science fiction: a self-healing membrane that acts as a reverse filter, blocking smaller particles and letting bigger ones through.

Penn State researchers have created the opposite of a conventional filter by using a stabilized liquid membrane that responds to an object's kinetic, or movement, energy—which, in most cases, is related to the object's size.

"Typically, a smaller object is associated with lower kinetic energy due to its smaller mass," says Tak-Sing Wong, the Wormley Family Early Career Professor and assistant professor of mechanical and biomedical engineering. "The larger object with a higher kinetic energy will pass through the membrane, while the smaller object with lower kinetic energy will be retained." Then, like water, the membrane self-heals after the object has gone through it.

The researchers envision any number of real-world applications for the membrane. In remote areas or battlefield hospitals, it could provide the clean environment needed to safely operate. Its self-healing properties would allow medical devices such as surgical tools to pass through while keeping out contaminants such as dust, allergens, and bacteria.

It could also help in areas where poor sanitation contributes to the spread of disease.

"One billion people in the world still openly defecate for many reasons, one being that latrines smell bad," says graduate student Birgitt Boschitsch Stogin. "But if this could be applied to those toilets, it could allow solid waste to pass through the membrane, while the odor-causing gases will remain trapped."

—ERIN CASSIDY HENDRICK

CHEMICAL CLUES SHOW DRILLING IMPACTS

Chemical clues in waters near Marcellus Shale gas wells in rural Pennsylvania can reveal new drilling-related sources of methane contamination, according to scientists, and thereby help distinguish potential environmental impacts of shale drilling from pre-existing methane levels commonly found in Pennsylvania waterways.

The study focuses on an area where state regulators have cited multiple Marcellus Shale gas wells for well integrity issues. The nearest gas well was cited for contaminating five residential water wells with high levels of methane, an explosion hazard in enclosed spaces.

Natural gas is primarily composed of methane, and drilling can cause the gas to escape into waterways or the atmosphere. But methane is common in Pennsylvania waterways, caused by natural sources like bogs and wetlands, as well as natural migration from sources deep underground.

"Because we lack good baseline data for water quality throughout Pennsylvania, it can be difficult to identify possible impacts of shale drilling," says Susan Brantley, Distinguished Professor of Geosciences. "While we believe incidents of gas-well leakage are rare compared to the total number of gas wells, this study gives us a new tool to identity them when they occur."

Scientists analyzed pre- and post-drilling water samples from stream and well water around the reported leaks. They found that concentrations of some metals in the water began to rise shortly after the leaks began, indicating a gas plume moved into an aquifer from deep underground where horizontal drilling into shale has been accompanied by fracking. The clues could be used elsewhere to determine new leaks, they say.

—MATTHEW CARROLL

Joshua Woda/ Penn State

Wild brook trout in Pennsylvania streams carry few genes from hatchery fish.

- SHANNON WHITE and TYLER WAGNER

Ecology and Pennsylvania Cooperative Fish and Wildlife Research Unit

Icons Nudge People to Reveal More

Pictures may be worth a thousand words, but icons may be even more powerful in nudging people to disclose personal information online, according to a Penn State study.

The researchers found that people using an online sexual health forum featuring computer graphics, or icons, that implied a sense of crowd size and connectivity revealed more sensitive information than visitors to a site without those visual cues, says S. Shyam Sundar, co-director of the Media Effects Research Laboratory. Pictures of people in a group or holding hands did not affect the users' sense of community or how much they disclosed.

The researchers tested the icons on a sexual health forum because, while people tend to be reluctant to share information about their sexual behavior, disclosure is important to help them access health information.

"We found that once the users got the sense that they were connected to others in the same network, they were more willing to disclose their private information and revisit the forum," says graduate student Andrew Gambino.

While the icons could help build stronger online communities, they might also lure people into revealing more personal information than they otherwise would have, says Sundar.

"If people don't reveal information in an online forum, the vitality of that forum decreases because not enough people are sharing details that make the forum worthwhile," says Sundar. "On the other hand, if spam sites use these cues, they may be able to get more people to reveal sensitive information about their personal life, and that would be a bad thing."

—MATT SWAYNE

Icons that show a person's connections to other members of an online forum encourage people to share more personal information with the group than they would have otherwise.

Genes related to dyslexia may be linked to susceptibility to concussion.

- SEMYON SLOBOUNOV and ALEXA WALTER
Kinesiology

People with autism may not avoid looking at people in photographs.

- KRISTA WILKINSON
Communication Sciences and Disorders

Adults who sleep 6 hours per night, rather than 8, are more likely to be dehydrated.

- ASHER ROSINGER
Biobehavioral Health and Anthropology

STRESSED SOYBEANS YIELD STRONGER OFFSPRING ‹‹

By temporarily silencing the expression of a critical gene, researchers fooled soybean plants into sensing they were under siege from a wide range of stresses. The progeny of those plants crossed with the original stock "remembered" the stress-induced responses and became more vigorous, resilient, and higher-yielding plants.

Lead researcher Sally Mackenzie, professor of biology and plant science, says this was accomplished not by introducing any new genes but by epigenetic programming—changing how existing genes are expressed. That is important because it portends how crop yields and tolerance for conditions such as drought and extreme heat could be enhanced in the future.

Researchers worked with a gene, MSH1, that exists in all plants and is important for modifying how the plant regulates other genes. When MSH1 is dialed down or turned off, the plant senses it is dealing with several stresses simultaneously, such as drought, extreme cold, and heat, and it boosts the expression of other genes to respond to those stimuli.

"The plant has a memory of that stress—and by 'memory' I mean its growth features are very different from the plant we started with," says Mackenzie. "And it will remember the stress generation after generation after generation, as long as we don't make any crosses and keep it in the same lineage."

Because the technique does not alter the genes themselves, the plants are not "genetically modified organisms" requiring special regulatory approval. They can go right into the field. The approach can probably be applied to any crop; Mackenzie's lab has already demonstrated that it works in tomatoes and sorghum.

—JEFF MULHOLLEM

Unsplash/ Amy Hamerly

Microbes native to hot springs were found in about half the hot water heaters tested from across the U.S. How they got there has not yet been determined.

» What's in *Your* Water Heater?

Microbes that thrive in some of the most extreme places on Earth have discovered another cozy place to live—inside homes across the United States.

Extremophiles like those found in hot springs are common in residential water heaters, according to a nationwide study that sheds new light on the extent of extremophile colonization in homes. The microbes pose no health concerns for humans.

"Most of the time when you think about extreme environments, you are thinking about going out into nature and into these weird and inaccessible places," says Regina Wilpiszeski, a recent Penn State doctoral recipient. "But the truth is, we spend the vast majority of our time indoors. And we really just don't necessarily know what is living there."

The researchers found evidence of microbes in about half of the samples they obtained from water heaters in all 50 states, Washington, D.C., and Puerto Rico. One species, *Thermus scotoductus*, dominated, even in locations near natural hot springs that host other strains. In nature, *T. scotoductus* has been found at hot springs in Iceland, hydrothermal waters off the coast of Hawaii, and deep in a gold mine in South Africa.

Water heaters offer high temperatures and low levels of organic matter, ideal conditions for extremophile microbes, says Christopher House, professor of geosciences. Cooler temperatures would not kill the microbes, which could survive being transported from outside water sources. Further study is needed to determine the exact paths extremophiles take to enter our homes.

—MATTHEW CARROLL

Unsplash/ Agto Nugroho

› Early Birds

It's likely that somewhere in the American Southwest or northern Mexico lie the ruins of a scarlet macaw breeding operation from between 900 and 1200 C.E., say archaeologists who sequenced the mitochondrial DNA of bird remains found in the Chaco Canyon and Mimbres areas of New Mexico.

Scarlet macaws were valued by ancient Pueblo cultures for their vivid feathers, but how they came to live with humans in what is now the American Southwest has not been established. None of the sites where the parrot remains were found contained eggshells or other evidence of breeding. The nearest wild macaws lived thousands of miles away in eastern coastal Mexico and Guatemala, and the only evidence of macaw breeding closer to the Southwest dates from well after Chaco Canyon was abandoned in the late 1100s.

In the study, co-led by Douglas Kennett, professor of anthropology, researchers obtained full mitochondrial DNA (mtDNA) sequences of 14 scarlet macaws from the New Mexico sites. Radiocarbon dating showed that all 14 birds lived between 900 and 1200 C.E. Because mitochondrial DNA is inherited only from the mother, it can show direct lineage: All siblings have the same mtDNA as their mother, and she has the same mtDNA as her own siblings and mother, all the way back through their ancestry.

All the mtDNA samples were from one small genetic group. The probability of obtaining 14 birds from the wild that were so similar genetically was extremely low, suggesting that the birds came from a breeding population in the American Southwest or northern Mexico.

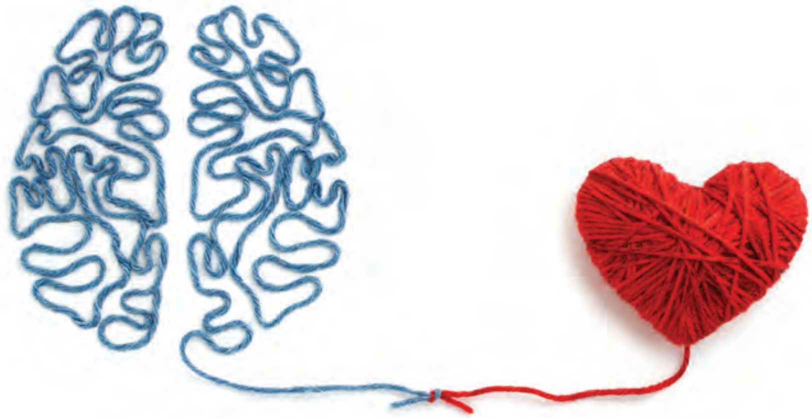
—A'NDREA ELYSE MESSER

Persistent lung inflammation from childhood asthma is linked to adult anxiety.

- SONIA CAVIGELLI and JASMINE CAULFIELD
Neuroscience

The oldest plant virus ever reported was found in 1,000-year-old corn cobs from Pueblo ruins.

- MARILYN ROOSSINCK
Plant Pathology and Environmental Microbiology
&
- MAHTAB PEYAMBARI and NICHOLAS STOLER
Center for Infectious Disease Dynamics



Getty Images/ TanyaJoy

Heart-Brain Link Could Predict Epilepsy

Heartbeat irregularities connected to abnormal brain activity may lead to the ability to predict epileptic seizures in subjects who suffer physical or infectious brain insults, according to Penn State researchers who studied mouse models of cerebral malaria.

Cerebral malaria causes death and brain injuries, including epilepsy, in Africa and East Asia where this strain of malaria is endemic. However, other diseases and physical trauma also cause injuries that eventually lead to epilepsy, and acquired epilepsy does not always occur immediately. Visible symptoms can take months to years to display, according to Bruce Gluckman, professor of engineering science and mechanics, neurosurgery, and biomedical engineering.

While working on a mouse model, in a project led by Steven Schiff, Brush Chair Professor of Engineering in the Departments of Neurosurgery, Engineering Science and Mechanics, and Physics, graduate student Fatemeh Bahari noticed heartbeat anomalies that seemed to associate with abnormal brain activity in mice that later developed seizures. Bahari then was able to show a relationship between the anomalous heart and brain readings, and also that they could be used to predict which mice would develop epilepsy.

In the initial experiment, spearheaded by Paddy Ssentongo, now assistant research professor of Engineering Science and Mechanics, the researchers used electrocardiographs and electroencephalographs to monitor heart rates and brain waves, respectively.

“There is currently no biomarker to determine who will develop epilepsy after a brain insult,” says Gluckman. “With this delayed coincidence from brain to heart, we can clearly separate the mice that became epileptic from those that did not, weeks before development of epilepsy.”

—A’NDREA ELYSE MESSER

A BITTER LINK TO CANCER ‹‹

High bitter-taste sensitivity is associated with a significantly increased risk of cancer in older British women, according to researchers who conducted a study of 5,500 women whose diet, lifestyle, and health has been tracked for about 20 years.

The research examined the relationship between the ability to taste the bitter-tasting chemical phenylthiocarbamide, known as PTC, or the presence of specific genetic differences in a bitter taste receptor that binds to PTC, and risk of cancer in a subset of the UK Women’s Cohort Study.

Researchers analyzed the women’s food intake. Depending on the level of sensitivity to bitter tastes, study participants were classified as super-tasters, tasters, and non-tasters. The researchers hypothesized that women with higher bitter-taste sensitivity would consume fewer protective vegetables and therefore have higher incidence of cancer, but they found no correlation between bitter-taste sensitivity and vegetable intake. They did find that, among older women, bitter-taste sensitivity was associated with greater cancer risk, according to lead researcher Joshua Lambert, associate professor of food science.

Getty Images/ DronG

“The difference in cancer incidence between the women with the highest bitter-taste sensitivity and those with the lowest was striking,” Lambert says. “Super-tasters had about a 58 percent higher risk of cancer incidence, and the tasters had about a 40 percent higher risk of developing cancer, compared to women who were classified as non-tasters.

“Maybe, if we pull back and look at the whole-diet level, we will see that women who are super-tasters have a poorer quality overall diet compared to women who are non-tasters,” he says.

—JEFFERY MULHOLEM

JET STREAM EXTREMES ‹‹

In 2018, summer weather included flooding in Japan; record heat waves in North America, Europe, and Asia; and wildfires in Greece and even parts of the Arctic. Heat and drought in California led to the worst wildfire season ever recorded there.

Continued burning of fossil fuels is likely to fuel even more extreme summers because of its impact on the jet stream, according to an international team using climate models to predict changes in the occurrence of so-called Quasi-Resonant Amplification (QRA) events.

QRA events produce extreme summer weather when the jet stream exhibits broad north-south meanders and becomes stationary with the peaks and troughs locked in place.

"Most stationary jet stream disturbances will dissipate over time," says Michael Mann, Distinguished Professor of Atmospheric Science. "However, under certain circumstances the wave disturbance is effectively constrained by an atmospheric wave guide, something similar to the way a coaxial cable guides a television signal. Disturbances then cannot easily dissipate and very large amplitude swings in the jet stream north and south can remain in place as it rounds the globe."

QRA played an important role in last summer's unprecedented events, Mann says. However, the rapid disappearance of aerosols produced by pollution could mitigate the impact of QRA until mid-century if countries like China phase out these fuels, he adds.

"The future is still very much in our hands when it comes to dangerous and damaging summer weather extremes," he says. "It's simply a matter of our willpower to transition quickly from fossil fuels to renewable energy."

—A'NDREA ELYSE MESSER

Larger cities have smaller "water footprints" than smaller cities.

- CAITLIN GRADY and TASNUVA MAHJABIN
Civil Engineering

Partners Since Dinosaur Days

Coral-algal partnerships have endured numerous climate change events in their long history, and at least some are likely to survive modern-day global warming as well, suggests an international team of scientists.

The team's conclusion is based on the finding that the relationship between corals and the mutualistic micro-algae that enable them to build reefs is considerably older and more diverse than previously assumed.

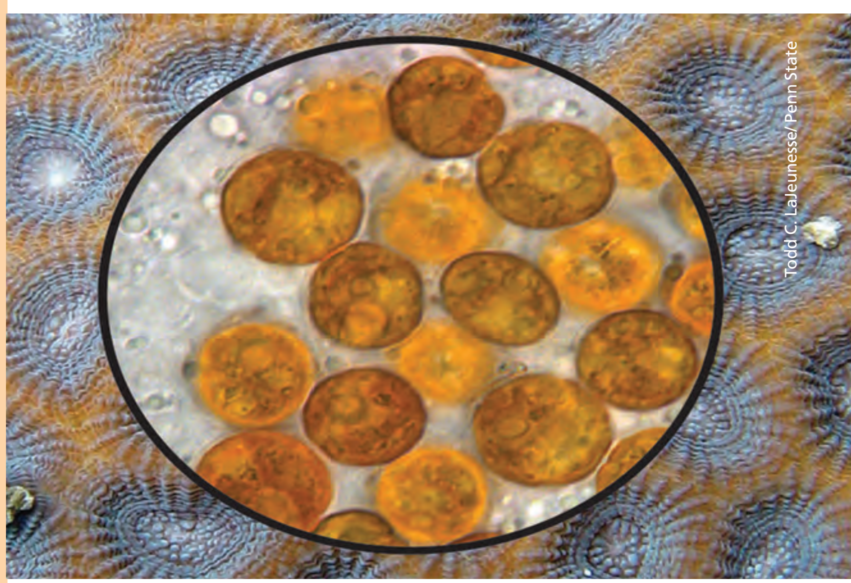
"Past estimates placed the initiation of these symbiotic relationships at 50 to 65 million years ago," says Todd LaJeunesse, associate professor of biology. "Our research indicates that modern corals and their algal partners have been entwined with each other for much longer—since the time of the dinosaurs, approximately 160 million years ago. During their long existence, they have faced severe episodes of environmental change, but have managed to bounce back after each one."

According to LaJeunesse, the micro-algae, commonly called zooxanthellae—of the dinoflagellate family Symbiodiniaceae—live inside the cells of corals, allowing them to acquire energy from sunlight and to build the massive, economically valuable reef formations upon which countless marine organisms rely for habitat.

The team used genetic evidence to calculate the micro-algae's approximate age of origin. Researchers also used classical morphological techniques in which they compared visual characteristics of these symbionts using light and electron microscopy, along with computer modeling and other methods, to discover that in addition to being older, the algae family is far more diverse than previously perceived.

—SARA LAJEUNESSE

Microscopic algae seen against a background of young coral polyps. The photosynthetic algae live inside coral cells, allowing the coral to acquire energy from sunlight and build the massive reefs upon which countless other organisms depend.



Getty Images/ hkuchera

›› Large Carnivores Leave Big Footprints

Anywhere large-bodied mammalian carnivore species are present, other, smaller carnivores are less likely to occur, according to an international team of researchers that conducted the first global assessment of carnivore interactions using camera trap data.

This finding is important because populations of large mammalian carnivores are declining as habitat is lost, and often where large carnivores disappear, a chain reaction is set off that affects smaller carnivores, prey species, and even plant and insect communities, says David Miller, associate professor of wildlife population ecology, whose research group led the study.

The researchers analyzed data from camera traps—sites watched over by automated trailcams—across 12 countries on five continents. They found that carnivore species pairs co-occurred more frequently than expected at random. However, co-occurrence decreased when the pair included a large-bodied carnivore.

"This finding, that large carnivores exclude other carnivores, is true in North America, South America, Africa, Europe, and Asia," Miller says. "When you lose a large-bodied species of carnivore, you have other smaller carnivores increase in density, putting pressure on other smaller carnivores, and that can lead to increases in prey species."

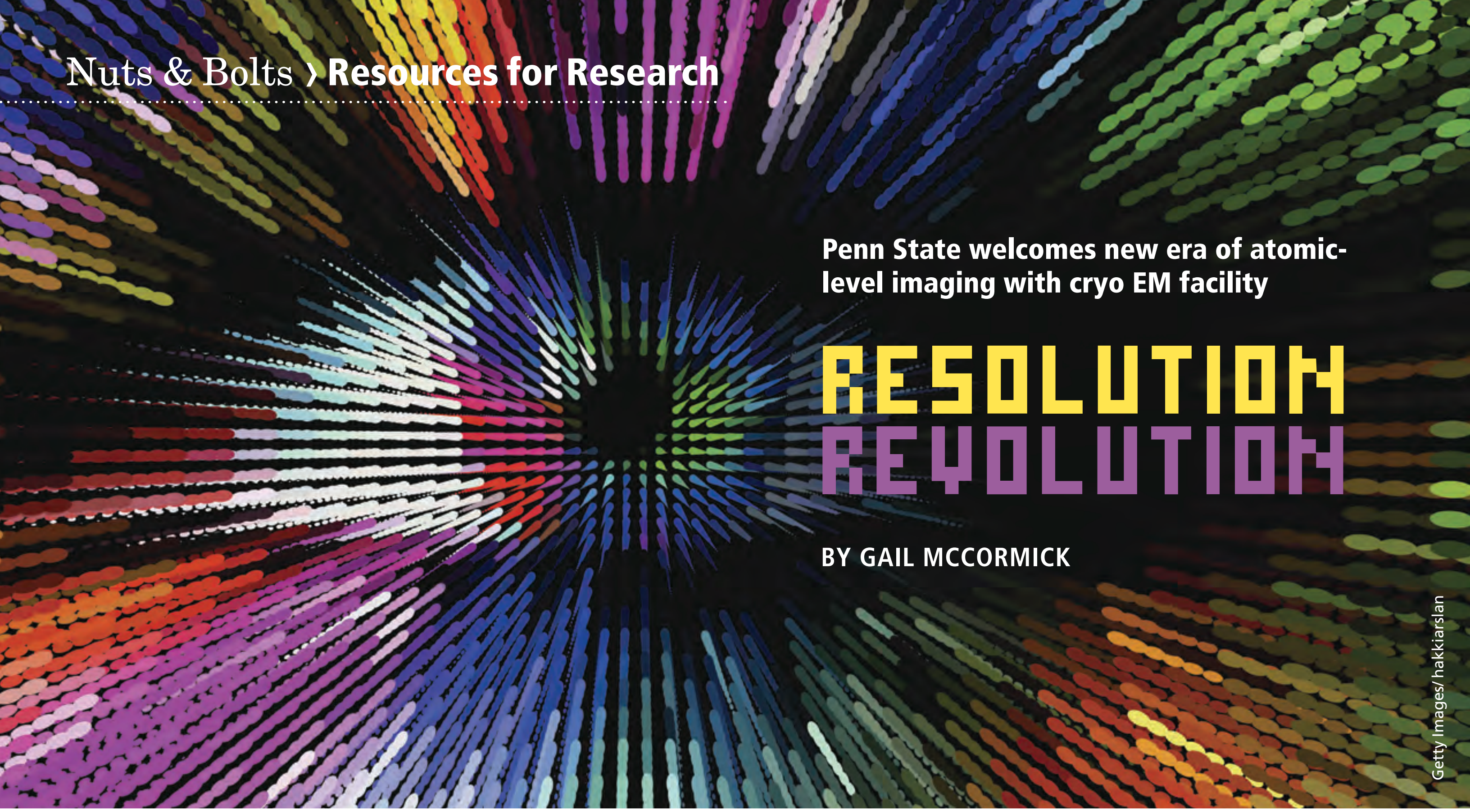
An example in the United States is the disappearance of wolves and cougars in the East, which has opened up vast areas where coyotes and bobcats roam unregulated. This has implications for how our forests are structured, Miller says. "The fact that we don't have wolves and cougars means we have more deer, and those deer have overbrowsed the forests."

—JEFF MULHOLLEM

MUSHROOM MAGIC ‹‹

Ready to be picked and sautéed in garlic butter, oyster mushrooms (*Pleurotus ostreatus*) grow from a spawnbag at Penn State's Mushroom Spawn Lab. The Lab explores ways to improve mushroom cultivation and provides starter cultures for labs and growers worldwide. Mushrooms are the fruiting bodies of a fungus that produces a mycelium, a network of filaments that feed on roots, decaying organic matter, and other substrates. Research technologist Edward Kaiser captured the delicate beauty of oyster mushrooms growing on a bagged mixture of spent coffee grounds, used coffee filters, straw, wheat bran, and soybean meal. In this picture, the mycelium is mostly deep inside the spawn bag, but a bit of it can be seen at lower left.

Photo by Edward Kaiser



Getty Images/ hakkiarslan

Penn State welcomes new era of atomic-level imaging with cryo EM facility

RESOLUTION REVOLUTION

BY GAIL MCCORMICK

When you sit down to watch your new 4K television for the first time, suddenly those old standard-definition re-runs of Star Trek don't look so futuristic. The leaps in scientific and technological knowledge responsible for the advance in video quality since the starship Enterprise took its first voyage in the 1960s are worthy of Starfleet.

But gains in image quality have not been limited to photography and film. A new way of capturing images with cryo-electron microscopes has sparked what is being called the "resolution revolution." Using extreme cold to arrest fluid samples in motion, cryo EM allows researchers to see proteins, clusters of molecules, and viruses with astounding clarity—to the point where individual atoms may become visible.

The Titan Krios cryo-electron microscope looms over facility director Susan Hafenstein.

Nate Follmer

In 2017, the Huck Institutes of the Life Sciences unveiled its Cryo Electron Microscopy Facility, which allows researchers to quickly create high-resolution three-dimensional models of intricate biological, chemical, and synthetic structures.

"It's like putting on glasses for the first time," says facility director Susan Hafenstein. "With cryo EM, we have gone from a general idea of structure to crystal-clear detail."

HOW IT WORKS

Like other electron microscopes, the facility's Titan Krios microscope creates images by firing electrons through a sample, where they encounter tiny structural features, and recording their image when they emerge. Sophisticated software uses thousands of images from each sample to create a 3D image of the structure in question.

The cryo EM differs from other kinds of electron microscopes in that the sample consists of many copies of a particle, such as a protein, suspended in a liquid and then plunged into liquid nitrogen to preserve the natural shape of the particles and arrest them mid-movement. This allows scientists to glimpse processes such as an enzyme changing its shape as it catalyzes a chemical reaction, or a protein forming a complex with other molecules.

The Titan Krios can produce a 3D rendering of a structure in two ways. Single-particle reconstruction provides a high-resolution view of something relatively small, like a single protein. Cryo-tomography provides a view of larger structures in context, such as enzymes and other proteins bound together in a functional complex.

Both techniques generate thousands of images per sample—up to 10 terabytes of data per day. To meet the new challenges for data processing, transfer, and storage, Penn State implemented a high-speed fiber-optic network that allows data transfer from the microscope to the researcher ten times faster than before, and allocated additional storage space for researchers using the microscope.

"Penn State has made a huge investment in infrastructure," says Hafenstein. "We needed to set it up so the data coming off the Krios has someplace to go, and someplace to go as fast as it is being created."

During planning for the facility, scientists from the Materials Research Institute urged that the instrument be outfitted with a powerful upgrade: the ability to do spectroscopy on a sample being imaged. This would make it possible to see the overall structure of a particle and identify the chemical elements within it at the same time, opening up whole new lines of inquiry. To date, Penn State's instrument is the only one in the world to have this dual capability.

COLLABORATIONS ABOUND

Hafenstein uses the Titan Krios in her own research on how viruses bind to and enter host cells.

"There are all kinds of steps that the virus has to go through to enter and infect a human cell," she says. "In the past we were never really able to see this entry process. Now with cryo EM we can, and that's pretty exciting."

She consults with researchers across campus who are using the new microscope to investigate questions as varied as how certain proteins are involved in the transmission of the malaria parasite and how sticky proteins called amyloids cluster into potentially damaging plaques in the brain. The work isn't all biological; materials scientists are taking advantage of the instrument's ability to provide high-resolution images of fragile "soft" materials that are hard or impossible to examine with other microscopic techniques.

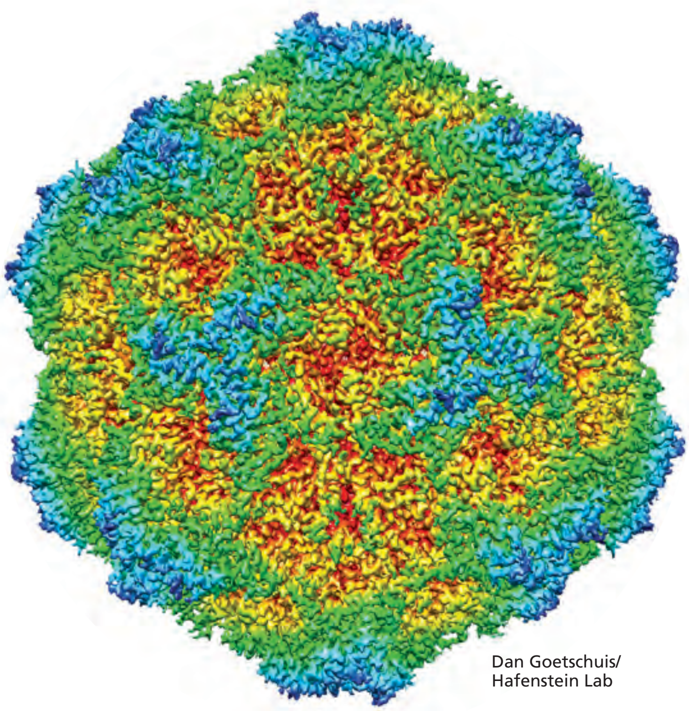
Like the other ten core facilities managed by Huck, the Titan Krios is available for use by all Penn State researchers and by outside academic and private sector clients. Scientists on campus meet often to share the newest ways to analyze data, discuss the challenges of particular projects, and explore how to enhance the vast potential of the new facility.

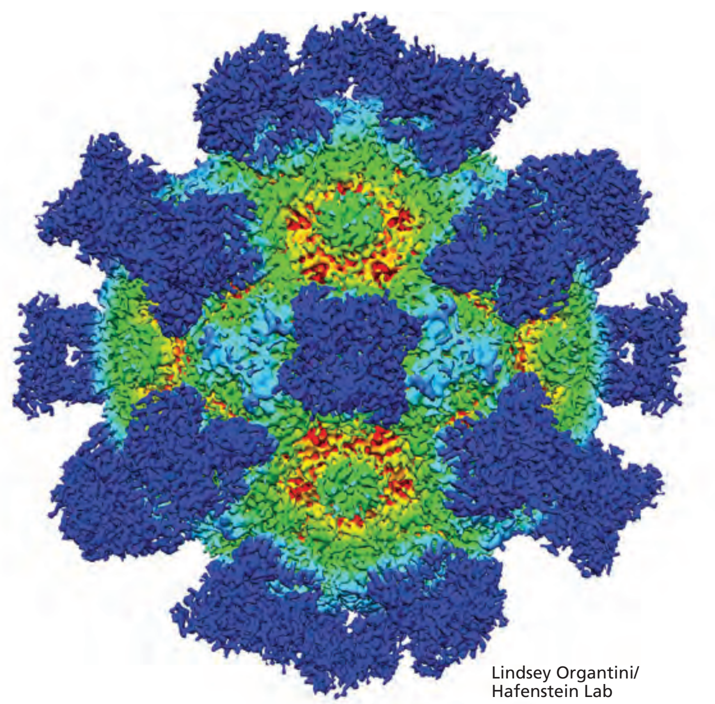
The combination of cryo EM technology and spectroscopy has positioned Penn State to make significant contributions to the field of structural biology and beyond.

"There are about 100 of these microscopes in the world today," says Hafenstein, "but because of the unique combination of imaging technologies, ours is a one and only."

Susan Hafenstein is associate professor of medicine, microbiology, and immunology at Penn State College of Medicine, associate professor of biochemistry and molecular biology in the Eberly College of Science, and Lloyd & Dottie Huck Chair of Structural Virology.

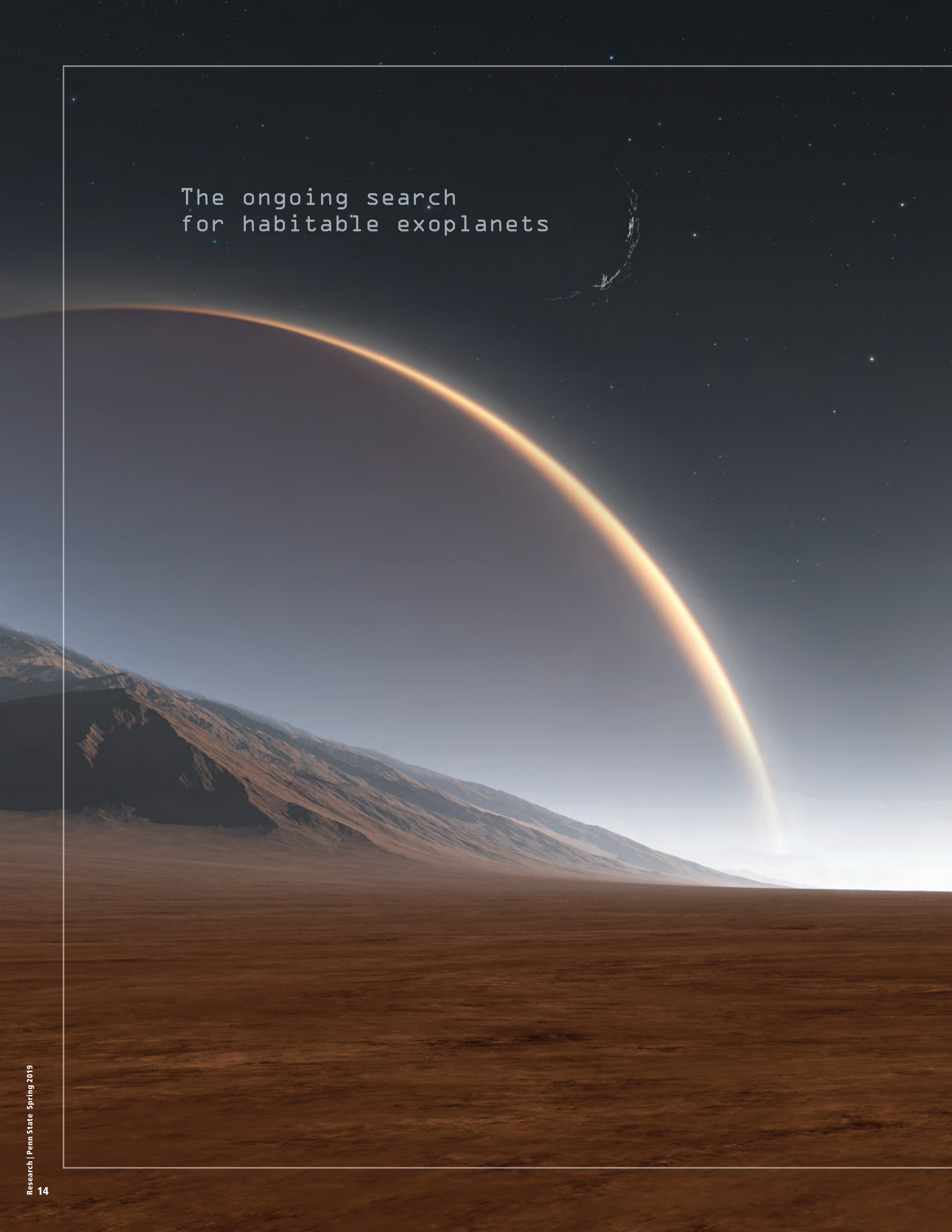
An in-depth version of this story appeared in Science Journal [https://tinyurl.com/ResoRevo].

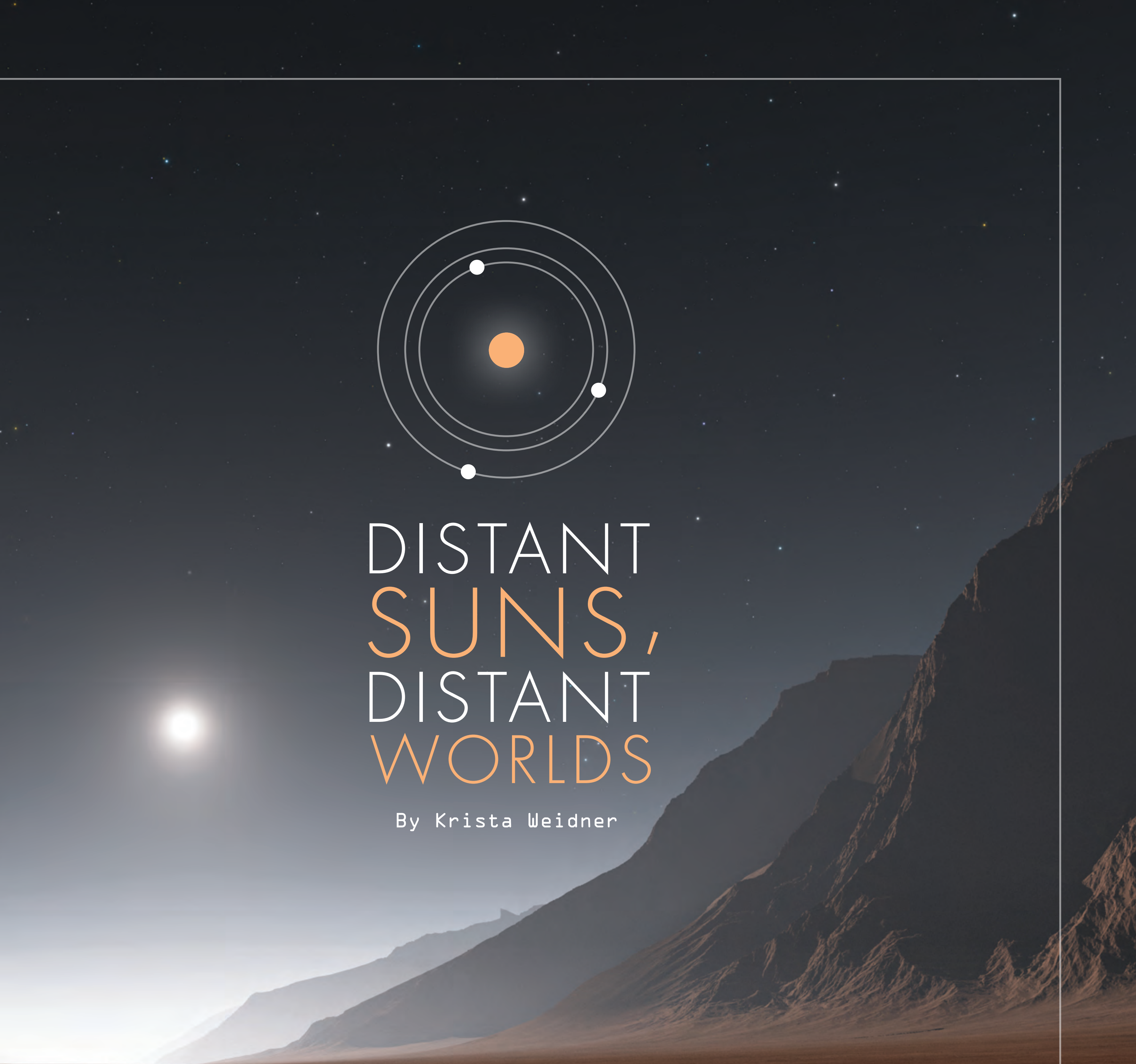




Hafenstein's lab uses cryo-electron microscopy to make high-resolution models of viruses such as the canine parvovirus (CPV) shown here. At left is a CPV capsid, or protein shell, color-coded to indicate surface features. Red areas are depressed and light blue areas are elevated. The capsid at right has been treated with antibodies, shown in dark blue. Binding to the antibodies caused changes in the capsid surface, offering clues to how the virus might be inactivated.

The ongoing search for habitable exoplanets





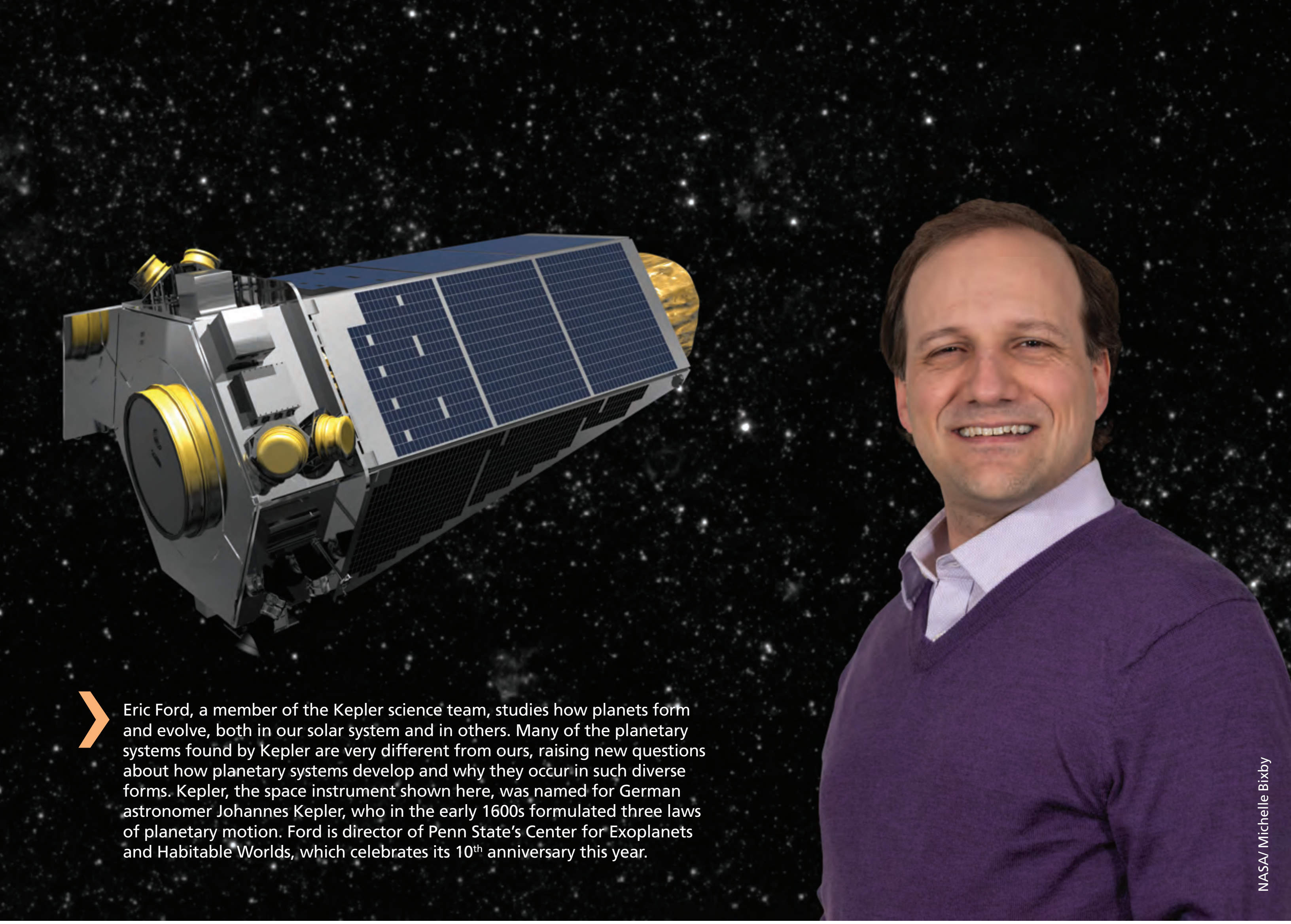
DISTANT SUNS, DISTANT WORLDS

By Krista Weidner

March 6, 2009. A balmy Florida evening, and my family and I stood on Cocoa Beach, looking north toward the Cape Canaveral Air Force Station. We were part of a seaside crowd gathered to witness the launch of NASA's Kepler Space Telescope. As the fireball appeared and slowly began to rise in the distance, we cheered with our fellow observers. About 30 seconds later, we felt the ground rumble and heard the deep roar, watching the Delta II rocket climb into the night sky and accelerate as it headed out over the ocean.

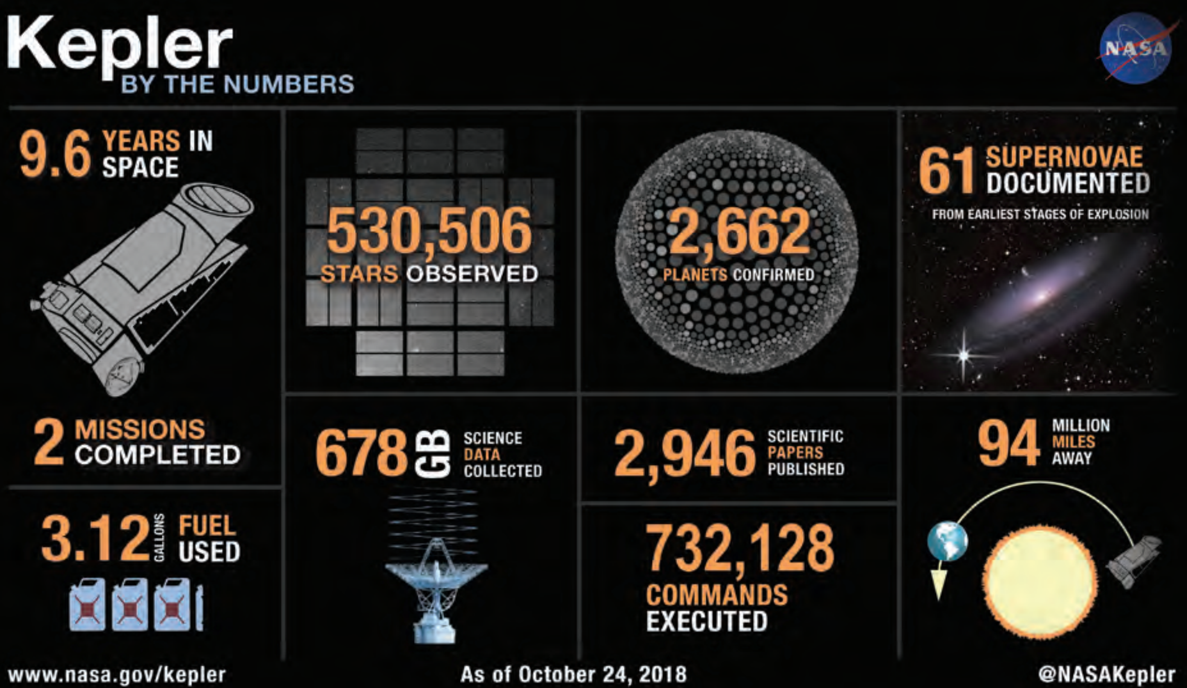
Kepler went on to spend nine years in deep space searching for galactic neighbors like us: Earth-sized planets orbiting Sun-like stars. Kepler watched a patch of the Milky Way galaxy that included millions of stars. It beamed back data on nearly 200,000 of them and found more than 2,600 exoplanets—planets outside our solar system.

Getty Images/ Pitris



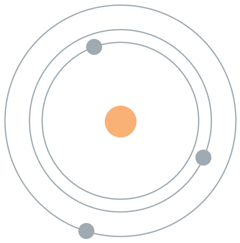
Eric Ford, a member of the Kepler science team, studies how planets form and evolve, both in our solar system and in others. Many of the planetary systems found by Kepler are very different from ours, raising new questions about how planetary systems develop and why they occur in such diverse forms. Kepler, the space instrument shown here, was named for German astronomer Johannes Kepler, who in the early 1600s formulated three laws of planetary motion. Ford is director of Penn State's Center for Exoplanets and Habitable Worlds, which celebrates its 10th anniversary this year.

NASA/ Michelle Bixby



The Kepler space telescope was retired in October 2018, after completing two missions over a deployment of 9.6 years. Scientists are still analyzing data collected by Kepler.

NASA/ Ames/ Wendy Stenzel



> “Is Earth a great coincidence, or does planet formation often produce similar planets?” —ERIC FORD

“With data from Kepler, we have more precise and detailed information than we’d ever had before,” says astrophysicist Eric Ford, who was part of the Kepler science team. Ford and his colleagues at Penn State’s Center for Exoplanets and Habitable Worlds are building on the legacy of Evan Pugh Professor Alex Wolszczan, who discovered the first known exoplanets in 1992 using surveys from ground-based instruments. “Kepler found thousands of planets,” Ford says. “Astronomers would love to learn more about all of them, but there is not enough telescope time. Since people are particularly interested in learning more about those that may resemble Earth, we plan to concentrate on characterizing planets in the habitable zones of their planetary systems.”

The habitable zone is a region within a solar system—a distance not too close and not too far from a sun—where a planet would have the conditions necessary to have liquid water on its surface, an important requirement for the existence of carbon-based life as we know it. James Kasting, Evan Pugh Professor of Earth Sciences, was one of the early developers of the concept. The planet’s surface temperature must be above the freezing point of water and below the boiling point. Other conditions also come into play, including the planet’s mass, rotation, and atmosphere. Among the Kepler exoplanets that have been analyzed so far, several dozen are considered to be in the habitable zone of their star.

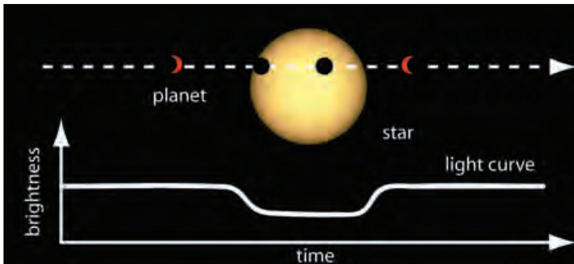
HOW TO FIND AN EXOPLANET

In its search for exoplanets, the Kepler mission employed the transit method, using digital-camera-like technology to detect and measure tiny dips in a star’s brightness as a planet crosses in front of its star. With observations of transiting planets, astronomers can calculate the ratio of a planet’s radius to that of its star—essentially the size of the planet’s shadow—and with that ratio they can calculate the planet’s size. “We know the size of thousands of planets thanks to the transit method,” Ford says.

Although its solar-powered electronics could continue working for a long time, this past fall, Kepler ran out of the hydrazine fuel needed to orient itself precisely, and NASA retired the spacecraft. It’s now 94 million miles away, in an orbit trailing Earth around the Sun. But the mission produced enough data to keep astronomers busy for years to come. And now, a new NASA mission is expanding on Kepler’s census of exoplanets by targeting closer, brighter stars. TESS (Transiting Exoplanet Survey Satellite), which launched last April, is scanning almost the whole sky, one patch at a time, looking for transiting planets around the nearest stars. While the typical stars Kepler observed were from 300 to 3,000 light-years away (one light-year is about six trillion miles), TESS is looking at stars that are mere tens of light-years away. And rather than spending years looking at one patch of sky, as Kepler did, TESS will move from one patch of sky to the next.

Using TESS observations of brighter stars—on average 30 to 100 times brighter than the stars Kepler surveyed—astronomers will be able to inspect planets more closely and make follow-up observations more easily. “With TESS, we’re focusing on searching for planets around stars that are closer to us, since we’ll be able to characterize them more efficiently,” Ford says. Data from TESS will provide information on a planet’s size and orbital period, and follow-up observations with other instruments will allow researchers to measure the masses and describe the atmospheres of those planets.

But as valuable as the transit method is to planetary studies, it has its limitations. “Transits only let you see planets that happen to cross between us and the star we are looking at,” explains astrophysicist Fabienne Bastien. “Radial velocities enable us to see planetary systems in other orientations.”



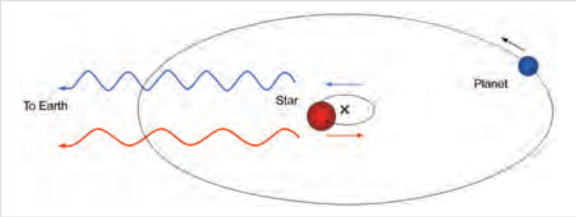
When a planet crosses in front of its star, as viewed by an observer, the event is called a transit. Transits by terrestrial planets produce a small change in a star’s brightness of about 1/10,000, lasting for 2 to 16 hours. By measuring the drop in brightness and knowing the size of the star, scientists can determine the radius of the planet. The orbital period of the planet—the time it takes to make one complete orbit of its star—can be determined by measuring how much time elapses between transits. Once the orbital period is known, Kepler’s Third Law of Planetary Motion can be applied to determine the average distance of the planet from its star.

NASA/ Ames

Fabienne Bastien focuses on stars that host planetary systems, how they vary, and how that variability affects our ability to detect and characterize exoplanets. Much of her work is based on data from radial velocity studies, which tell us a lot about the suns that host exoplanets. It's fairly easy to find a star, but much harder to discover whether a star has planets orbiting around it. A new generation of spectrographs, such as the NEID that will soon be deployed at Kitt Peak National Observatory, shown here, will provide precise details about distant stars and their planetary systems.

Mark Hanna/ NOAO/ AURA/ NSF/ Michelle Bixby

Also called Doppler spectroscopy, the ground-based radial velocity method was actually the first technique to detect exoplanets hosted by Sun-like stars. It's based on the fact that a star wobbles slightly in response to an orbiting planet's gravitational tug. These tiny movements affect the star's light spectrum, or color signature. As the star moves slightly away from an observer, the wavelength of its light lengthens slightly, shifting toward the red end of the spectrum. As the orbiting planet pulls the star slightly toward the observer, the star's light shifts toward the blue. Through repeated observations of changes in the star's spectrum, researchers can calculate the planet's mass.



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The radial velocity method, also known as Doppler spectroscopy, relies on the fact that a star does not remain completely stationary when it is orbited by a planet. It moves slightly, responding to the gravitational tug of the planet. These slight movements affect the star's normal light spectrum, or color signature. When the star moves toward a distant observer, its spectrum shifts slightly toward the blue; when it moves away, the shift is slightly toward the red. As the planet continues to orbit the star, the shifts repeat at regular intervals. These shifts are detected by sensitive spectrographs on Earth.

Bastien, whose research focuses on the host stars of planetary systems, combines transit data with radial velocity studies to learn more about distant suns. "These suns have spots and flares and all kinds of activity that can either mimic or mask an exoplanet signal," she says. "Much of my work involves disentangling the planetary signal from the stellar signal, so we can confirm it's actually a planet that we're seeing. Penn State is already a radial velocity powerhouse, and I'm excited about two new spectrographs that are much more sensitive than what we've had to date and that will dramatically advance our studies." [see sidebar, p. 21]

These new world-class, highly sensitive spectrographs, built by a Penn State team led by astrophysicist Suvrath Mahadevan, are about to change the radial velocity landscape. They'll measure radial velocities extremely precisely to characterize low-mass planets in or near the habitable zones of their stars. One spectrograph is designed for optical study of nearby Sun-like stars, and the other for detecting cooler, fainter, lower-mass stars using infrared light.

"I can't wait to use these spectrographs to explore some ideas I have for finding habitable exoplanets," Bastien says. "I want to start a planet search around some stars that haven't received much attention because they're too noisy—there are complicating factors around them that make them difficult to study. The group here is enthusiastic and collaborative and open to new ideas, so there are all sorts of possibilities."

"Much of my work involves disentangling the planetary signal from the stellar signal, so we can confirm it's actually a planet that we're seeing." —FABIENNE BASTIEN

ALL PLANETARY SYSTEMS ARE NOT ALIKE

As researchers learn more about potential habitable zones of distant solar systems, they also want to learn about how those systems might have formed and evolved. That's the research focus of astrophysicist Rebekah Dawson. "It's an exciting time because so many new planets have been discovered in other solar systems and they're very different from the planets in our solar system," she says. "Exoplanet discoveries forced us to change our understanding of solar system and planet formation."

For example, Kepler found a lot of planets with sizes between that of Earth and Neptune (about four times Earth's diameter) that are as close to their stars as Mercury is to the Sun, or even closer. "These planets are common in other planetary systems, and we have nothing like them in our solar system," Dawson says. "So we're going back to the drawing board with some of our theories for how planets form and what happens early in planetary systems, now that we don't have just our solar system to judge these theories against."

Dawson's research on planetary systems can in turn inform and provide context for studies of individual planet formation. By understanding what might have been happening early on in a planetary system, she and her colleagues can develop theories about how planets might form in that system. For example, as giant planets gravitationally interact with each other, they could be sending asteroids and comets into regions where terrestrial planets are forming, and that could influence the composition of those planets.

Among Dawson's research interests are hot Jupiters, some of the first exoplanets ever discovered. Similar in mass to our Jupiter, these giant gas planets are much closer to their sun than Jupiter is to our Sun. They complete an orbit in three to four days. "That's not where we expected to find giant gas planets in their solar systems," Dawson says. "We're trying to understand their origin and how they could be so close to their star. One theory is that after these hot Jupiters formed, they were put into an extremely elliptical orbit that would bring them close to their star, and then tidal friction—tides raised on the Jupiter by the star—caused the orbit to shrink and become more circular.

"I sometimes think of a planetary system as an ecosystem that could support a potentially habitable planet, and we have to understand how the whole thing functions to really understand if that planet is habitable and what its formation history is," Dawson continues. "When we started to learn about those hot Jupiters and how their orbits might have been altered, that has implications for the rest of the planetary system. If that were happening, it would probably wipe out any planets in between the hot Jupiter and the star, so that region wouldn't be a likely place to find a habitable planet"—even if it's the right distance from the star to be in the habitable zone.

WHERE DO WE GO FROM HERE?

Fabienne Bastien recalls the sense of wonder she felt when, as a graduate student, she heard Kepler scientist Natalie Batalha speak of her own realization that the stars we see at night are more than distant suns. "Now we know that they're not just stars, they're planetary systems," she says—each one potentially home to habitable worlds.

With everything astronomers have learned about that potential, there's still much that remains a mystery. Current methods are just beginning to characterize the atmospheres of exoplanets and determine whether a planet in the habitable zone might have a surface that is conducive or hostile to life. Recent progress gives scientists a better idea of what questions to ask and what kinds of instruments are needed to address them.

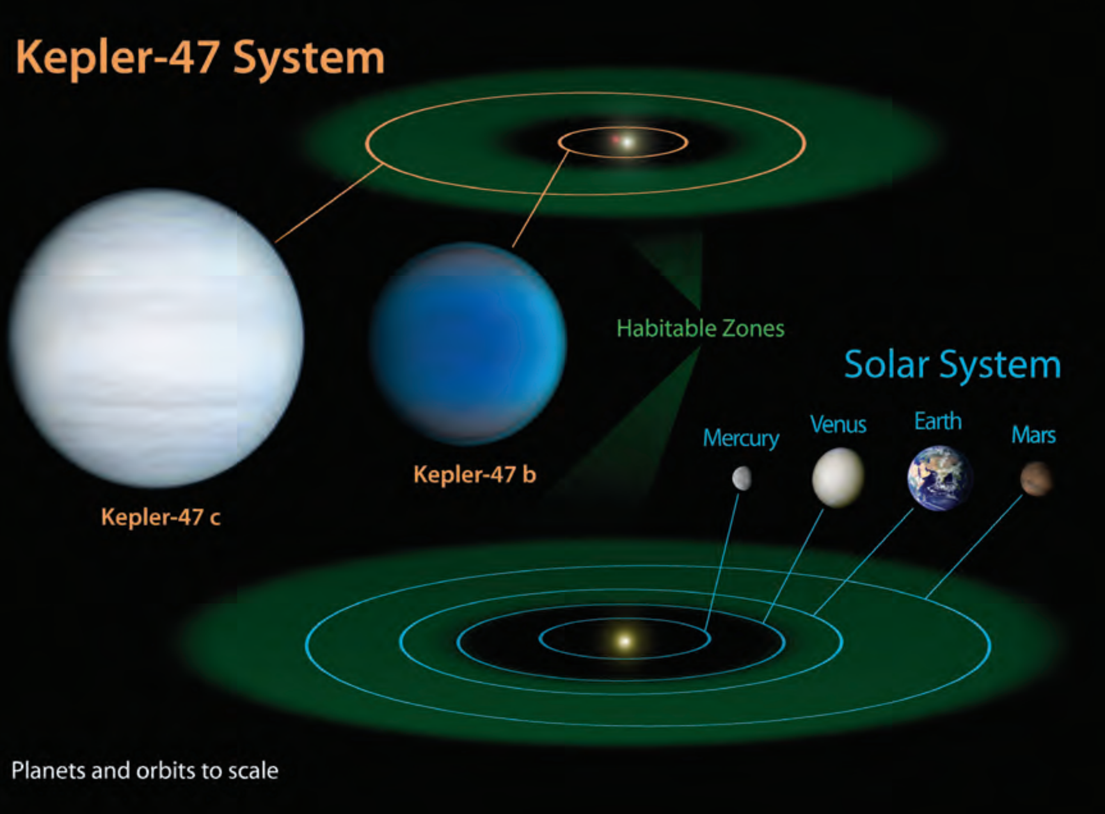
"When astronomers have just discovered a planet, we could say it's potentially habitable, but that is more a statement of our limited knowledge than of the properties of the planet," Ford says. "We want to design a hypothesis that is testable through observations we're able to make. If we can find 100 rocky planets in the habitable zone and characterize their atmospheres to look for water and biomarkers, then we might find some really fascinating planets—but there's also the possibility that we conclude that none of them are suitable for Earth-like life."

One long-term goal for astronomers is direct detection of exoplanets, rather than having to infer their existence through transit or radial velocity studies. Dawson is now serving on a team laying the groundwork for a Large UV Optical Infrared Surveyor (LUVOIR), a multi-wavelength space observatory concept being studied by NASA's Goddard Space Flight Center. LUVOIR is envisioned to be a twelve- to fifteen-meter diameter telescope that would operate about a million miles from Earth. It would allow scientists to recognize planets directly, as small bright bodies against the dark of space. Once a planet is identified, other techniques could then be used to measure its mass and examine other important features.

As researchers look to new technologies such as the new spectrographs, LUVOIR, and other future missions, they're optimistic that one day we'll know

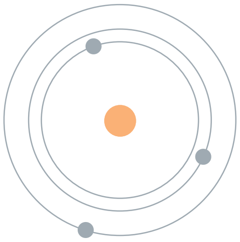
NASA/JPL-Caltech/ T. Pyle (SSC)/ Michelle Bixby

Rebekah Dawson uses information from Kepler discoveries to study how planetary systems formed and evolved. She is especially interested in “hot Jupiters” like the one shown in this artist’s conception. Like Jupiter in our solar system, these planets are gaseous, with no solid surface, and huge, some much larger than Jupiter. They also orbit very close to their stars, completing an orbit in just three to four days. Their temperature has been estimated to range from 2,200 to 3,000 degrees Fahrenheit, hotter than molten lava.



Just because a planet is in a system’s habitable zone doesn’t mean it is habitable. This diagram compares our own solar system to Kepler-47, a double-star system discovered by the Kepler space telescope. The habitable zone of each system, the area in a planetary system where liquid water might exist on the surface of a planet, is shown as a green band. Kepler-47 contains two planets, one orbiting too close to its suns to be habitable. The other, named Kepler-47c, orbits well within the habitable zone, but is not likely to host life. It is thought to be a gaseous giant, with an atmosphere of thick water-vapor clouds and no solid surface.

NASA/ JPL-Caltech/ T. Pyle



"Before exoplanets were discovered, I think a lot of us expected every planetary system to look like the solar system" —REBEKAH DAWSON

whether our solar system is a rare phenomenon or if life does indeed exist on other planets.

"If you think about it, it's amazing that Earth has both continents and oceans, as well as an atmosphere and climate that sustain life," Ford says. "Is that significant? Is it just the right balance? Is Earth a great coincidence, or does planet formation often produce similar planets?"

"Before exoplanets were discovered, I think a lot of us expected every planetary system to look like the solar system, or we thought most stars don't have planets," Dawson adds. "But instead, what we're seeing is that most stars *do* have planets, and a lot of these planetary systems are very different from our solar system. Does that make the solar system unusual? We don't know yet. Despite our best instruments and technology, we're still only looking in our own little neighborhood of the galaxy.

"Luckily, I don't think we necessarily need to look at all the stars in the galaxy to know whether our solar system is unusual. And every time there's a new mission or a new instrument that can do something different or dramatically improve the quality of data, there's something surprising that keeps us excited."

Fabienne Bastien is assistant research professor of astronomy and astrophysics. Rebekah Dawson is assistant professor of astronomy and astrophysics. Eric Ford is professor of astronomy and astrophysics and director of the Center for Exoplanets and Habitable Worlds. Suvrath Mahadevan is associate professor of astronomy and astrophysics. The Center for Exoplanets and Habitable Worlds includes 18 faculty members and more than 20 graduate, undergraduate, and postdoctoral researchers.

STATE OF THE ART

Two new world-class spectrographic instruments will bring unprecedented precision to bear on the hunt for nearby Earth-like planets. Both were built at Penn State by teams led by Suvrath Mahadevan, associate professor of astronomy and astrophysics.

The **Habitable Zone Planet Finder** was designed specifically to discover habitable planets orbiting "M dwarfs," stars near our solar system that are smaller and fainter than our Sun. Most of the light that M dwarfs emit is in the infrared wavelengths of electromagnetic radiation—longer than the wavelengths human eyes can see.

The Planet Finder was installed in 2018 on the William P. Hobby–Robert E. Eberly Telescope in West Texas, a giant optical telescope whose innovative design was conceived by Penn State astronomers Lawrence Ramsey and Daniel Weedman in the 1980s. Equipped with a "laser frequency comb" developed by the National Institute of Standards and Technology to tease out individual wavelengths of light, the Planet Finder is expected to match or exceed the precision of any other existing infrared instrument.

"The Habitable Zone Planet Finder will allow us to detect the existence of planets that are similar in mass to Earth and that also are in orbits where liquid water can exist on their surfaces," Mahadevan says.

A sister instrument, called **NEID**, was recently delivered for installation on the WIYN Telescope at Kitt Peak National Observatory in Arizona. An echelle spectrograph like the Habitable Zone Planet Finder, NEID is designed to detect optical light—the kind that human eyes can see.

"This optical instrument is expected to be more precise than the Habitable Zone Planet Finder, since it needs to be so in order to find terrestrial planets around Sun-like stars," says project manager Fred Hearty, research professor in astronomy.

NEID was built with funding from NASA's Jet Propulsion Laboratory and Astrophysics Division. Its name means "to discover" or "to visualize" in the native language of the Tohono O'odham, on whose land Kitt Peak is built. The instrument is the centerpiece of a partnership between NASA and the National Science Foundation called the NASA-NSF Exoplanet Observational Research program (NN-EXPLORE).

— Barbara Kennedy

A longer version of this sidebar can be found at ***https://bit.ly/2uugjL4.***

Ethan Tweedie Photography

Hobby-Eberly Telescope

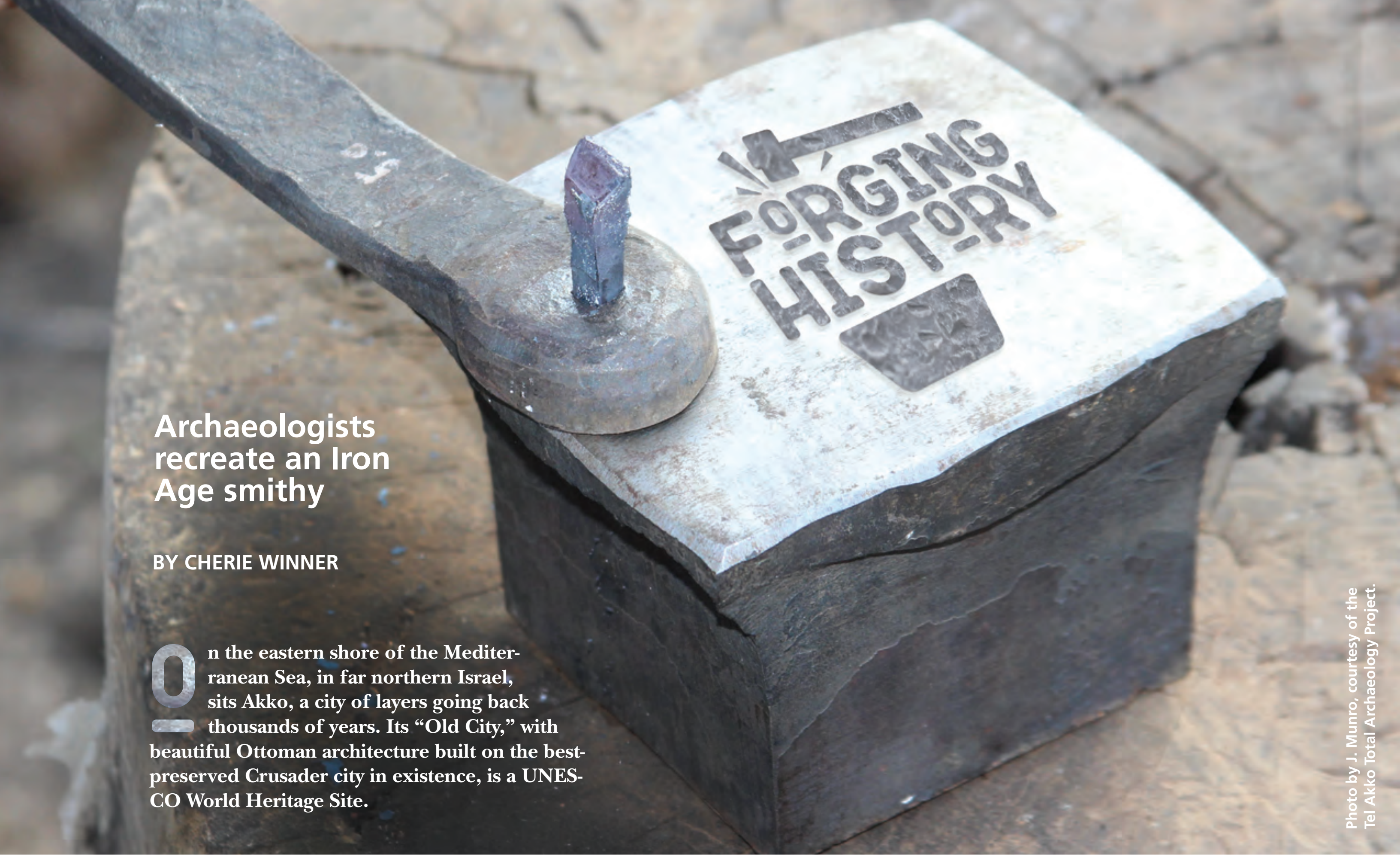


Photo by J. Munro, courtesy of the Tel Akko Total Archaeology Project.

Archaeologists recreate an Iron Age smithy

BY CHERIE WINNER

On the eastern shore of the Mediterranean Sea, in far northern Israel, sits Akko, a city of layers going back thousands of years. Its "Old City," with beautiful Ottoman architecture built on the best-preserved Crusader city in existence, is a UNESCO World Heritage Site.

Akko today gracefully blends old with new, eastern with western, religious with secular. Twenty-six religions are represented here; it is among the holiest sites in the Bahá'í and Sufi faiths. "It's a very spiritual and cosmic place," says Penn State archaeologist Ann Killebrew. "People who come here want to come back."

Some of those who come back time after time are archaeologists trying to understand the previous inhabitants, who included the biblical Canaanites and Phoenicians, by unearthing and examining what they left behind. Some explore the historic old town. Others, like Killebrew, work at Tel Akko, "the hill of Akko," a 60-80-foot-tall mound a mile east of the Old City.

Looking west, the view from above Tel Akko includes the Mediterranean Sea, the Old City (on the point of land at upper left), and the high-rises of modern Akko. The tel was in use for more than 3,000 years, spanning many regimes, environments, and cultures. The Persian period iron smithing area being excavated is just above the curved path in the foreground. Photo by Griffin Higher Photography, courtesy of the Tel Akko Total Archaeology Project.

Killebrew first worked here in the late 1970s, as a grad student on the first major dig at the site. "I fell in love with the place. It was my dream to come back," she says. In 2010, she did, as co-director of a new "Total Archaeology Project" that blends a field school, sciences such as archaeometallurgy and archaeobotany, survey work, excavation, conservation, and community outreach.

The next year, members of her team were digging at a depth corresponding to about 600-400 B.C., when the resident Phoenician culture was part of the Persian, or Achaemenid, Empire. They began turning up large amounts—hundreds of pounds—of iron slag. "We're not talking about producing for local people, we're talking about *industrial* production," says Killebrew. The more they looked, the more evidence of ironworking they found, including small pit hearths, the earth beneath them vitrified from intense heat. When the team ran a magnet over the loose dirt near a hearth, it came back bristling with hammerscales, tiny flakes that break off when red-hot iron is beaten during the forging process.

The harbor and Old City of Akko (also called Acre), a UNESCO World Heritage Site.

Getty Images/ Ruslan Dashinsky

Ann Killebrew, co-director of the Tel Akko Total Archeology Project, holds a magnet studded with iron hammerscales it picked up from a Persian period smithing hearth. Photo by J.C. Skinner, courtesy of the Tel Akko Total Archaeology Project.

Akko at that time was a major economic and administrative center for the Achaemenid Empire, which was engaged in a series of military campaigns against Egypt. It made sense that this hub of industrial activity might include ironworking, but proving that was not easy. Ancient iron work is hard to study. The few objects that have survived are usually so badly corroded there's little left to examine. Analytical methods have also been lacking.

"I call iron the poor stepchild of archaeometallurgy, because of the structure of the metals and the kinds of analysis you can do," says Killebrew. "Bronze you can source. Tin you can source. But until recently, iron was impossible to source."

Identifying where a metal was mined is crucial to understanding the political connections, trade routes, and transportation systems that moved the ore from the mine to where it was turned into useful objects and then to where those objects were used. For iron, that only became possible a few years ago, when scientists at the Curt-Engelhorn Center for Archaeometry in Mannheim, Germany, developed a technique to use osmium isotopes to match an iron sample to its source. Killebrew and her colleagues sent slag from Tel Akko to Mannheim and learned that despite the presence of iron ore within a few miles of the tel, much of the iron at their dig likely came from a major source near modern Ajloun, Jordan—more than 85 miles away. Further tests showed that the ore was probably smelted near Ajloun and the resulting iron ready for smithing carried to Akko.

"They knew exactly where to get the best iron," says Killebrew. "They were transporting it 85 miles or more. And it's heavy. It takes a great deal of infrastructure to organize something on this scale." That implied that the ironworks at Tel Akko were of importance to the Empire and probably under state control. But it didn't answer the question of whether the remnants of ironworking at the site really were evidence of large-scale production. Could the small pit hearths they'd found be used to forge tools and weapons?

In the summer of 2018, Killebrew's group did an experiment to find out. Archaeometallurgist Ümit Güder, of Canakkale Onsekiz Mart Universitesi in Turkey, spelled out their questions: What was the design of the forging hearths? How were they made? What fuel did the ancient smiths use? What was their air supply? Could these small, simple hearths generate enough heat to forge iron? What can be forged in this setting?

Penn State students excavating on Tel Akko in 2018. The site was industrial through much of its history, with abundant signs of skilled trades including bronze working and the production of pottery, glass, and "royal" purple dye. The discovery of massive amounts of slag suggested that ironworking could be added to that list. Photo by A.E. Killebrew, courtesy of the Tel Akko Total Archaeology Project.


FORGING HISTORY


1


4


2


5


3


6

HERE'S HOW THEIR EXPERIMENT WENT

1. The team made two pit hearths similar in size to those they had found on the site. The pits were ringed with stones, and each included a stone slab about a foot and a half tall, set upright at the pit's rim to confine the heat. Below the slab (not visible here), they placed a clay tuyère, or tube, to carry air from a bellows into the hearth. More tuyères, shaped of local clay, were set along the hearth to be fired for future use. Photo by L.G. Meiberg, courtesy of the Tel Akko Total Archaeology Project.

2. Traditional blacksmith Gökhan Bakla (left) and archaeometallurgist Ümit Güder used air bellows to fire the experimental hearth. Güder says the amount of smithing slag found at Tel Akko is the most he's ever seen in the region. Photo by L.G. Meiberg, courtesy of the Tel Akko Total Archaeology Project.

3. Archaeologists haven't yet determined what fuel was used by the original smiths 2,500 years ago. There probably was not enough wood nearby, but because the area around the tel was marshy then, reeds might have been used. The area around ancient Akko was home to large olive groves, so olive mash left over after pressing out the oil was a possibility. The researchers found, though, that it burned too hot and too fast. For this experiment, the group used charcoal. They also didn't have the same iron to start with, so they used lengths of iron rebar. Photo by J. Munro, courtesy of the Tel Akko Total Archaeology Project.

4. When Bakla judged the iron to be soft enough, he carried it to an anvil placed on a large tree stump, and used traditional tools such as hammer and tongs to produce small objects such as nails. He said the reconstructed hearth worked fine except for the lack of shade. "When they're heating the iron, they can tell by the color when it's ready to be worked, and shade helps them see the color," says Killebrew. Photo by J. Munro, courtesy of the Tel Akko Total Archaeology Project.

5. Using the replica hearths and traditional smithing tools, team members and blacksmith Bakla forged blades and nails like the one shown here by Penn State undergraduate Ian Seasholtz. Photo by J. Munro, courtesy of the Tel Akko Total Archaeology Project.

6. Tools and products of an ancient trade: tongs, anvil, and hammer (resting against the right side of the stump); and a small peg (at left) and blade (resting on the anvil) made with the replica hearth. Results of their experiment were unequivocal: These simple hearths *could* have produced iron objects on an industrial scale. Killebrew and Güder plan to recruit local blacksmiths to help with future tests of fuels and Ajloun-sourced iron. Photo by A.E. Killebrew, courtesy of the Tel Akko Total Archaeology Project.

Ann Killebrew is associate professor of classics and ancient Mediterranean studies, Jewish studies, and anthropology.

WHERE CURIOSITY LEADS

The search for a styrofoam replacement leads to biomaterials with broader impact

BY RACHEL GARMAN

Every scientific discovery has one thing in common: It started with a question. But, as materials scientist Jeffrey Catchmark will attest, sometimes the most ingenious answers come from questions you didn't even know to ask.

Catchmark is developing new biomaterials by manipulating compounds found in nature. His research with biomaterials began with a single question: Is there an eco-friendly alternative to styrofoam?

OPEN TO CHANGE

Catchmark didn't start his materials science career thinking he'd invent a potential replacement for styrofoam. He didn't even start out as a materials scientist. He earned a doctorate in electrical engineering and spent nearly ten years working on lasers and optics for telecommunications companies.

In 2000, he left industry, coming to Penn State to manage the Nanofabrication Laboratory. Soon after, he took an even more radical step, switching fields from electrical to biological engineering.

"As I've gotten older, I've learned to be more purposeful about how I spend my time," Catchmark says. "Looking at the work I was doing, I felt like I was a step removed from seeing any tangible impact my research could have on the world. Being a nature lover, I wanted to focus on ways my research could impact sustainability, and I couldn't do that by working on lasers."

He buried his nose in textbooks and attended conferences that, as he puts it, he "had no business being at as an electrical engineer." Fueled by curiosity and a lot of research, he thrived in the biological engineering community where he has spent the past 17 years.

UNEXPECTED DISCOVERIES

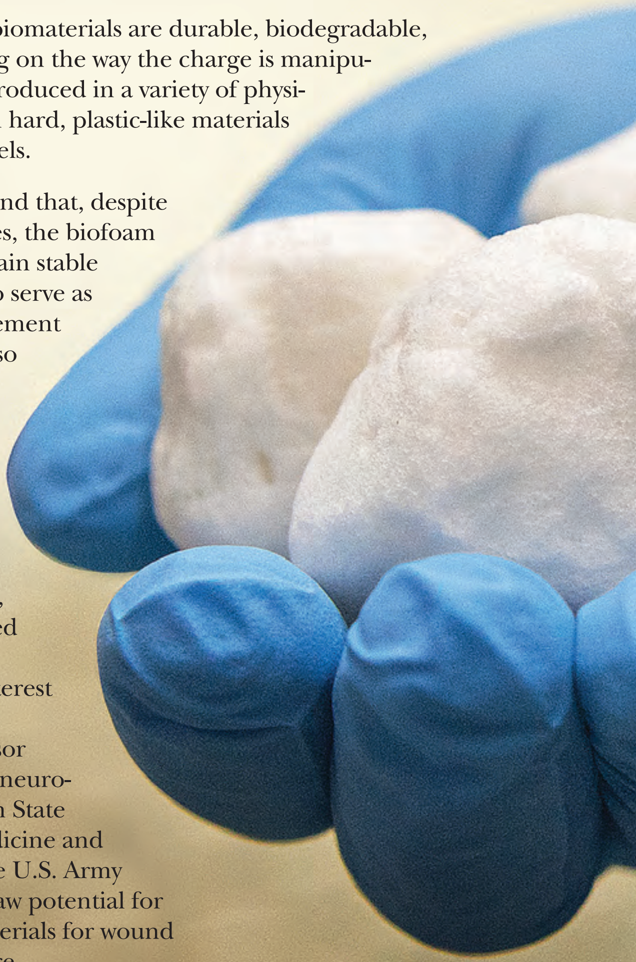
Now a professor of agricultural and biological engineering, Catchmark focuses much of his research on exploring how naturally-derived biomaterials might reduce the world's reliance on plastics.

"We were searching for a biomaterial that could compete with styrofoam from a materials standpoint—resilient, durable, and impermeable—while still being inexpensive to produce," he says.

He started by looking at polysaccharides—long chains of carbohydrates found in plants and animals. Catchmark zeroed in on celluloses, found in plant cell walls; starches, found in a variety of plant tissues; and chitin, found in the exoskeletons of shellfish and insects.

On their own, these polymers exhibit none of the properties Catchmark was looking for. But he and his team discovered that applying electrostatic charges to pairings of polysaccharides "locks" them together, similar to the way freshly-dried clothes stick to one another due to static cling.

The resulting biomaterials are durable, biodegradable, and, depending on the way the charge is manipulated, can be produced in a variety of physical forms, from hard, plastic-like materials to foams and gels.



Catchmark found that, despite these properties, the biofoam would not remain stable long enough to serve as a viable replacement for styrofoam, so he looked for other possible applications. While presenting his research at a materials science lecture, he was delighted to be met with enthusiastic interest from Dr. Scott Armen, professor of surgery and neurosurgery at Penn State College of Medicine and a colonel in the U.S. Army Reserve, who saw potential for using such materials for wound and trauma care.

(This page) Jeffrey Catchmark displays blocks of wound-healing foam. Like soft sponges, they can be compressed and put into a wound, where they will expand to fill the space.

(Facing page) Postdoc Kai Chi paints a compostable bowl with a fluid that, when dry, will form a barrier that keeps the bowl usable longer while keeping it biodegradable. Photos by Patrick Mansell

Traditional cotton bandages tend to stick as they're removed, sometimes reopening a wound. The biofoam Catchmark and Armen developed is flexible, durable, and can be molded to fit inside wounds like those caused by gunshots and shrapnel. As healing progresses, it transforms into a gel that slowly breaks down into glucose, which the body absorbs.

"This potential application wasn't expected," Catchmark says. "Through this discovery process, we've learned that despite what we thought we were looking for, what we ended up finding is something with much broader impact."

CREATING A SUSTAINABLE FUTURE

Catchmark's biomaterials could lead to eco-friendly products such as compostable food containers and replacements for the plastic microbeads in cosmetic products, which often end up in oceans, lakes, and rivers. "There's potential to remove tens of millions of tons of plastic from our waste stream," he says.

While he pursues that goal, Catchmark has begun following his curiosity down another unexpected path.

"It became apparent to me that work in sustainability is very often work in ethics," he says. "It is about identifying your values and acting on them." He's joined Penn State's Bioethics Program and Rock Ethics Institute, where he helps students incorporate their moral and ethical values into their scientific endeavors.

"One of the most rewarding experiences of my research is being able to translate scientific discovery into something that helps the world," he says. "I wouldn't have been able to get to that point without realizing one thing: Science is all about curiosity, and sometimes you have to follow it and see where it leads."

A TINY CLOT MOVES UP THROUGH THE CAROTID ARTERY, INTO A BRANCH THAT LEADS TO THE RIGHT HALF OF YOUR BRAIN. The vessel narrows and branches again; the clot snags on the vessel wall, blocking the flow of blood to parts of the right cerebral cortex. Stroke.

By the time doctors dissolve the clot and restore circulation to that part of your brain, thousands of nerve cells will have died. The functions they controlled, such as movement of the left arm and hand, will be severely impaired, perhaps forever. Within days, you will start getting occupational therapy to help your clenched left hand relax and regain what function it can, and to learn how to do routine tasks like dressing yourself with just your healthy right hand.

That's been the standard therapeutic approach for decades, but it misses something important, says Penn State neuroscientist Bob Sainburg. Your right hand, the one on the same side as the brain damage, is not quite normal. It's a little clumsy, a bit off in its movements. Compared with the left, it is your "good" hand, says Sainburg. "But it's a *bad* good hand."

Stencil painting of ancient hands, Cave of the Hands, Argentina. © 2010 Javier Etcheverry Photography.

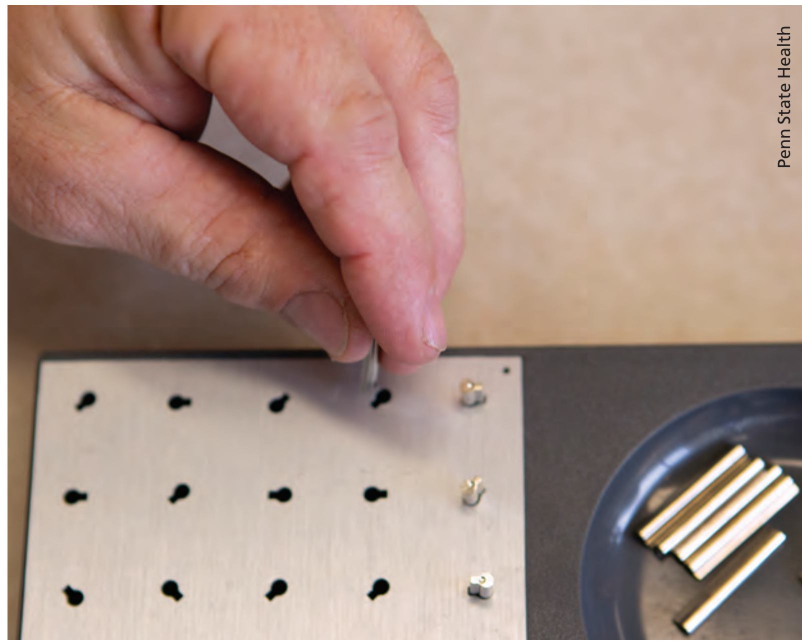
When it comes to therapy for stroke victims, sometimes treating the wrong hand is exactly right.

THE OTHER HAND

by Cherie Winner

Professor of kinesiology and neurology Robert Sainburg at his lab at Penn State Health in Hershey. Also an occupational therapist, Sainburg is organizing a group of early-career OT researchers to raise awareness of how basic neuroscience can inform OT practice.

Occupational therapy for people who have had a stroke includes exercises handling everyday objects, such as picking up cups and placing them in the appropriate stacks based on color.



Even more challenging is the task of putting small, flanged pegs into holes.

NOT JUST A NEUROSCIENTIST

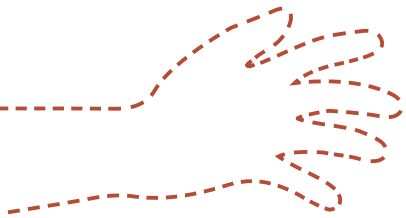
Sainburg wasn't the first person to note that the "good" hand of stroke patients often doesn't move well, but he was the first to try to answer the million-dollar question: If each hand is controlled by the opposite side of the brain, as clinicians believed, why is a stroke patient's "good" hand often so bad at certain tasks?

He comes at the question from an unusual perspective. He's not just a neuroscientist; he's also an occupational therapist (OT), adept at evaluating movement and devising ways to improve it. Starting out in the 1980s as a pediatric OT, "I worked with a lot of kids with cerebral palsy," he says. "Just like with stroke, you feel a bit powerless in terms of how to facilitate better movement. Brain damage is very resistant to recovery. And so I was very frustrated."

He soon found he could not keep doing the standard therapies, which sometimes helped the kids but were not based on a deep understanding of how the brain controls movement. "Some therapists are comfortable at that level," he says. "I wasn't. I needed to understand the mechanisms before starting to do an intervention."

Sainburg returned to grad school to study the basic neurobiology of motor control. After finishing his Ph.D. and post-doctoral training, he began to focus on handedness, the different abilities of the left and right hands. He reasoned that if the greater skill of a person's dominant hand is not simply due to practice—if it stems from differences in the two sides of the brain—then handedness might offer a window into how the brain controls movement. He began by exploring the possibility that motor control in people is *lateralized.*

"Lateralization means one side of your brain does things that the other side doesn't," he says. "Where it really stands out is with language. If you have a lesion in specific areas on the *left* side of your brain, you will have an aphasia, which means you can't call up words and phrases, and you can't figure out the sequence of words.



WHY LATERALIZE?

Why are our systems made this way? Why not have both sides equally capable of performing every function? Sainburg thinks there's a strong evolutionary advantage to segregating the functions. In experiments with the Kinereach, healthy participants took about twice as long to initiate a task when they were given the option of using either hand than when they were told which hand to use. "In evolutionarily important conditions, that extra time could really matter," he says. "I think it's a huge advantage to not have to make decisions about which hand to use. If you can have some asymmetry, so that certain tasks automatically go to one side and others automatically go to the other side, maybe that's more advantageous than we tend to think."

If you have a lesion in specific areas of the *right* hemisphere, then you will be able to get words, you will be able to put them in the right sequence, but you won't be able to interpret and express non-verbal aspects of language." For example, you wouldn't be able to tell the difference between a polite request to "Come here" and an angry demand to "COME HERE!"

There was reason to think the neural control of movement might show a similar kind of segregation. At the time, researchers elsewhere were discovering that many motor behaviors are lateralized in a variety of animals. Chickens tend to keep a lookout for predators with the left eye and search the ground for edible tidbits with the right. Schooling fish tend to dart to the right to flee danger, and tend to be better at detecting danger coming from their left.

LEFT BRAIN, RIGHT BRAIN

Sainburg set out to learn exactly what each hand does well and not so well. He invented a virtual-reality apparatus, now called the Kinereach, to test the ability of each hand to do tasks requiring specific skills. A shuffleboard game in which a hand makes a cursor strike a digital puck toward a target tests that hand's ability to aim a movement and use the necessary speed and force. A reaching game in which the hand encounters resistance along the way tests how well the hand adapts to changing conditions in the environment. Sensors on the arm and hand record the movements, and Sainburg developed software that lets him analyze each movement in detail.

All the participants in his studies were healthy, and they were all right-handed; lefties comprise only about 10 percent of the population, making it hard to find enough for a study. More importantly, they have been shown to be very different from one another in terms of differences in right-and left-hand coordination. Because of this, lefties are not a good group for studies on how the brain is lateralized for motor control.

After dozens of experiments, a clear picture began to emerge: The left hand is just as adept as the dominant right hand, but at different things. The right hand is good at aiming a movement accurately and executing it efficiently, but it doesn't adapt well to changing conditions. The left hand is not as good at the initial aim, but is very good at countering outside forces, responding to changes in stiffness or friction, and homing in on a target accurately.

It looked like the motor centers on the two sides of the brain have different command responsibilities. The right hemisphere stabilizes the hand and enables it to adapt to changing conditions, and the left hemisphere directs efficient, precise movements. Each hand is controlled primarily by the opposite side of the brain, but the division of labor is not complete. Each hand has some ability to do what the other is expert at, suggesting that both hands receive guidance from both sides of the brain.

To really nail that down, Sainburg needed a way to test the hands of people who had lost function in motor-related areas on one side. That's what led him to work with stroke patients.

He recruited volunteers who had suffered an ischemic (blood clot) stroke in one side of the brain and now had severe disability of the opposite arm and hand. He tested how well their other hand, the "good" hand, did at various tasks. Conventional wisdom said the good hand would be unaffected by the stroke, but Sainburg's results showed otherwise. In patients with right-brain damage, their right hand did badly on tests of how accurately it could stabilize at the end of a reaching movement ("badly" meaning substantially worse than in subjects who had not had a stroke). In patients with left-brain damage, the left hand did badly on tests of how well it initiated a movement and set a trajectory.

In other words, damage on one side of the brain did affect the hand on the same side, depriving it of guidance needed for well-coordinated movement. Since a lesion in one side of the brain affected both hands, each side of the brain must normally provide information and instruction to both hands, not only the hand on the opposite side of the body.

Getty Images/ Buenaventuramariano

Penn State Health

Sainburg's lab manager, Candice Maenza, helps volunteer Mike Boyer settle into his seat at the Kinereach before he demonstrates how the apparatus works. Several years ago, Boyer had a stroke on the left side of his brain, leaving his right hand with minimal function. In Sainburg's earlier AHA study, Boyer received training of his "good" left hand, therapy he said was the best he'd had since the stroke.

THE RESISTANCE IS STRONG

To Sainburg, the potential of applying this new knowledge to therapy situations was obvious: The "good" hand might benefit from therapy to try to recover what it lost due to the stroke.

That conclusion was not so obvious to others, however. The dogma that each hand was controlled exclusively by the opposite side of the brain was firmly entrenched, and the clumsiness of the "good" hand had always been chalked up to stress or fatigue or some other general reaction to the stroke. Sainburg's earlier work on handedness had been well received, but when he started presenting his work on the "other" hand of stroke patients, he got a very different response.

"It's the wrong hand, Bob!" he laughs, dropping into the broad English accent of the hapless Wallace of *Wallace & Gromit*, the stop-action show about a man and his dog. "I keep thinking of the line, 'It's the wrong trousers, Gromit!' For me it was 'It's the wrong hand, Bob!'"

He heard that refrain for years, at professional meetings, from colleagues, even from friends. The interactions often became heated. "I had to go to a lot more conferences, trying to get our story out there to clinical scientists so they would see that this is not crazy," says Sainburg. "We are absolutely not suggesting that therapists ignore the 'bad' hand, but that they include testing the motor abilities of the 'good' hand into their assessments, and include treatment of this hand if it is indicated."

TREATING THE WRONG HAND

Finally, in 2015, Sainburg was awarded a grant by the American Heart Association to do a pilot study to test his ideas about doing therapy with the "good" hand of stroke patients. The grant did not come easy.

"We put in the proposal for just a little bit of money, enough to get patients in and test this," he recalls. "And they said, 'It's the wrong hand.' So we sent back a revision and said, 'We know it's the wrong hand, but here's why.' And they gave it to us."

In that study, 15 patients whose "good" hand showed substantial deficits in coordination were given training for that hand for an hour and a half, three times a week. They worked with the Kinereach, focusing on the specific skills the hand was having trouble with, and did standard exercises to improve skills like stacking cups, clipping a clothespin to a line, tracing shapes, and throwing and catching a ball. After only three weeks, the patients scored 20 percent higher on standard tests of hand function. Even better, they all reported improvements in their ability to do daily tasks—with the fringe benefit of becoming more active in general.

"One patient said, 'My wife doesn't have to come in the bathroom and help me in the morning,'" says Sainburg, "He's leaning down and putting his socks on with his good hand, he's getting up and getting his lunch, instead of sitting on the couch and letting his wife do it for him. Which, as you can imagine, is a massive, life-altering thing for her *and* him."

With those encouraging results, Sainburg, along with Carolee Winstein at the University of Southern California, won funding from the National Institutes of Health for more detailed and extensive studies. In the first experiment, which started in January, patients will receive training of their "good" hand for five weeks, to see if they will improve in functional independence and activities of daily living more than control participants who receive traditional therapy focused on the "bad" hand. Patients will be tested before and shortly after the training period and again four months later, to see if progress they made during training is maintained. Sainburg and Winstein will also do scans of each patient's brain and spinal nerve tracts before and after the training, to look for changes that might be related to the therapy.

Getty Images/ Buenaventuramariano

REMEMBER THE SHOW *WALLACE & GROMIT*? I KEEP THINKING OF THE LINE, "IT'S THE WRONG TROUSERS, GROMIT!" FOR ME IT WAS "IT'S THE WRONG HAND, BOB!" **—Bob Sainburg**

In one exercise at the Kinereach, Boyer sees a virtual-reality game projected onto a reflective surface just below his face. In this game, the patient would be asked to trace a shape projected onto the mirror.

Boyer's "good" arm and hand—secured to a mouse-like cursor control and sensors that track their movements—move in the space below the surface where the game appears.

The results from this study will help Sainburg design future experiments to refine the treatment protocols. He hopes to develop specific recommendations so that, in addition to therapy for the "bad" hand they do now, therapists will also test the "good" hand and do appropriate training of that hand where it's needed.

ACCEPTANCE

After so many years of being told he was working with the wrong hand, Sainburg is enjoying the sense that his hypothesis about motor control and handedness is being taken seriously. "It's not like it's *accepted*, but it's accepted *enough* that we can pursue it more," he says.

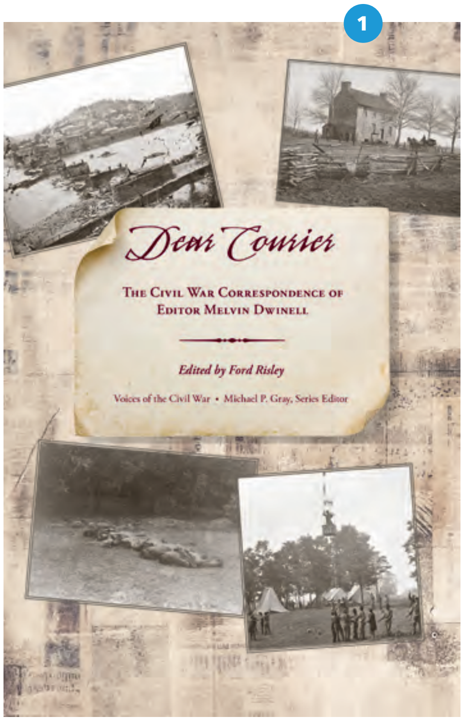
Sainburg is delighted, and more than a little surprised, to find himself back in OT mode after years in fundamental neuroscience. That wasn't his goal at the outset. He just wanted to know more about how the brain controls movement.

"I knew it was important to understand these mechanisms, but I didn't know that it was going to be directly applicable," he says. "And I certainly didn't think that *we* were going to do that application. It's pretty satisfying. It's pretty fun."

He's also come to a new understanding of the battle he went through to get to this point.

"When I was younger, I thought that resistance is a bad thing, that people just don't want to accept new ideas," he says. "And then I realized it's a good thing. It's a filtering system. I think if you didn't have that, you'd have people in science jumping down rabbit holes at too high a frequency. It's frustrating when people don't believe you, but at the same time, why should they believe you? You really have to show evidence, evidence, evidence, before people start to change their minds."

1



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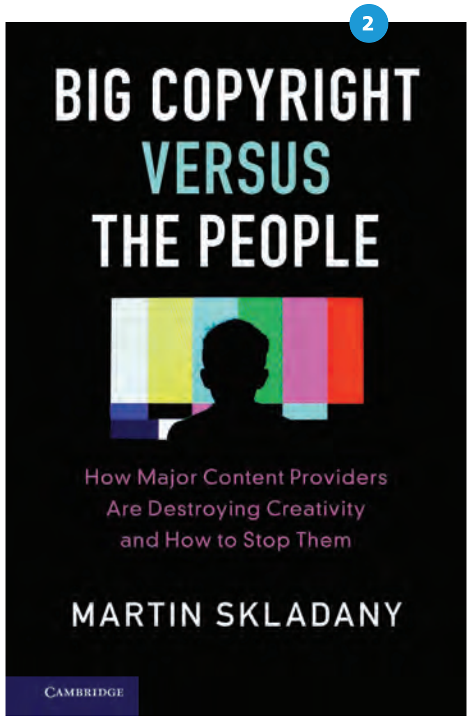

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BOOKS BY PENN STATE FACULTY

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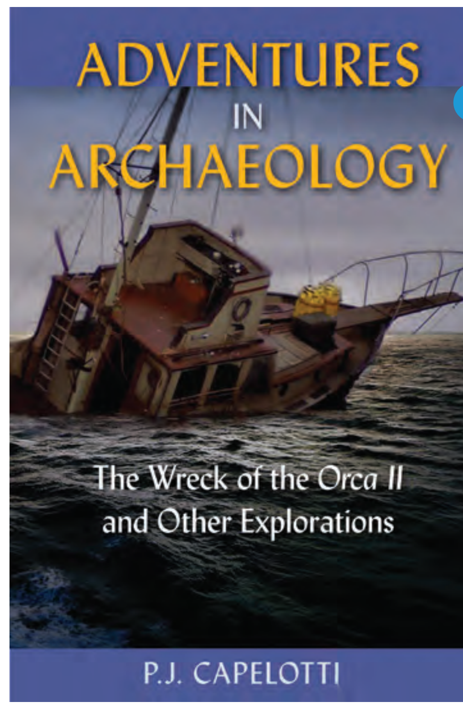

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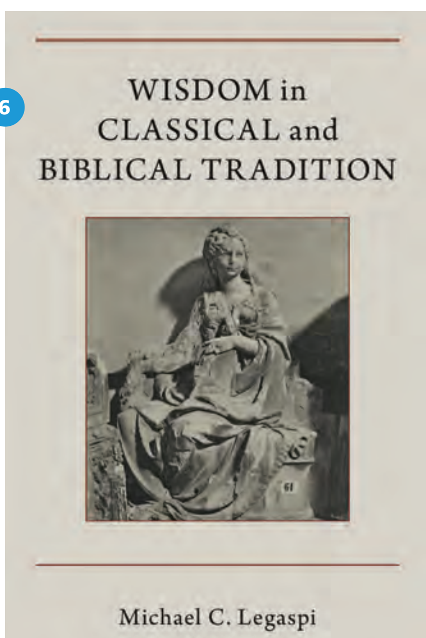

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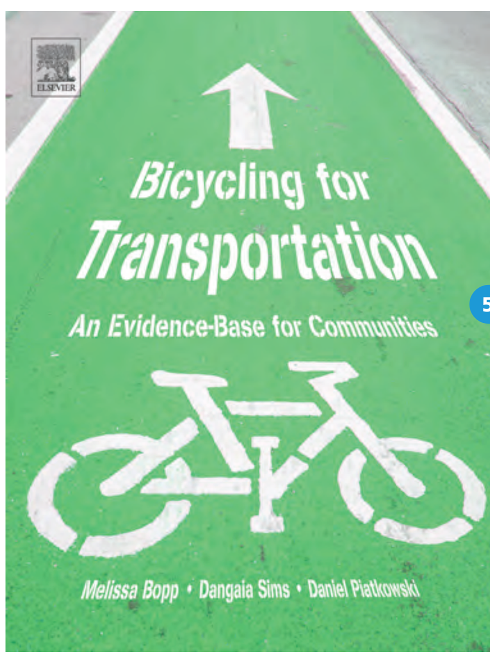


FOR MORE BOOKS:

This list is not exhaustive. For more books by Penn State faculty, visit a Penn State campus bookstore or ask your local librarian.

1

DEAR COURIER: The Civil War Correspondence of Editor Melvin Dwinell

edited by Ford Risley, professor of journalism

Among the many extant volumes of Civil War correspondence penned by military men, few can boast the writing quality of this one, part of the Voices of the Civil War series published by the University of Tennessee Press. Dwinell, a Yankee-turned-Rebel, was both fighter and journalist: second lieutenant of the Rome Light Guards and editor of the *Rome (Georgia) Courier*. Born in Vermont, he moved to the South and was won over to its way of life. Though he initially opposed Georgia's immediate secession, Dwinell fully supported his adopted state's cause. At the outbreak of the war, he joined the Eighth Georgia Infantry and began an almost weekly correspondence published in his newspaper. His letters provide vivid descriptions of some of the war's most important campaigns. Scholars have drawn upon Dwinell's accounts because of the author's grasp of strategy, strong writing skills, and journalistic instincts.

2

BIG COPYRIGHT VERSUS THE PEOPLE: How Major Content Providers Are Destroying Creativity and How to Stop Them

by Martin Skladany, associate professor of law, Dickinson Law

When the idea of copyright was enshrined in the Constitution, it was intended to induce citizens to create. Today, however, copyright has morphed into a system that protects mainly a small number of major corporate content providers, a group the author dubs "Big Copyright." This has turned us from a country of creators into one of consumers who spend, on average, ten hours each day on entertainment. In this alarming and illuminating book published by Cambridge University Press, Martin Skladany examines how Big Copyright got such a lethal grip on our culture, shows how it is unraveling important threads—of family, friendship, and community—in our society, and offers a treasury of ideas, some down-to-earth and some absolutely mind-expanding, about how to keep Big Copyright in check and open up more space for creativity in our daily lives.

3

REPORT FROM A PLACE OF BURNING

by George Looney, Distinguished Professor of English and Creative Writing, Penn State Behrend

It's summer in a small Midwestern city, and babies are burning to death in their cribs. A number of theories are presented by the six narrators of the novel, but the truth is elusive. In exquisite and precise language, author George Looney unspools a host of secrets that culminate in a haunting and moving whole. With vivid, often dreamlike, imagery, he invites the reader to experience these accumulating revelations, casting a spell as much as offering a tale. A defunct Heinz factory with the acrid smell of vinegar lingering in the air is the perfect surreal setting for this bleak (and, at times, humorous) narrative in which it is up to the reader to discover the truth, since one of the underlying issues of the novel is the difference between knowing and believing. Published by Leapfrog Press.

4

ADVENTURES IN ARCHAEOLOGY: The Wreck of the Orca II and Other Explorations

by P.J. Capelotti, professor of anthropology, Penn State Abington

Remnants of the curious and peculiar ways humankind has marked the archaeological landscape are abundant but often ignored: wrecked aircraft, abandoned airfields, old highway billboards, derelict boats, movie props, and deserted mining operations. In this book, published by the University Press of Florida, archaeologist P.J. Capelotti explores places and things not typically thought of as archaeological sites and artifacts, introducing readers to the most extreme fieldwork taking place today. Capelotti shows that even seemingly ordinary objects from the recent past hold secrets about the cultural history of humans. And he doesn't stop at the limits of the planet, discussing debris in space and equipment left on the Moon. He explains how the unusual sites of shorelines, sea, air, and space represent the farthest reaches of human civilization. His enthusiasm may inspire readers to set out on their own to investigate the secret meanings of treasures hiding in plain sight.

5

BICYCLING FOR TRANSPORTATION: An Evidence-Base for Communities

by Melissa Bopp, associate professor of kinesiology, Dangaia Sims, and Daniel Piatkowski

Bicycling for Transportation examines individual and societal factors that influence transportation choices and biking behavior. Through case studies, it examines the variability in biking participation among different demographic groups and the multiple sources of influence on biking. The book, published by Elsevier, aims to inform researchers and practitioners on the effective use of community resources and for public health professionals trying to encourage physical activity through biking. It also makes the case for new infrastructure that supports such initiatives and provides evidence-based insights on cost-effective approaches to increasing bicycle ridership.

With chapters on why we bike and why we don't, institutional and community strategies to promote biking, the benefits and risks of bicycling for transportation, and more, this book will be useful for urban planners, public health practitioners, community organizers, and anyone interested in using their bike to get around.

6

WISDOM IN CLASSICAL AND BIBLICAL TRADITION

by Michael C. Legaspi, associate professor of classics and ancient Mediterranean studies

Wisdom in Classical and Biblical Tradition, published by Oxford University Press, begins with the recognition that modern culture emerged from a synthesis of the legacies of ancient Greek civilization and the theological perspectives of the Jewish and Christian scriptures. Part of what made this synthesis possible was a shared outlook: a common aspiration toward wholeness of understanding which featured prominently in both classical and biblical literatures as an ultimate good. In this book, Michael Legaspi seeks to explain in formal terms what wisdom is. Though wisdom involves matters of practical judgment affecting the life of the individual and the community, it has also been identified with an understanding of the world and of the ultimate realities that give meaning to human thought and action. His second aim is to analyze texts that have shaped the traditional understanding of wisdom, and in doing so, to explain why the search for wisdom remains an important but problematic endeavor today.

In June, Vice President for Research Neil Sharkey will retire after almost six years at the helm of Penn State's research enterprise. Under Sharkey's leadership, research expenditures reached an all-time high of $927 million in 2017-18. Among his accomplishments, Sharkey has been instrumental in expanding and improving upon the University's research infrastructure as well as the development of the Invent Penn State initiative, which has led to the creation of 21 innovation hubs at Penn State campus communities statewide. Sharkey recently sat down with David Pacchioli to look back on his tenure.

WHAT SETS PENN STATE APART, IN YOUR EYES?

We've got one of the best, if not the best, collaborative research enterprises in the nation. The institute model, established by my predecessors, has really served to make us a place where people think collaboratively from the get-go. It has rendered a culture that is really equipped to deal with big problems that require trans-disciplinary thinking. It's also a can-do culture, a land-grant culture, that's sort of ingrained in everything Penn State does.

Another thing that sets Penn State apart is the Applied Research Lab. The magnitude of Penn State's contributions to naval defense is just remarkable. It's kind of a well-kept secret.

WHAT ACCOMPLISHMENTS ARE YOU MOST PROUD OF?

I'm proud of the steep incline over the last couple of years in our research expenditures. We're on our way to a billion dollars a year. That's a credit to our faculty.

The whole entrepreneurial thrust is another point of pride. I think Invent Penn State has exceeded anyone's expectations. It's been wildly successful, and it started from nothing, really. It's amazing what you can do when you've got a president out front, stirring things up!

I'm personally proud to have brought more recognition and prestige to research in areas beyond the classic STEM disciplines. Social and behavioral science has been elevated, and is doing really well on this campus. The same goes for the arts and humanities.

WHAT ARE SOME NEXT STEPS FOR YOUR SUCCESSOR?

A biomedical research institute here at University Park is a major priority. A lot of work has been done toward this, and it's getting close to fruition. And we now have the infrastructure in place to grow our collaborations with industry. That's something that's been on my mind since I walked in the door. I like to think that with a couple more wins we'll hit a critical mass and it'll start to get easier.

WHAT ARE YOUR THOUGHTS ON THE FUNDING LANDSCAPE, PARTICULARLY AT THE FEDERAL LEVEL?

Right now there seems to be a lot of enthusiasm on both sides of the aisle for investment in R&D, but I worry about how sustainable that is. I worry that more and more of the funding for R&D comes from higher-ed institutions themselves. These are things that people are going to have to grapple with in order for the U.S. to maintain a healthy national R&D enterprise. And it's imperative that we do, or we will lose our global position. We're not the big giant all alone out in front anymore.

AND ON PENN STATE'S ROLE AS AN ECONOMIC ENGINE FOR THE COMMONWEALTH?

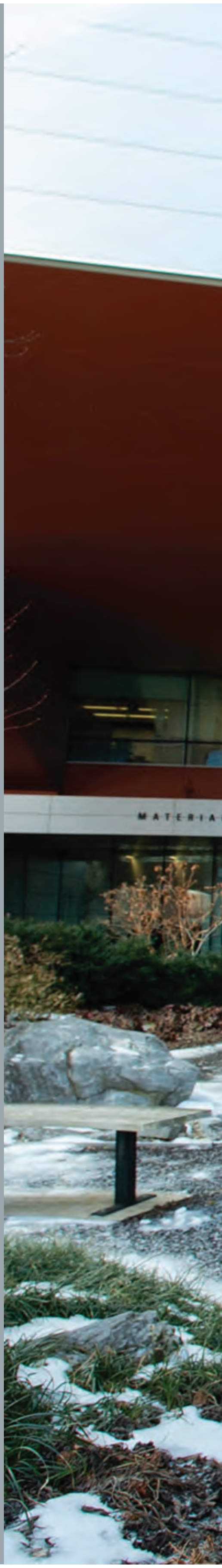
We have a huge economic impact just by virtue of our size and employment numbers. But we're also creating new jobs. Our undergrads are standing up new businesses through Invent Penn State, and our postdocs and grad students are doing so by developing the high-end IP that comes out of our federal awards. The trick is to keep these job creators here in Pennsylvania, provide the environment they need for success.

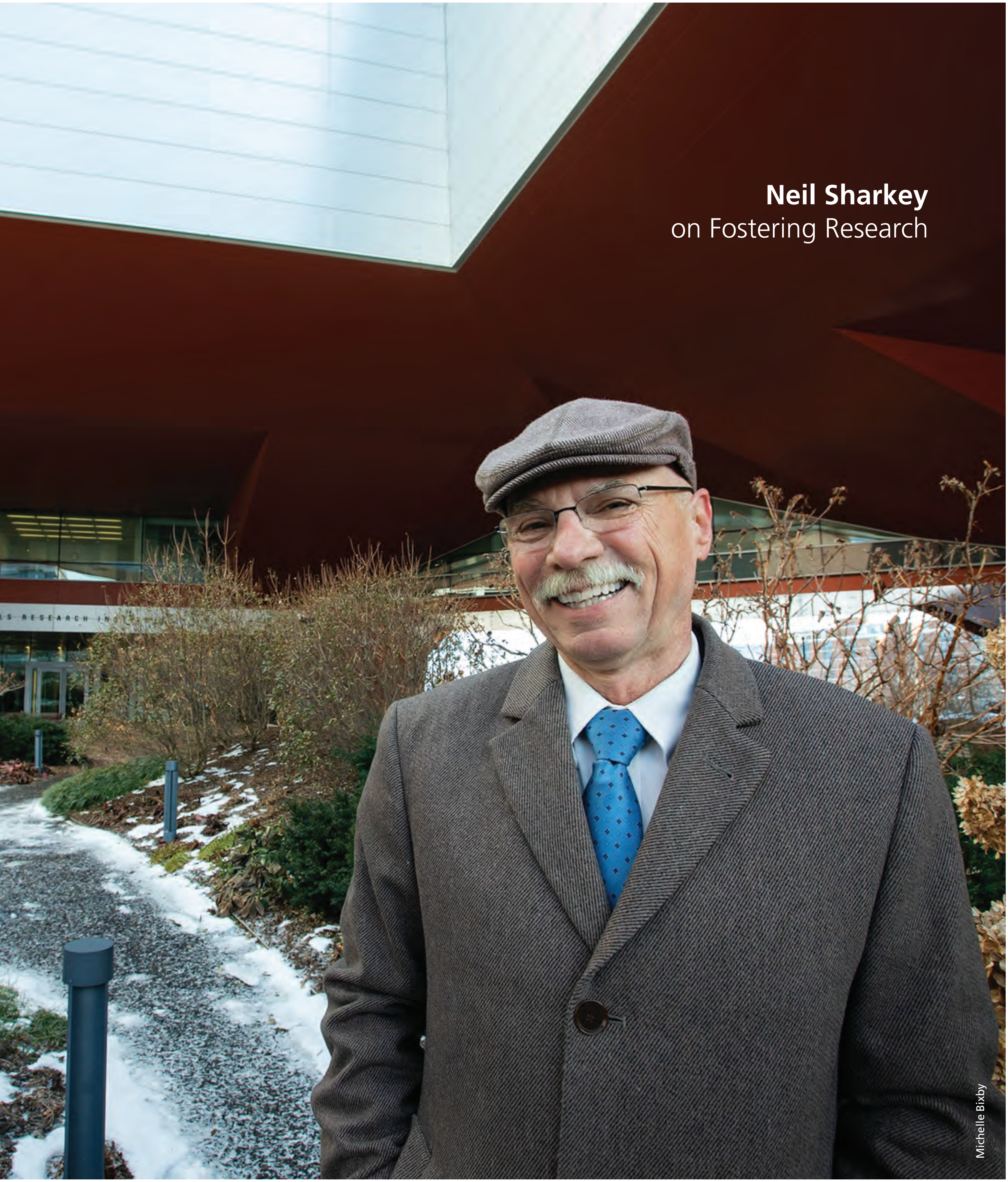
WHAT ADVICE WOULD YOU GIVE YOUR SUCCESSOR?

Take your time. Look around. Don't fix what ain't broken. Fill in those gaps where we should be, like biomedical research, but not at the expense of what we already do well. Listen. That's probably my number one piece of advice. Recognize that you're not always the smartest person in the room.

WHAT HAVE YOU ENJOYED THE MOST?

It's been such a privilege to be able to talk to some of the world's best researchers, across all domains, on a regular basis. It has made me really proud to be at Penn State, and made me realize the scope of Penn State's contributions to science and to humankind. I know that sounds corny, but it really is true.




Neil Sharkey
on Fostering Research
Michelle Bixby

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PennState

The Other Hand

In right-handers, the left hand is just as adept as the right hand, but at different things. When cutting a bagel, the right hand is good at wielding the knife and the left hand is good at holding the bagel still. Read how studies of handedness led to a new approach to therapy for stroke patients.

SEE PAGE 28

Patrick Mansell