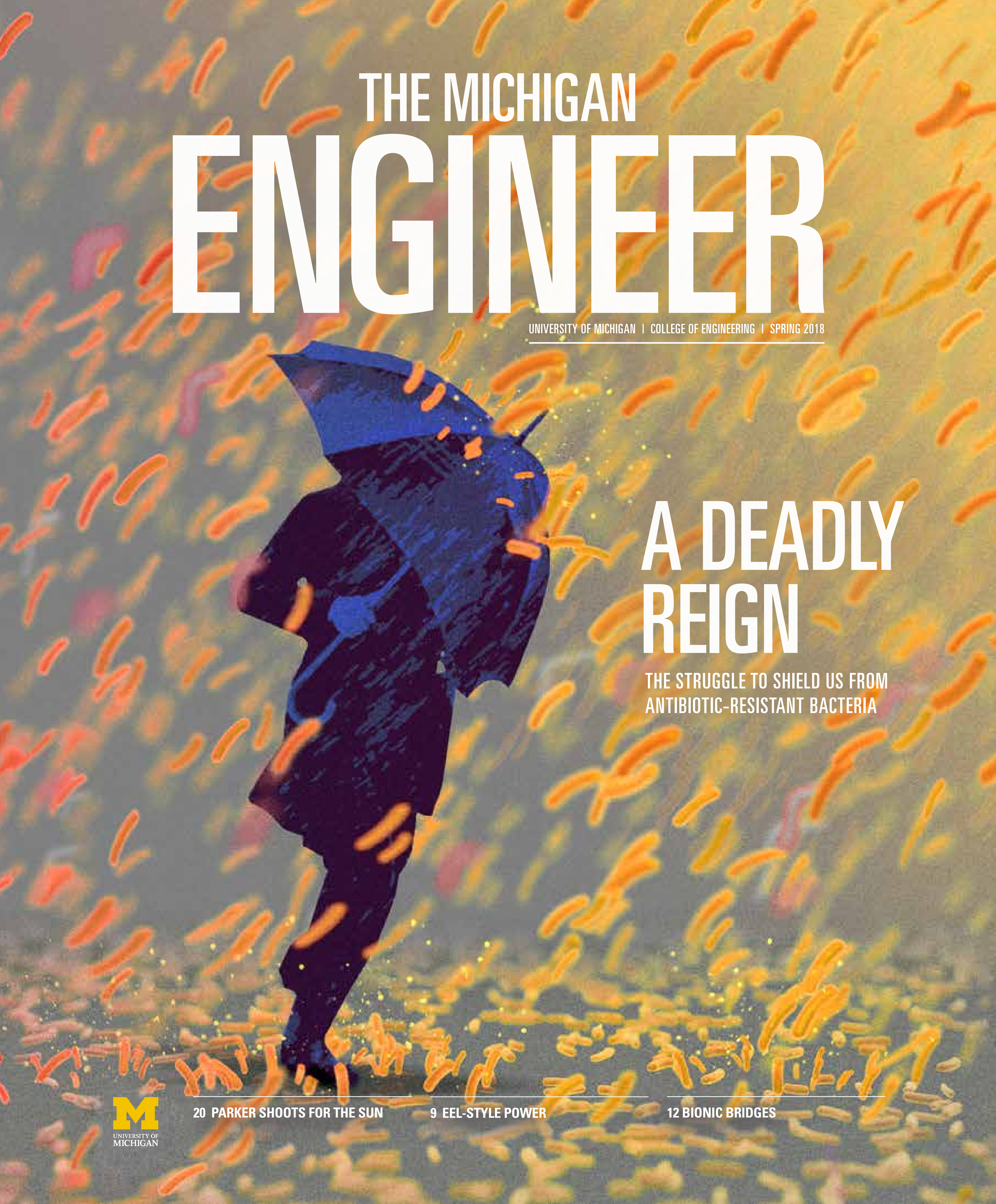

THE MICHIGAN ENGINEER

UNIVERSITY OF MICHIGAN | COLLEGE OF ENGINEERING | SPRING 2018

A DEADLY REIGN

THE STRUGGLE TO SHIELD US FROM ANTIBIOTIC-RESISTANT BACTERIA

UNIVERSITY OF MICHIGAN

700 CLICKS TO ADELAIDE
Novum, the U-M solar car team's newest solar-powered electric vehicle, races through the Australian outback during last October's Bridgestone World Solar Challenge, a 3,000-kilometer race from Darwin to Adelaide. Novum is a drastic departure from conventional solar car design; it delivered a second-place finish in the race, the U-M team's best-ever results. Learn more about Novum's radical design on page 11.

PHOTO: Evan Dougherty

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Talking physics, space and Ohio State with Nobel laureate Samuel Ting

PHOTO: Jan Collsioo/Pressens Bild AB, courtesy AIP Emilio Segrè Visual Archives, Gift of Eleanor Dahl

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UNIVERSITY OF MICHIGAN

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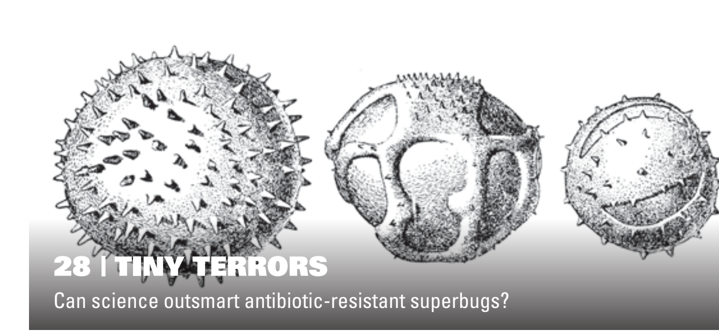

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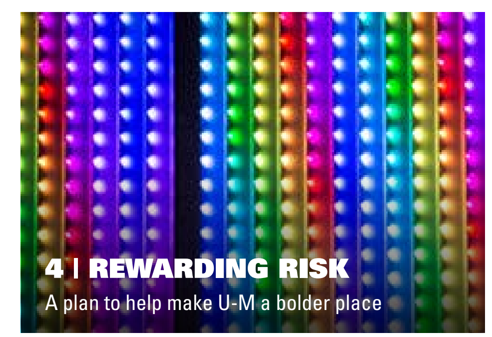

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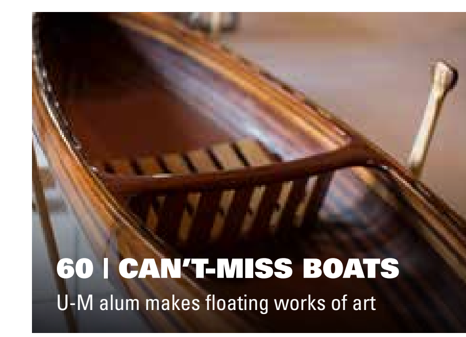

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U-M alum makes floating works of art

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Cover illustration: Stephen Alvey

ACCELERATING BOLDER IDEAS

A novel funding program enables aggressive research exploration

Michigan Engineering has set its sights on enhancing its culture of creativity, innovation and daring, and is implementing a unique approach to investing in faculty research as a key part of the plan.

Three new funding programs, enacted as part of the research pillar in the Michigan Engineering 2020 strategic plan (see p. 16 for details), will enable researchers to explore the boundaries of creative thought and risk-taking.

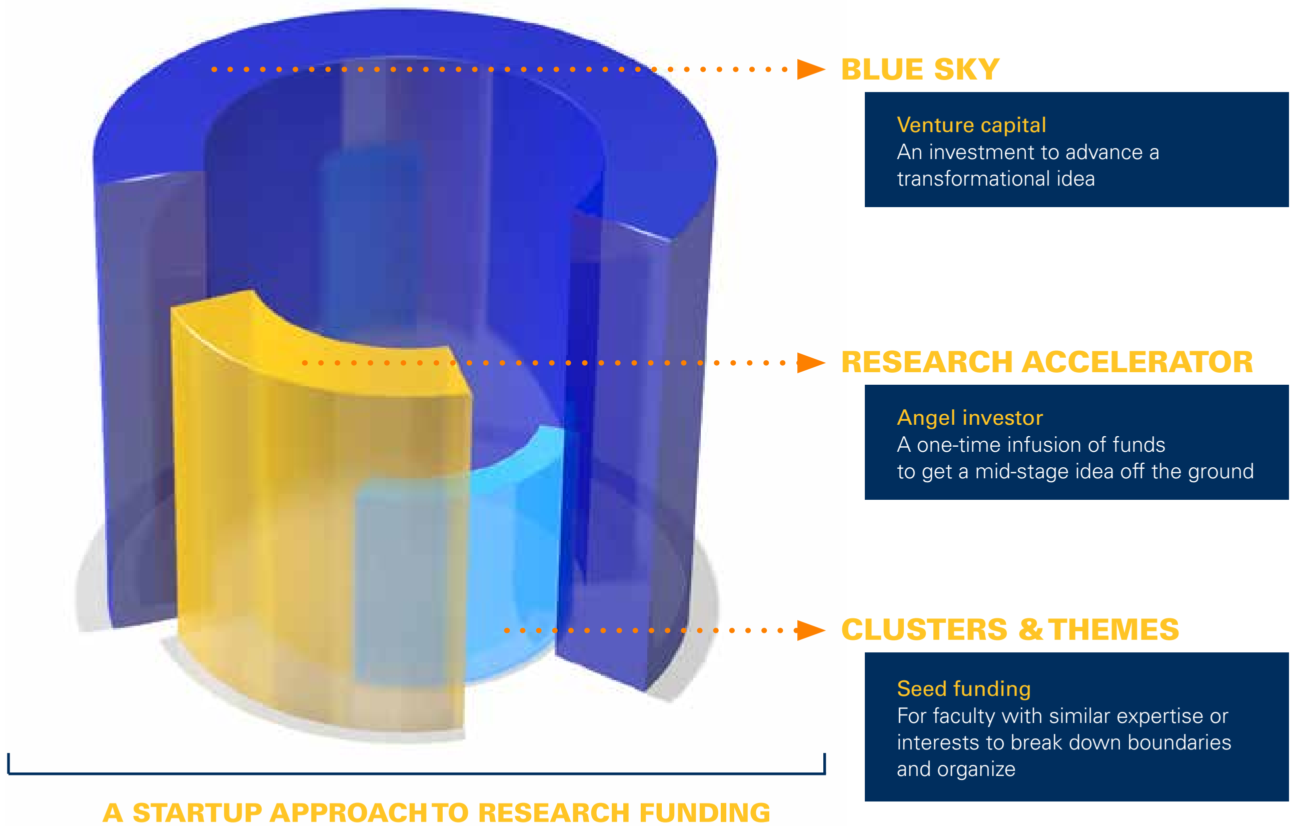
The programs draw inspiration from entrepreneurial funding models, introducing three separate funding options that are analogous to early-, mid-, and late-stage funding for a startup business. However, the analogy is not one-to-one – commercial viability is not the main or only goal. Instead, it is about engaging in bold research.

"We're doing this to catalyze and incentivize faculty – especially teams of faculty – to pursue high-risk, high-impact ideas," said Steve Ceccio, associate dean for research and Vincent T. and Gloria M. Gorguze Professor of Engineering. "Our hope is that these new funding mechanisms will give faculty the freedom to be more daring in pursuing new research ideas that are not yet ready for more traditional research funding agencies."

The program builds on the existing success for funding research at Michigan Engineering. Faculty are already accomplished researchers and are good at attracting funding for their projects. These initiatives leverage this track record of success to broaden and define areas of scientific and technological leadership, creating incentives for teams to form, and acknowledging and supporting the resources required to pursue transformational ideas.

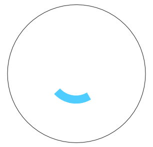
"The intent is to reinforce and expand our research excellence and the capabilities of our faculty, better positioning teams to secure support from external partners," said Alec D. Gallimore, the Robert J. Vlasic Dean of Engineering. "We aim to help foster an ecosystem that celebrates bold thinking, embraces noble failures and engenders intellectual curiosity. I am excited to see what happens when we open new doors for our faculty to explore."

Gallimore is also an Arthur F. Thurnau Professor, and the Richard F. and Eleanor A. Towner Professor of Engineering.



A STARTUP APPROACH TO RESEARCH FUNDING

CLUSTERS & THEMES UP TO $25K

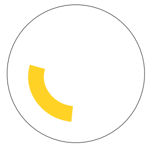


These seed investments are meant to kickstart an idea that is earlier-stage or has not yet taken definite shape.

A **cluster** is a group of faculty with related expertise. For example, a dozen researchers working in microfluidics across campus could organize to buy a piece of equipment or hire someone to run a joint lab.

Themes form when faculty with similar research interests – but different expertise – join to tackle a problem. This could be sorting cancer cells or reducing carbon emissions. Funds could be used to organize a workshop or conference, or to hire a student to help the group work together.

RESEARCH ACCELERATOR UP TO $250K



Faculty can apply to the Research Accelerator for a one-time investment of funds to advance an idea. It is similar to angel investors or accelerators in a startup funding model in that it provides a jumpstart.

This is a good option for faculty when they require resources to move concepts past a critical juncture in their development. For example, a group of faculty working on affordability solutions for health care might need funding to generate preliminary data or acquire a unique piece of equipment.

BLUE SKY UP TO $2.5M OVER THREE YEARS

The Blue Sky initiative supports transformational concepts – high-risk, high-reward ideas. While it is analogous to the later-stage, higher-dollar contributions of venture capital funding for entrepreneurs, the goal is not to launch a company. Instead, teams will progress through a series of defined milestones to consistently assess the development of their concept, and will have a strategy in place to explore and secure external investments to develop and expand the concept. This could come from a federal entity like NASA or the NSF, or from a corporate partner.

Blue Sky will give teams the resources to aggressively pursue an idea to either reinforce or define Michigan's leadership position in areas ranging from revolutionizing mobility to utilizing big data.

What is a Michigan Engineer?

Responses to Laura Murphy's op-ed in the fall 2017 issue about the definition of a Michigan Engineer

It hurt to read that Laura Murphy had so many negative experiences en route to earning her BSE ME – I had hoped that Michigan Engineering would be much more inclusive today. I too had a very lonely journey in ChE 40 years ago. With rare exception, no one wanted to be my lab partner or ask me to join a study group.

Like Laura, it made all the difference in the world for me to establish a connection with a professor and see the bigger picture. I'm very grateful that I received encouragement from Dr. Hand, Dr. Curl and especially Dr. Fogler. I'm proud to be a Michigan Engineer. I hope that Laura comes to be proud as well and finds a way to make a difference for the next generation of engineers.
Sue (Pierce) Green (BSE ChE '78)

As I am both a former employee of the Wilson Student Team Project Center and a four-year member of the MRacing Formula SAE team, Laura Murphy's account of her experience in a campus machine shop resonated strongly with me. The training procedures and attitude of the shop in Laura's story are unsafe and unbecoming of a Michigan Engineering facility. No student should ever be discouraged from exploring the full breadth of Michigan's resources nor made to feel embarrassed when she is hesitant about using high-energy machine equipment.

I trained hundreds of Michigan students in the safe operation of mills, lathes and other machinery in hands-on sessions. Instructional videos simply aren't enough to enable safe use of a lathe.
Ryan Kraft (BSE ME '09)

Kudos for Corinne

Response to our story about Haitian IOE alum Corinne Joachim Sanon and Les Chocolateries Askanya

I am so proud of Corinne! She has been my mentor since 2014, helping me with my transition from high school in Haiti to college in the United States.

Corinne is always there for me, and her passion has inspired me to help in Haiti after I graduate. As challenging as it is to start a business like this in Haiti, she is still fighting for what she believes in. I can only admire her for that!
Medinah L.

This is a beautiful story. Imagine how great Haiti would be if even a small percentage of the ones that leave come back to help. Amazing.
Alain Emmanuel

I loved the article from the University of Michigan, it really highlights your career and the obstacles you encountered. I'm proud of you and what you're doing for our country.
Djhénane Franck

The article from the University of Michigan is superb! Emotive and stimulating at the same time. I love the photo of the laptop on the bucket. Bravo chérie!
Anaise Chavenet

Congratulations! You are a role model for young people.
Wolf Petersen Gelin

"We try hard, we try different ways until it works." That is the attitude to have!
Sabrina Jocelyn-Aucourt

Tall tale in nuclear engineering

Response to the opening of the Nuclear Engineering Laboratory, featured in Random Access

I'm going to suggest y'all line up by height next time …
Michael Ternes

Groovy guy unmasked

A response to a photo published in the "Something Groovy This Way Comes" photo essay.

One just never knows where their past will come back to haunt them – in this case on page 48 of the fall 2017 issue of The Michigan Engineer. After puzzling over it for a minute, I suddenly realized that I was looking at a photo of myself.

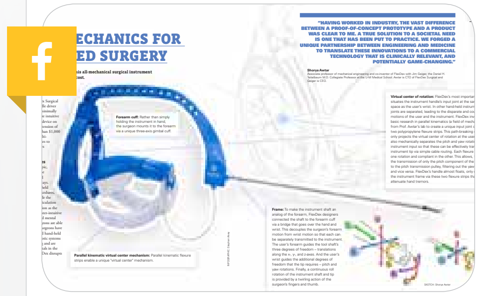
I was editor of the Technic at that time, and the last page of each issue was our humor page. Here we were having a little fun at our own expense, hiding in the closet in disguise so no one would realize we were reading this publication. I'm the one on the left, and Chuck Schotts is the one on the right. I'd be curious to know where you got the picture?

Working on the Technic would prove to be an important and invaluable part of my university experience and education. The things I learned there would pay dividends the rest of my life, writing, leadership and commitment. What we published was never as important as our participation in the publication.

All student organizations are difficult to sustain both financially and with human resources. Therefore, it is no surprise to me that the magazine met its demise only a few years later, but no less disappointing. We had an office in East Engineering which the college furnished and graciously allowed us to use, but I suspected that would end with the move to North Campus.

It would be great to see a revival of something similar. With electronic media, the expense of publication can be virtually eliminated. What would be even better is a related for-credit class that would draw students in.
Raymond Barry (BSE EE '77)

We got this photo, along with the others in the photo spread, from the Bentley Historical Library on North Campus. –Editor



FlexDex

Responses to the article on FlexDex, a surgical tool developed by a U-M startup.

I am very proud to say I was a part of this team in the early stages of development. It is absolutely amazing to see the progress the team has made since my departure. This is what Michigan Engineering is all about! I simply cannot wait to see the positive effect this device will have on patients, surgeons, and hospitals not only in the United States, but across the globe! Congratulations FlexDex!
Matthew Schneider

It's raining, geeks

Responses to our bicentennial article on Michigan Engineering alum Jeff Masters, founder of Weather Underground

Great read!!
@weatherunderground

Currently, I find Wunderground and AccuWeather apps to be MOST accurate, according to my geeky standards.
@JerseyAttitudes

Superhydrophobia

Response to the article on the development of an ultra-durable water repellent coating.

This is pretty cool! I'm curious about sheer force – how does the material behave under it? Also how is it machined? Also, uh, what is it made out of? Thanks!
Anand Jay Kalra

The coating is made of fluorinated polymer elastomer mixed with a specialized water-repellent molecule called "F-POSS." It's sprayed on and bonds tightly to the surface below. –Editor

Corrections

A caption on page 45 of the fall 2017 issue incorrectly stated that students were readying a GE J79 Turbojet engine for a wind tunnel experiment. The engine was a display model provided as a gift by General Electric.

The article "Out of the Cold War's Shadow" should have stated that the Tomahawk missiles launched at Syria in April of 2017 bore 0.5-ton chemical warheads, not 500-ton. Also, Robert Lewis was the co-pilot of the Enola Gay rather than the pilot.

Have something to share? Email us at MichiganEngineer@umich.edu

RANDOM ACCESS

PHOTO: Biophysics group, Adolphe Merkle Institute

FROM KEVLAR TO CARTILAGE

PHOTO: Jospeh Xu

Knee replacements might be on their way to an upgrade thanks to a new synthetic cartilage made with Kevlar, a material best known for bulletproof vests. The material was developed in the lab of Nicholas Kotov, the Joseph B. and Florence V. Cejka Professor of Chemical Engineering.

Like real cartilage, it's mostly made of water – more than 80 percent – in addition to the Kevlar fibers and a hydrogel that's common in contact lenses. The fibers build a tough framework while the hydrogel fills in gaps, trapping the water in chambers. The water resists stresses on the network. But the network can also yield – releasing some water only to recover it later when the stress is removed. It works a bit like a sponge. No other synthetic material comes as close to the unique "liquid strength" of cartilage.

ELECTRICITY, EEL STYLE

Inspired by the electric eel, a flexible, transparent electrical device could lead to body-friendly power sources for implanted health monitors and medication dispensers, augmented reality contact lenses and countless other applications.

Designed by Michigan Engineers collaborating with researchers from the University of Fribourg in Switzerland and the University of California, San Diego, the soft cells are made of hydrogels and salt and generate a steady buzz of electricity at high voltages but low currents, a bit like an extremely low-volume but high-pressure jet of water.

Electric eels can synchronize the charging and discharging of thousands of cells in their bodies simultaneously, says Max Shtein, a professor of materials science and engineering. Shtein applied a unique origami solution to the large sheets of hydrogels, devising a way of folding a flat sheet of gels so the right cells come into contact in the right order.

The device can't hold a candle to the electric eel, which can pump out far more power in short bursts to zap prey or defend itself. But the researchers say they have taken an important first step that advances a fundamental understanding of soft power sources.

PHOTO: NASA

"WE ALREADY KNOW THAT HALL THRUSTERS WORK WELL IN SPACE. THEY CAN BE OPTIMIZED EITHER FOR CARRYING EQUIPMENT WITH MINIMAL ENERGY AND PROPELLANT OVER THE COURSE OF A YEAR OR SO, OR FOR SPEED — CARRYING THE CREW TO MARS MUCH MORE QUICKLY."

– **Alec D. Gallimore**, Robert J. Vlasic Dean of Engineering, in Popular Mechanics

Gallimore leads research on the X3, a prototype Mars engine under development by U-M, NASA and the U.S. Air Force. The X3 is a 500-pound Hall thruster that recently broke records for operating current, power and thrust generated by a thruster of its kind. Gallimore is also the Richard F. and Eleanor A. Towner Professor, an Arthur F. Thurnau Professor and a professor both of aerospace engineering and of applied physics.

PHOTO: Joseph Xu

DRONE ZONE

The M-Air outdoor fly lab opened in February, making U-M the only university in the nation with advanced robotics facilities for air, sea, land and space. The netted, four-story complex offers 9,600 square feet for untethered flight.

"M-Air will allow us to push the edge of our algorithms and equipment in a safe way, where the worst that can happen is it falls from the sky," said Ella Atkins, professor of aerospace engineering. "With this facility, we can pursue aggressive educational and research flight projects that involve high risk of flyaway or loss of control – and in realistic wind, lighting and sensor conditions."

HIGH-RISK, HIGH-REWARD

U-M has tripled its investment into daring, boundary-crossing research through Mcubed, a one-of-a-kind, $30 million funding program spearheaded by engineering professors in 2012. Mcubed rapidly gives seed grants to teams of three professors from at least two different disciplines and does not require a formal application process.

$94M Follow-on funding to Mcubed projects

476 Interdisciplinary projects jump-started

225+ Studies published in peer-reviewed journals

60+ Other results such as companies & artistic exhibitions

Mcubed was approved for another three-year cycle that opens in fall, 2018. Read more at **umicheng.in/mcubedRA**

PHOTO: Joseph Xu

"WHAT WE HAVE TO DO IN THIS COUNTRY IS MAKE SURE WE DON'T TEACH OUR CHILDREN TO HATE. KINDNESS IS SOMETHING YOU CAN GIVE AWAY, AND YOU'LL NEVER UNDERSTAND THE IMPACT THAT YOU HAD ON ANOTHER."

Colin Powell, a retired four-star general and former secretary of state and chairman of the Joint Chiefs of Staff, who visited with engineering and ROTC students before speaking to more than 2,000 people in Hill Auditorium. Powell joined Alec D. Gallimore, the Robert J. Vlasic Dean of Engineering, for a conversation on geopolitics, race and wisdom for the next generation as part of the 2017 James R. Mellor Lecture.

UNPRECEDENTED DESIGN. EXTRAORDINARY RESULTS.

The solar car team's 14th vehicle took second place in the 2017 Bridgestone World Solar Challenge. No U-M team has ever placed so high. Here's how they did it:

"WE TOOK A CHANCE ON GOING WITH A SMALL CAR, AND WE'RE GOING TO BE AHEAD OF THE CURVE FOR YEARS TO COME BECAUSE OF THAT."

Neil Dasgupta
Team faculty advisor and assistant professor of mechanical engineering

RELIABILITY

Novum spent almost no time on the side of the road. The caravan pulled to the shoulder just once, for only a few minutes, to repair an internal aero component that was causing a power spike. The team credits the simplification of Novum's design and mechanical systems, which were less prone to failure. They also point to its 4,135 miles of testing.

STABLE DYNAMICS

An optimized battery design contributed to a lower center of gravity. For simulated worst-case-scenario crosswinds, Novum's suspension allowed for a deflection of under 3.5 mm, ensuring that the car didn't produce more lift than the previous car, Aurum.

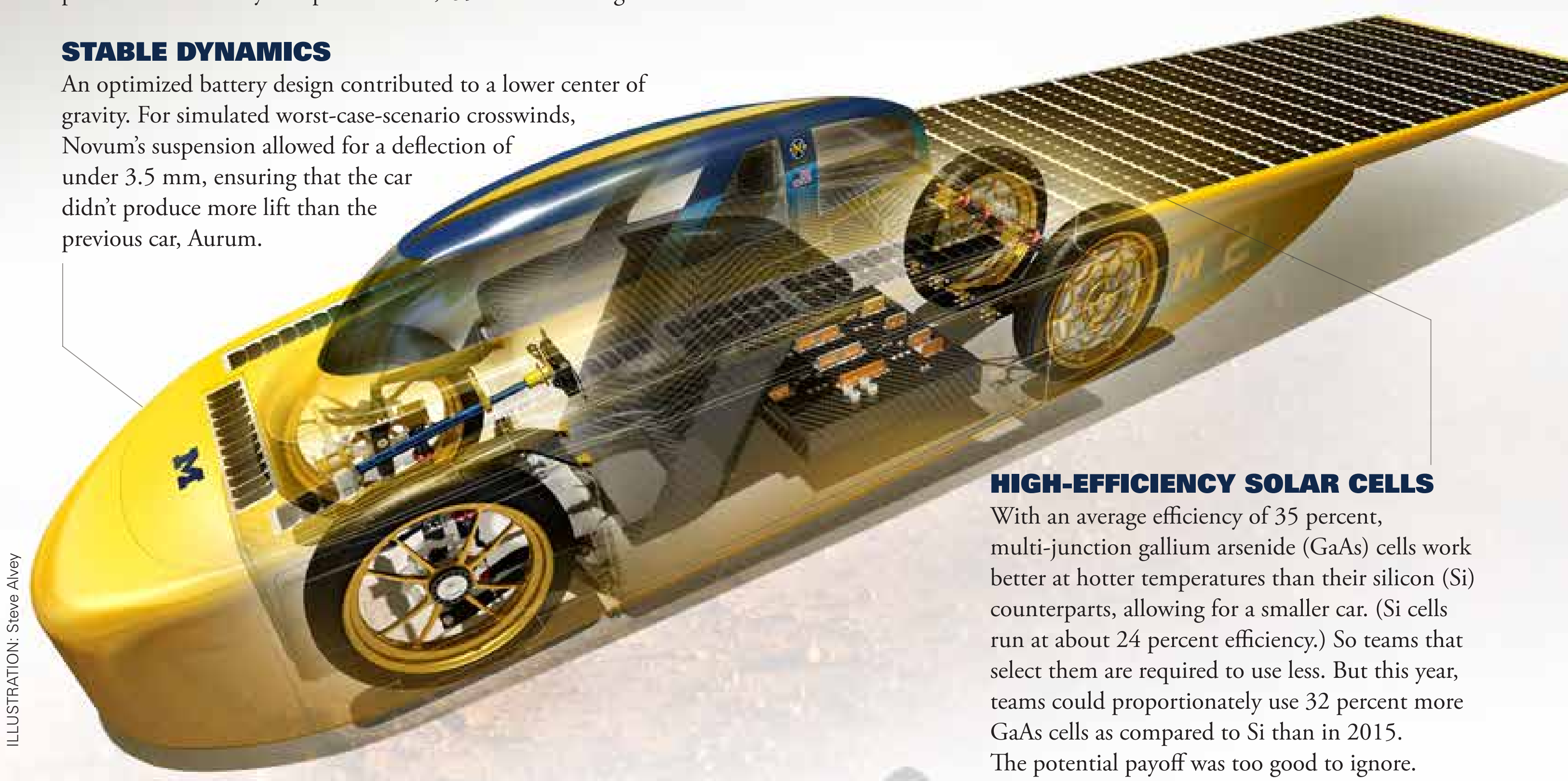


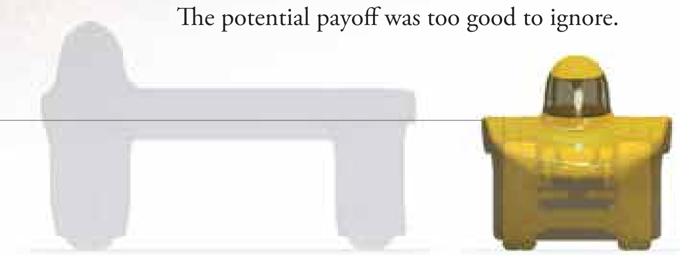
ILLUSTRATION: Steve Alvey

HIGH-EFFICIENCY SOLAR CELLS

With an average efficiency of 35 percent, multi-junction gallium arsenide (GaAs) cells work better at hotter temperatures than their silicon (Si) counterparts, allowing for a smaller car. (Si cells run at about 24 percent efficiency.) So teams that select them are required to use less. But this year, teams could proportionately use 32 percent more GaAs cells as compared to Si than in 2015. The potential payoff was too good to ignore.

STREAMLINED SHAPE

Michigan was one of only two top teams that raced a skinny, monohull car – a radical departure from the proven catamaran design that dominated the field. Novum is 43 percent narrower than Aurum.



A CURE FOR THE COMMON CONCRETE

REGULAR CONCRETE

Strength level: 4,000 pounds per square inch – the equivalent of two cars

Drawback: Deterioration over time creates problems for municipalities trying to keep up with maintenance costs

ULTRA HIGH-PERFORMANCE CONCRETE (UHPC)

Strength: 22,000 pounds per square inch – as much as 11 cars

Drawback: Strength comes from higher density than regular concrete due to inclusion of small steel fibers, but cost has proven prohibitive

U-M BLEND OF UHPC

Strength: Tested as high as 36,000 pounds per square inch in the lab, strong enough to support 18 cars

Benefit: Costs more than regular concrete, but at 70 percent less than commercial brands currently on the market, the cost is low long-term

PHOTO: Robert Coelius

The United States faces a backlog of roughly $500 billion in necessary road and bridge repairs. And for many communities, the problem lies in not being able to afford the handful of stronger, longer-lasting concretes on the market.

Michigan Engineers have created their own non-proprietary blend of ultra high-performance concrete (UHPC) – and are giving the formula away for free, creating a drastically cheaper alternative for longer-lasting concrete.

U-M's blend of UHPC is higher density, preventing water from getting into the concrete and causing deterioration, while a sprinkling of small steel fibers bolsters its strength. Where regular concrete begins to show deterioration at 28 freeze/thaw cycles, U-M's blend showed virtually no deterioration at 90 freeze/thaw cycles.

While UHPC is still more expensive than normal concrete, engineers believe its extended life will more than pay for itself in the long run.

"Our UHPC brings down the cost of long-term maintenance," said Sherif El-Tawil, professor of civil and environmental engineering. "It's still more expensive than regular concrete, but if you consider the effect over the lifetime of a bridge, the cost becomes very competitive."

GAME THEORY FOR ELECTRIC VEHICLE CHARGING

By Ian Hiskens, Vennema Professor of Engineering and professor of electrical engineering and computer science

Electric vehicles (EVs) will play a vital role in decarbonizing road transportation. As society moves toward a more sustainable energy future, we anticipate that the population of EVs will steadily increase. So too will the energy requirements for charging all these vehicles, placing great strain on the electricity generation and supply infrastructure. We addressed an important aspect of this challenge by establishing a decentralized approach to optimally schedule EV charging, making the best use of the fleet of generators that supply the electricity grid. Namely, EV charging should be distributed across the overnight "valley" in electricity demand.

The total load of a power system varies continually throughout the day: low overnight, when most people are asleep, and high during the day's commercial and industrial activities. The shape of this daily load variation differs from day to day, and across seasons and regions, but typically displays a peak around 6 to 8 p.m. when most people arrive home and enjoy their electricity-intensive evening activities. This peak demand determines the number and size of power stations, or amount of generation, that is needed.

It would be tempting for EV owners to start charging their vehicles as soon as they arrived home from their evening commute. However, that would add even more load to the evening peak, requiring more expensive generation to be brought into service. Many utilities currently offer incentives for EV owners to postpone charging until around 10 p.m., for example. This helps spread the total demand and achieves better utilization of generation, but as the number of EVs grows, this strategy may have the undesirable consequence of inducing a second peak. The ideal solution minimizes electricity generation cost by scheduling EV charging to exactly fill the overnight load valley.

One way of achieving the optimal valley-filling strategy would be for a central controller to tell every EV when it could charge and at what rate. Not only would this approach be computationally challenging, it would not likely be embraced by EV owners, who would probably prefer more autonomy. Instead, we have established a decentralized process in which the EV owners make autonomous charging decisions but do so in a way that exactly achieves the ideal solution, minimizing generation cost and stabilizing demand.

The decentralized EV charging control problem that we studied can be thought of as a form of non-cooperative game, in which a large number of self-interested EVs share electricity resources over the charging horizon (the evening hours). Our proposed process involves an iterative exchange between a central utility and each EV. The utility initially broadcasts a prediction of the non-EV base demand over the charging horizon. With this broadcast information available, each EV independently determines its minimum-cost charging strategy. The utility collects these tentative charging strategies from all EVs, sums them to give the total aggregate EV demand over the horizon, and broadcasts that updated demand information back to all the EVs. This process repeats until the optimal charging strategies proposed by all the EVs no longer change.

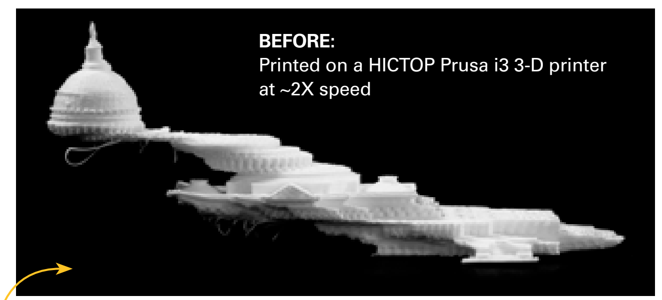
In our process, the EVs interact through the common electricity price signal. We established conditions for the existence of a Nash equilibrium and proved that the decentralized (iterative) optimization process converges to the unique Nash equilibrium. Furthermore, we showed that this Nash equilibrium is, in fact, the optimal valley-filling strategy given by central optimization. A range of examples illustrates our main results, in particular the fast convergence rate of the iterative algorithm.

In order to establish rigorous results, we considered a fairly abstract version of the large-scale EV charging problem. In doing so, though, we laid a foundation for designing and analyzing emerging decentralized processes for determining optimal EV charging strategies. Future EV drivers may be able to provide their preferred charging hours to a system that optimizes for lowest cost, obtaining the best possible rates while also helping the overall grid by filling the demand valley efficiently.

"Decentralized Charging Control of Large Populations of Plug-in Electric Vehicles," published in the January 2013 issue of IEEE Transactions on Control Systems Technology, is the journal's most highly cited paper over the past five years.

A TURBO BOOST FOR 3-D PRINTING

A new Michigan Engineering algorithm allows 3-D printers to "read ahead" of their programming during production so they can work faster and with greater accuracy.



BEFORE:
Printed on a HICTOP Prusa i3 3-D printer at ~2X speed

Going too fast causes 3-D printers to vibrate, leading to the reduced quality of the final product shown above. If the printer can anticipate which parts of the program will cause the greatest vibrations, it can adjust speed accordingly.

AFTER:
Printed on a HICTOP Prusa i3 3-D printer at ~2X speed WITH Michigan algorithm

Michigan Engineers have created an algorithm designed to throttle printing speeds up and down depending on the demands of the program, allowing for faster production times with higher quality (seen above). Developed by Chinedum Okwudire, an associate professor of mechanical engineering, the algorithm could double speeds and lead to broader use of 3-D printing.

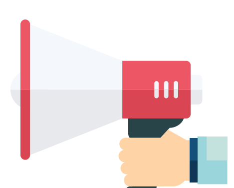
HOW IT WORKS

Okwudire uses the analogy of a person trying to deliver a speech in a large hall. In order to reach the ears in the farthest rows, that speaker would have to shout.

A megaphone might solve the problem. But if the speaker continues shouting, their voice will be loud and distorted. Using the megaphone in a normal voice, however, produces the right clarity and volume.

The algorithm developed by Okwudire's team acts similarly – allowing the 3-D printer to throttle up and down to prevent distortion.

"Our software is like that person who realizes their voice is going to be overly amplified. It acts preemptively."
-Chinedum Okwudire



REIMAGINING HOW COMPUTERS ARE DESIGNED

ILLUSTRATION: Steve Alvey and Joseph Xu

Valeria Bertacco, shown in this photo illustration, hopes her big ideas for a "plug-and-play" ecosystem will transform the way computer systems are designed and manufactured.

Today, you essentially need a PhD to design a new computing system – or you need people with that level of expertise on your team.

It's one of the reasons analysts worry that the industry is stagnating – caught between physical limits to the size of silicon transistors and the skyrocketing costs and complexity of system design.

A new, $32 million center at Michigan Engineering aims to change this, streamlining and democratizing the design and manufacturing of tomorrow's computing systems.

The Center for Applications Driving Architectures, or ADA, will develop a transformative, "plug-and-play" ecosystem to encourage a flood of fresh ideas in computing frontiers such as autonomous control, robotics and machine learning. Its name was inspired by Ada Lovelace, the 19th-century mathematician and writer who is considered the first computer programmer.

"We want to make it possible for anyone with motivation and a good idea to build novel, high-performance computing systems," said Valeria Bertacco, the Arthur F. Thurnau Professor and professor of Computer Science and Engineering who leads the center.

"Five years from now, I'd like to see freshly minted college grads doing hardware startups."

ADA's funding comes from a consortium led by the Semiconductor Research Corporation and the Defense Advanced Research Project Agency (DARPA). The five-year project involves researchers from Harvard, MIT, Stanford, Princeton, the University of Illinois at Urbana-Champaign and the University of Washington.

Among their key tasks, the researchers will identify patterns in the core algorithms of emerging applications – such as virtual reality, machine learning and augmented reality – in order to map those algorithms to new, tailored computational blocks. They will develop reusable, highly efficient algorithmic hardware accelerators for those computational blocks. And they will devise an open-source chip scaffold for these new, accelerator-centric systems.

"One will no longer need to send a design to the fab and wait for a chip to come back," Bertacco said. "They may still need a clean room to assemble a system, but this will be much simpler and more economical."

2020 MICHIGAN ENGINEERING

OUR STRATEGIC VISION

Michigan Engineering strives to anticipate the global, technological and educational changes ahead, and position our institution to lead the evolution of 21st-century engineering research and education for the benefit of the common good.

RESEARCH

We will use a startup investment model to spur innovative and collaborative research to solve grand challenges. Three funding approaches will be piloted, providing early-stage investment, mid-level investment modeled after "angel" investors and high-level strategic funding through a venture capital model.

EDUCATION

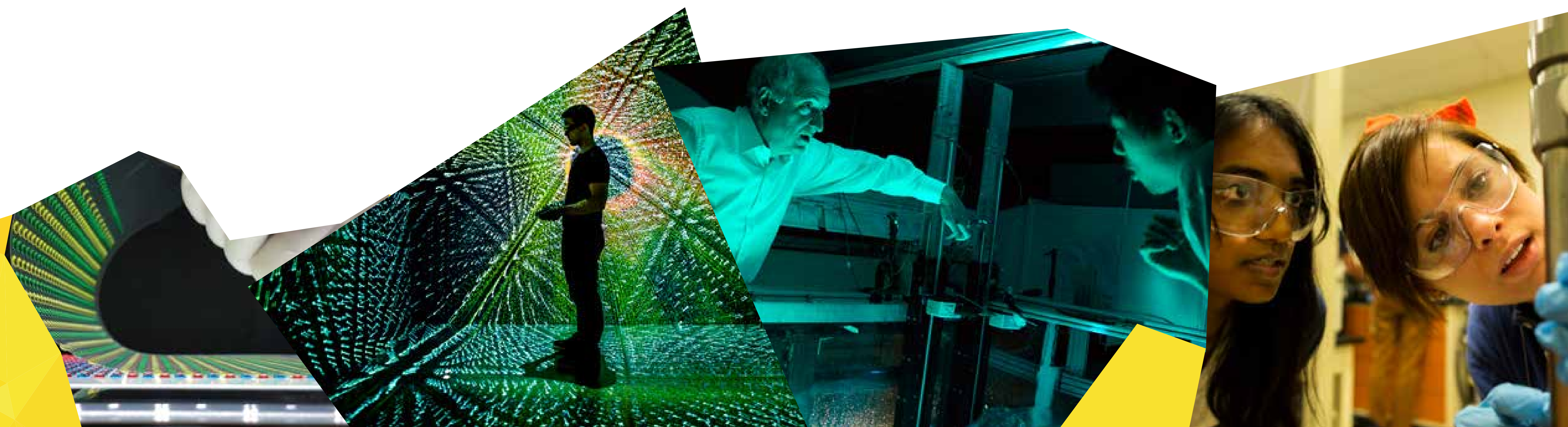
We will ensure that every Michigan Engineering student benefits from an educational experience that is among the finest in the world. We will introduce academic innovations consistent with preeminent engineering education, including new pedagogical and technological delivery methods, beyond-the-degree experiences and access to learning for students and professionals around the globe.

CULTURE

We will align our promotion process, incentives and career development with our core values to foster a culture of daring, leadership and inclusivity. Three initiatives we will undertake include articulating the tenure-track criteria, incentivizing faculty and staff for activities that are creative or daring, and creating culture-building activities and practices to increase understanding and adoption of our vision, mission and values.

See more about the vision, mission and values that will enable our strategic plan:

strategicvision.engin.umich.edu



A PLACE IN THE SUN

As buses rumble by on State Street, environmental engineering undergrad Alexandra Prince tunes into her classwork in front of Angell Hall.

PHOTO: Joseph Xu

SHOOTING FOR THE SUN

It's unclear when, exactly, NASA's $1.5 billion Parker Solar Probe will be incinerated by the heat of the sun's corona.

But by the time that happens, the sedan-sized probe will have racked up an impressive list of superlatives.

Parker will have become the fastest human-built object, reaching speeds of up to 430,000 miles per hour in its final orbits around the sun. It will also travel closer to the sun than any man-made object before it – within 3.8 million miles of the surface. Perhaps most importantly, it could help prevent massive electrical blackouts unlike anything Earth has seen before.

In the midst of this historic undertaking, you'll find Justin Kasper, a principal investigator on the Parker mission and a climate and space sciences and engineering professor at U-M. Ahead of the summer 2018 launch, he agreed to walk us through what promises to be an amazing road trip.

STORY BY JIM LYNCH
DESIGN BY STEVE ALVEY

BREAKING FREE

When Parker goes up, it will go in style. Named after American astrophysicist Eugene Parker, the probe will ride on a Delta IV Heavy, touted as the world's largest-capacity rocket in regular use.

Kasper describes the Delta IV Heavy as "three massive rockets in a line, bolted together and launched all at the same time." Its use for a scientific project like the Parker Solar Probe is a first. The massive launch vehicle is normally reserved for government or military projects.

Delta IV's manufacturer, United Launch Alliance, touts the rocket as delivering "our nation's most critical national security missions for the National Reconnaissance Office and the U.S. Air Force." The solar winds Parker will work to understand, and weather events in the sun's corona we detect via satellites, are part of what makes the mission "critical" in the eyes of researchers.

Why such a large rocket for a probe that only weighs about 1,000 pounds? It has more to do with slowing the probe down than speeding it up.

"Earth moves around the sun at about 30 km per second," Kasper said. "You can't just use any rocket to slow you down by tens of kilometers per second."

The power and fuel capacity of the Delta IV, along with an eventual gravity assist from Venus, will get the solar probe velocity down to a point where it can orbit the sun.

THE SOLAR THREAT

Within hours of leaving the launchpad in Florida, Parker will cruise past its first milestone, the Solar Dynamics Observatory (SDO). Essentially a floating camera, SDO sits about 36,000 kilometers from Earth. It gives us our first warnings about what scientists call "space weather," electromagnetic activity in the sun's atmosphere that could potentially cause disturbances here on Earth.

Major disturbances are rare, with the most extreme documented incident occurring back in 1859. But today's world is far more reliant on electricity, and solar weather could cause severe damage to the power grid, wiping out electricity to large swaths of the planet for months or years.

Each day, instruments onboard SDO capture and relay a terabyte of images of activity in the sun's corona – the images hint at possible space weather threats to Earth. But scientists can draw only limited conclusions from them now.

Parker is built to change that. Collecting information directly in the sun's atmosphere will enable better interpretation of SDO's images to determine whether trouble may be coming our way.

The worst trouble usually starts with sunspots, strong magnetic fields that crop up along the surface of the sun and cause the atmosphere above to twist. The buildup of magnetic energy leads to a sudden release, called a solar flare, that ejects radiation outward.

Such an event creates a coronal mass ejection, a burst of hot plasma sent into space. We get good looks at these ejections when they first happen thanks to SDO. With a major solar flare, the observatory's images capture the initial release from the sun, but not what happens after it leaves the atmosphere and flies off into space. And that's when it becomes a potential threat to earth.

"A large coronal mass ejection might involve an amount of plasma or radiation in the solar atmosphere that's roughly equal to the amount of water in Lake Michigan that goes from rest to about three million miles an hour in tens of minutes," Kasper said. "That's an incredible amount of energy."

Kasper likens the data awaiting the probe's instruments and sensors to the Rosetta Stone.

"Until we have a spacecraft that can enter the sun's atmosphere to directly measure electric fields and magnetic fields, take an inventory of the kinds of particles there and their activity … we just won't have the basic relationships established to figure out which of our theories are correct," he said. "These are the data points we've been missing."

EARLY WARNING

Roughly a day after departure, one percent of the way to the sun, Parker Solar Probe will reach Lagrange Point 1 (L1). This is where the gravitational pulls of the sun and Earth cancel each other out, and it's also home to Deep Space Climate Observatory (DSCOVR), a three year-old satellite that makes up another component in our space weather warning system.

Capable of analyzing the solar wind, DSCOVR's onboard plasma magnetometer suite measures the electrons, charged particles and magnetic field of the wind as it passes by, relaying the data back to Earth in real time.

"On the ground, we're able to process that data immediately to tell if a shockwave has reached that spacecraft," Kasper said. "If a coronal mass ejection reaches L1, we can detect it. That's usually enough warning, even with a strong, fast-moving event, to give people on Earth about an hour to prepare."

Lead time, even 60 minutes, could allow utilities to take steps to protect the power grid. Military units could prep the for loss of GPS and communications. But the data from the Parker Solar Probe could help us increase Earth's warning time by making it possible to hone theories about radiation and the solar wind into fact.

A close pass with the sun will show us how energy and heat move through the corona, how they're accelerated and how they're ejected during major solar weather events. That will likely lead to better models that will help us predict whether those events will affect us here on Earth.

Those models could potentially give us several days' warning before a solar weather event – enough time to give utilities in vulnerable areas the opportunity to take defensive measures to protect our electrical grids. Most vulnerable are the system's massive transformers. Because they're custom-made at a cost of tens of millions of dollars apiece, there are no spares. And because they can take up to six months to manufacture, a major failure could have lasting consequences.

But even a successful Parker Solar Probe mission won't make DSCOVR obsolete. Kasper said the observatory and its likely successors will remain on watch at L1 as a fail-safe in the future.

BORROWING ENERGY

"Haven't we passed that before?"

It's the kind of thing you don't want to hear from the backseat on any long trip, particularly one where the first leg is more than 90 million miles.

But the Parker Solar Probe will do a lot of backtracking during its multi-year trip. In fact, it will go back and forth between Venus and the sun seven times out of necessity. With each pass, Venus' gravity draws Parker closer, tightening the probe's elliptical path.

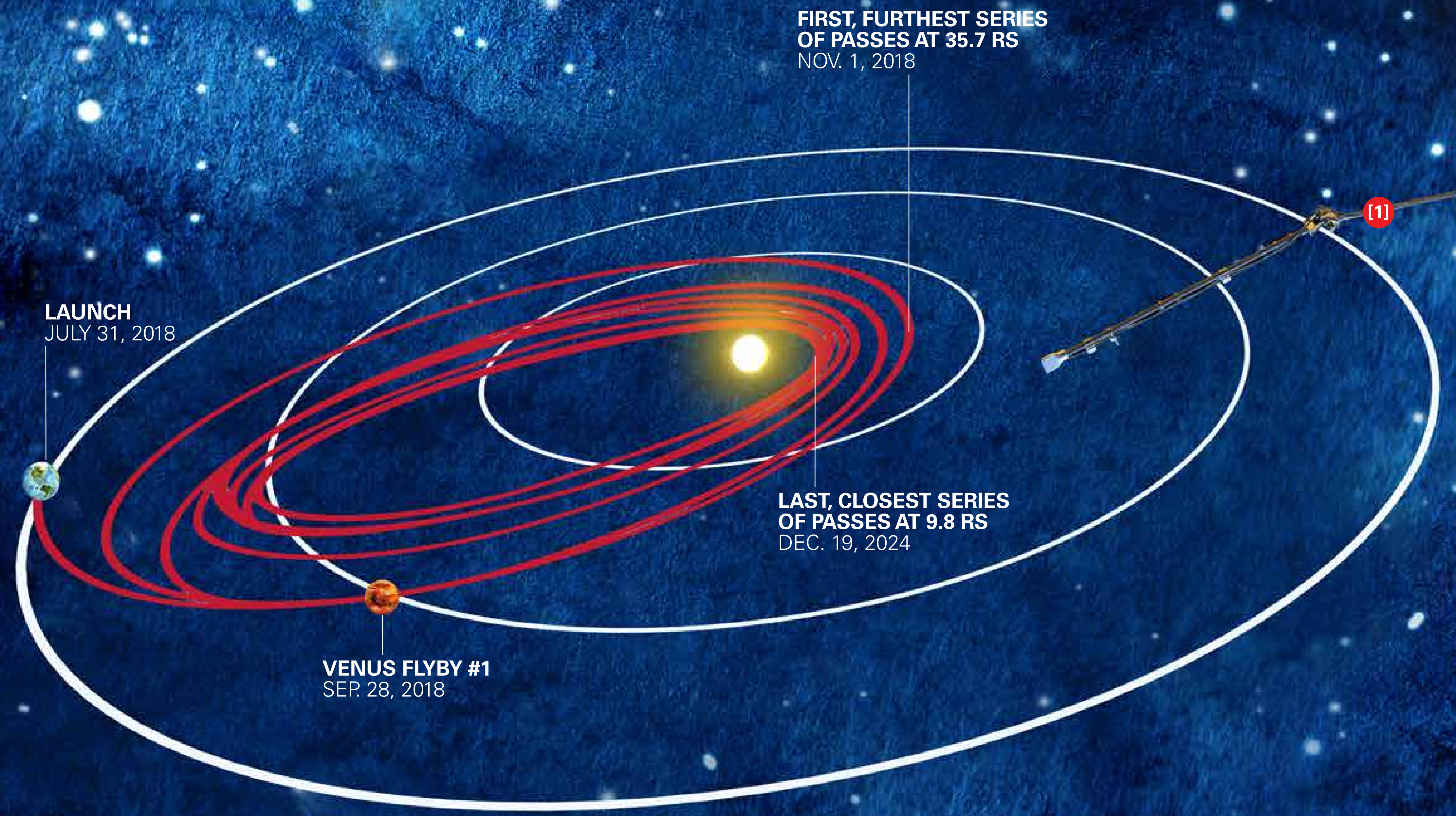
"The only way we get close to the sun is to borrow energy from Venus," Kasper said. "Each gravity assist lowers our perihelion, getting us closer and closer to the sun until, at the end of the mission in 2025, we close within 10 solar radii."

The seven Venus flybys will lead to a total of 24 orbits over the seven-year mission. Parker's nearest pass will make it closest manmade object to the sun at an estimated 3.7 million miles.

While NASA never intended for the probe to return to Earth, Venus represents a point of no return.

"There is no coming back because we can only lose energy with Venus," Kasper said. "Once we have that first encounter, we slow down. We can never make it back out to Earth's orbit."

But that's okay; there's history to be made up ahead.The last planet standing between the Parker Solar Probe and the sun is another soon-to-be-familiar landmark – Mercury. Just after the spacecraft passes it, about 27 million miles from the sun, it will break the current record for the closest manmade object to the sun. The previous record-holder, Helios 2, remains in this part of space more than four decades after its own launch from Cape Canaveral.



PARKER'S TOOLBOX

Sampling the sun's atmosphere requires NASA to pack the Parker Solar Probe with a variety of sensing and optical equipment. The gear is aimed at providing answers in four different areas of scientific inquiry.

In the FIELDS experiment, Parker will measure the strength of the magnetic and electric fields in the corona with **[1]** voltage sensors and magnetometers. It will also gauge the absolute plasma density and electron temperatures.

Parker's second task is cataloging the energetic electrons, protons and heavy ions that are accelerated in the atmosphere as well as the inner heliosphere. Dubbed the Integrated Science Investigation of the Sun (IS☉IS), this task is handled by the **[2]** Energetic Particle Instrument – it's made up of one double-ended high-energy telescope and a pair of low-energy telescopes.

You don't go on a good vacation without taking pictures, and the probe boasts a pair of telescopes designed to capture activity in the corona and further out from the sun in the inner heliosphere. This **[3]** Wide-field Imager for Solar Probe (WISPR) is designed to capture images of the solar wind and plasma in the atmosphere.

Kasper will ride herd over the Solar Wind Electrons and Protons (SWEAP) investigation. Going beyond images, SWEAP will use a **[4]** trio of sensors to break down the makeup of the solar wind – counting the electrons, protons and helium ions it includes and measuring their velocity, density and temperatures.

TAKING THE HEAT

It's the weirdest thing – and totally counterintuitive. The sun's outermost atmosphere, NASA scientists believe, is hotter than its surface.

You would expect temperatures to cool as you move away from the 10,340-degree-Fahrenheit surface of a burning ball of gas. But entering the sun's corona, things get hotter – up to 1,000 times hotter. And that's where the Parker Solar Probe is headed.

The extreme conditions are one of the main reasons a solar probe mission like this hasn't been undertaken before. It simply wasn't possible. But Parker features a series of innovations that will allow the probe to get close enough to do what needs to be done.

Key among these is the probe's heat shield, a 4.5-inch-thick plate of carbon foam that will sit three meters away from the craft's most sensitive equipment. Its front is covered by synthetic sapphire crystal across its eight-foot diameter to help survive temperatures of up to 1,600 degrees Celsius and five megawatts of sunlight.

Meanwhile, the back of the shield will remain at just a few hundred degrees.

To run all of the equipment protected by the shield, any self-respecting solar probe would utilize solar power, right? Before Parker, that was impossible, since solar panels weren't able to deal with the extreme heat. But Parker's engineers made it work – after launch, the probe will unfold a pair of long solar panels to each side for power. Their conductors, capable of handling the extreme heat and light of the mission, are a relatively new creation.

Yet even far away from the sun, those panels will need cooling, and the probe provides an elegantly simple solution. It pumps water from behind the panels to an area in the shade of the heat shield, where it cools quickly before being sent back to the panels.

"It's almost the same way coolant in your car's engine is circulated through a radiator, except we don't have any air to flow in space," Kasper said. "We just have to radiate it."

As Parker draws closer to the sun, roughly five days out, circulation will no longer do the trick, so the probe will draw in its solar panels behind the shield. The panels are designed with slanted ends that allow a small portion to stick out from behind the shield and continue to power the craft.

ATTITUDE ADJUSTMENTS

Sometime on or near Nov. 1, Parker Solar Probe will make its first orbit in the sun's atmosphere. At this point the spacecraft's ability to hold course becomes most crucial. Solar pressure on the craft's heat shield will try to spin the probe around, threatening to burn up the sensitive scientific equipment onboard.

The constant course corrections and adjustments needed at this point can't be handled 90 million miles away on Earth. The distance is too far for the real-time piloting needed and the margin for error is going to be slim. Even a few degrees change in the craft's attitude could incinerate most of it in seconds.

"At closest approach, the probe will be the fastest object ever made – moving at 430,000 miles an hour," Kasper said. "The spacecraft has to constantly and actively point the shield toward the sun."

To do this, the probe utilizes onboard autonomous technology – a slightly more sophisticated version of what you'd find in today's driverless vehicles.

A trio of onboard computers constantly take in data about the probe's orientation – steering by Parker's relation to the stars and the time of day and altering course with bursts from small rocket thrusters. Those three computers must constantly agree about what's going on. Any individual reading the other two computers don't agree with is overruled.

Diving into such an extreme environment requires backups. A buildup of radiation or a solar flare erupting nearby can temporarily blind the probe's cameras. Should that happen, Parker would use its onboard gyroscope and a snapshot of its last heading to steer the craft for up to two days.

Should those systems fail, Parker also comes equipped with high temperature sensors attached to series of protruding limbs. When sunlight hits them, they prompt corrective action from the spacecraft.

It's a lot of effort to protect the probe's scientific payload. But not all of Parker's goals can be achieved from behind the heat shield. To get direct samples of the solar wind, the probe will use a Faraday cup. It's a metal device, the size of a fist, that measures charged particles. To allow those particles to pass through the cup, it needs to "dip" into the solar wind.

A permanent strut attached to the side of the spacecraft allows the cup to extend beyond the shield and into the solar wind, where it could reach temperatures of up to 1,600 degrees Celsius.

HOW PARKER ENDS

Once the Parker Solar Probe completes that first perihelion, it begins its series of six more trips back and forth between Venus and the sun. Each new gravity assist and series of solar orbits will bring the craft closer and closer to the sun's surface – making history all the way.

That last perihelion is projected to take place in mid-June of 2025. With fuel provided by the sun, it's unclear when the probe will finally meet its end, but it will ultimately go out in a literal blaze of glory.

"One day, we will run out of fuel for the rocket thrusters that help us control trajectory and the solar probe will no longer be able to compensate for the pressure of the sunlight," Kasper said. "The sun will flip us around and the entire backside of the spacecraft should be incinerated in seconds."

But even the sun's heat won't likely be capable of erasing all traces of the Parker Solar Probe.

"The carbon heat shield, the Faraday cup and some other parts should be able to survive those high temperatures," he said. "So what you'll basically have is a sort of molten blob that will be in a ten-solar-radii orbit – for the next billion years or so."

Satellite and probe images courtesy of NASA

THE THREAT THAT NEVER SLEEPS: CAN SCIENCE STOP SUPERBUGS?

TRADITIONAL ANTIBIOTICS ARE LOSING THE BATTLE WITH BACTERIA AND MICHIGAN ENGINEERS ARE STEPPING INTO THE BREACH.

STORY BY JIM LYNCH
PHOTOS BY JOSEPH XU

They never released the woman's name. News articles and government reports that came out in early 2017, months after her death, referred to her as "a Northern Nevada woman," "a female Washoe County resident," or something similarly vague.

Her killer, however – they didn't miss that: Carbapenem-resistant Enterobacteriaceae.

Parse through those vowels and you'll dig out the reason for the interest: a drug-resistant strain of bacteria. In this case, it proved to be something particularly tenacious.

Doctors in the United States had 26 approved antibiotics available to treat infections in their patients.

The bacteria that killed the unnamed Nevada woman were resistant to every one of them.

Health officials around the globe are tracking an alarming rise in cases of bacteria that no longer respond to treatments with antibiotics – the go-to remedy for infections since the mid-20th century. Common infections that today we brush aside with a vial of pills are increasingly overwhelming the treatments. And projections on where we're headed are staggering.

In 2017, an estimated 700,000 people died from drug-resistant bugs. By the year 2050, that number could rise as high as ten million in what Britain's top medical officer describes as a "post-antibiotic apocalypse."

An obvious savior from such doom and gloom would be a new class of antibiotics – drugs that bacteria have never encountered and have not mutated to resist.

But the pipeline has been nearly empty for years.

Major pharmaceutical manufacturers are far more interested in drugs that consumers take regularly – think antidepressants, erectile dysfunction pills or diabetes medications. The payoff on products patients take continually goes far beyond what a company would make developing and marketing antibiotics that are taken for a week or, at the most, a few months.

A molecular biologist and former pharmaceutical company official wrote in Forbes last year: "Big Pharma has basically given up on antibiotics. It's not that the risks are too high; it is that the rewards are too low."

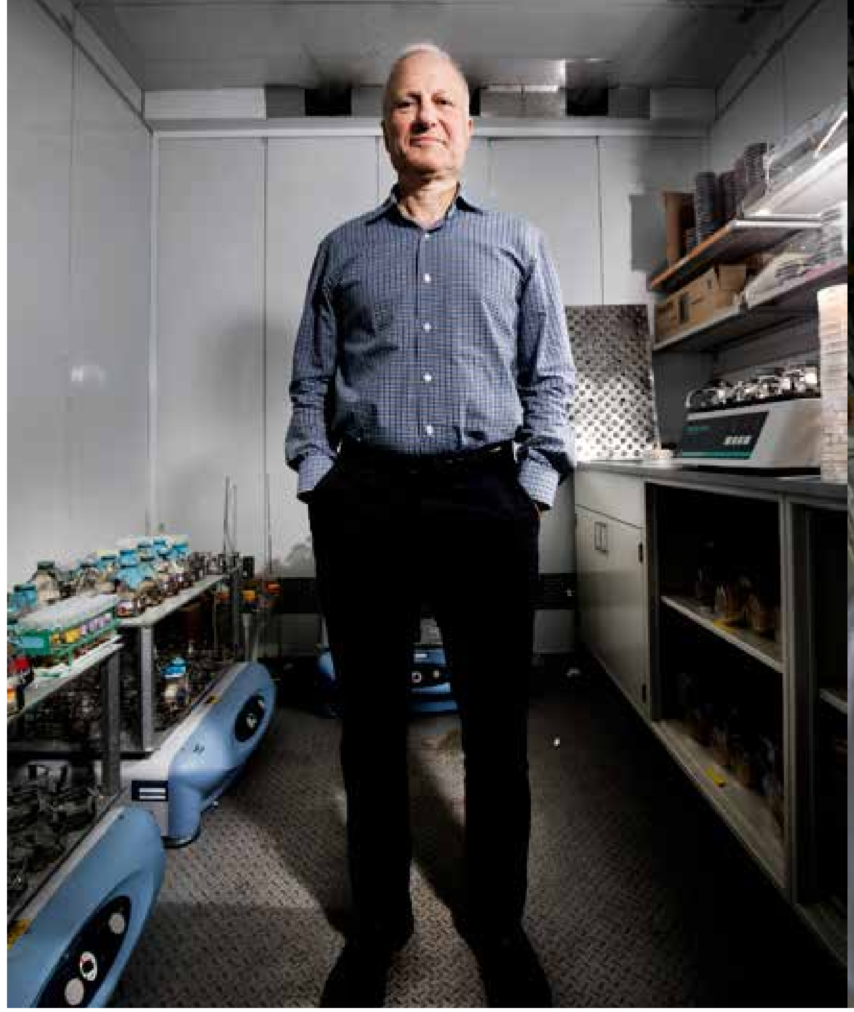
Engineers, including researchers at the University of Michigan, have stepped into the chasm between what we have and what we need. Work underway in labs across North Campus represents several new fronts in the fight, including killer nanomaterials and antibiotic combinations that mimic the immune system.

But we're going to start this story elsewhere: with a U-M guy on the bottom of the Red Sea.

SEEKING SERENDIPITY

The two-sentence version of one of the most important scientific discoveries in history goes like this: penicillin, the first modern-day antibiotic, was discovered by accident. A Scottish scientist found mold growing in untended petri dishes that turned out to have bacteria-curbing properties.

A game-changing infection killer derived from nature – it's exactly what David Sherman searches for on diving trips around the globe. The Hans W. Valtech Professor of Medicinal Chemistry in the College of Pharmacy is often found with a tank strapped to his back, eyes behind a facemask, scouring the seabed for organic material that could lead to the next class of antibiotics.



David Sherman scours the waters of the world in search of organic material that could lead to new classes of antibiotics. It's a practice that has been largely abandoned by the pharmaceutical industry.

Nicholas Kotov, Angela Violi and Scott VanEpps are crafting and deploying nanoparticles – dubbed nanobiotics – to interrupt the inner processes that keep bacteria alive. Identifying weak spots in a bacterium's cell walls and shaping nanoparticles to take advantage of them is the equivalent of designing a key to fit a specific lock.

"BIG PHARMA HAS BASICALLY GIVEN UP ON ANTIBIOTICS."

"There is so much opportunity to find new things because there has been very little exploration," said Sherman, who grew up in Minneapolis, far from the warmer waters he likes to work in.

In lieu of seeking natural keys to new antibiotics, large pharmaceutical companies tinker with existing ones. By altering the chemical makeup of an antibiotic that is no longer effective against certain bacteria, chemists can jumpstart its killing power and create something new.

"Companies were investing in finding new materials up until 20 years ago," Sherman said. "Then a new technology – combinatorial chemistry – came along. All of a sudden, robots started making millions of compounds very simply and very inexpensively – all based on known structural entities."

But many of the old antibiotics, as well as their reconfigured upgrades, target similar weak points or processes in bacteria. And minor changes in an antibiotic's makeup, according to a U-M biomedical engineer you'll meet later, create minor new hurdles for bacteria to overcome on their way to drug resistance.

In the lower levels of U-M's Life Sciences Institute, Sherman houses the fruits of his underwater endeavors – a library of microorganisms he and his team have pulled from marine sediments around the globe.

They represent hope for a new antibacterial M.O.

"What we're trying to do is actually identify new antibiotics that somehow target either a brand new part of a pathogen's machinery, or bind to a new part of an old target," Sherman said. "It's a wide open area, and I think we've only really explored a small number of the potential effective targets."

While Sherman investigates what can be found in nature, U-M engineers using nanotechnology are creating a new class of antibiotics – composed of materials hundreds of times smaller than bacterial cells – that are tailor-made to exploit new targets.

CRAFTING KILLERS

A high-stakes version of Tetris is underway on North Campus, played by a chemical engineer, a mechanical engineer and a biomedical engineer who happens to be an emergency room doctor.

And they're cheating.

When an antibiotic does its killing work, it essentially shuts down a process the targeted bacterium needs to survive. That could be the ability to build cell walls or to generate proteins capable of turning food into energy.

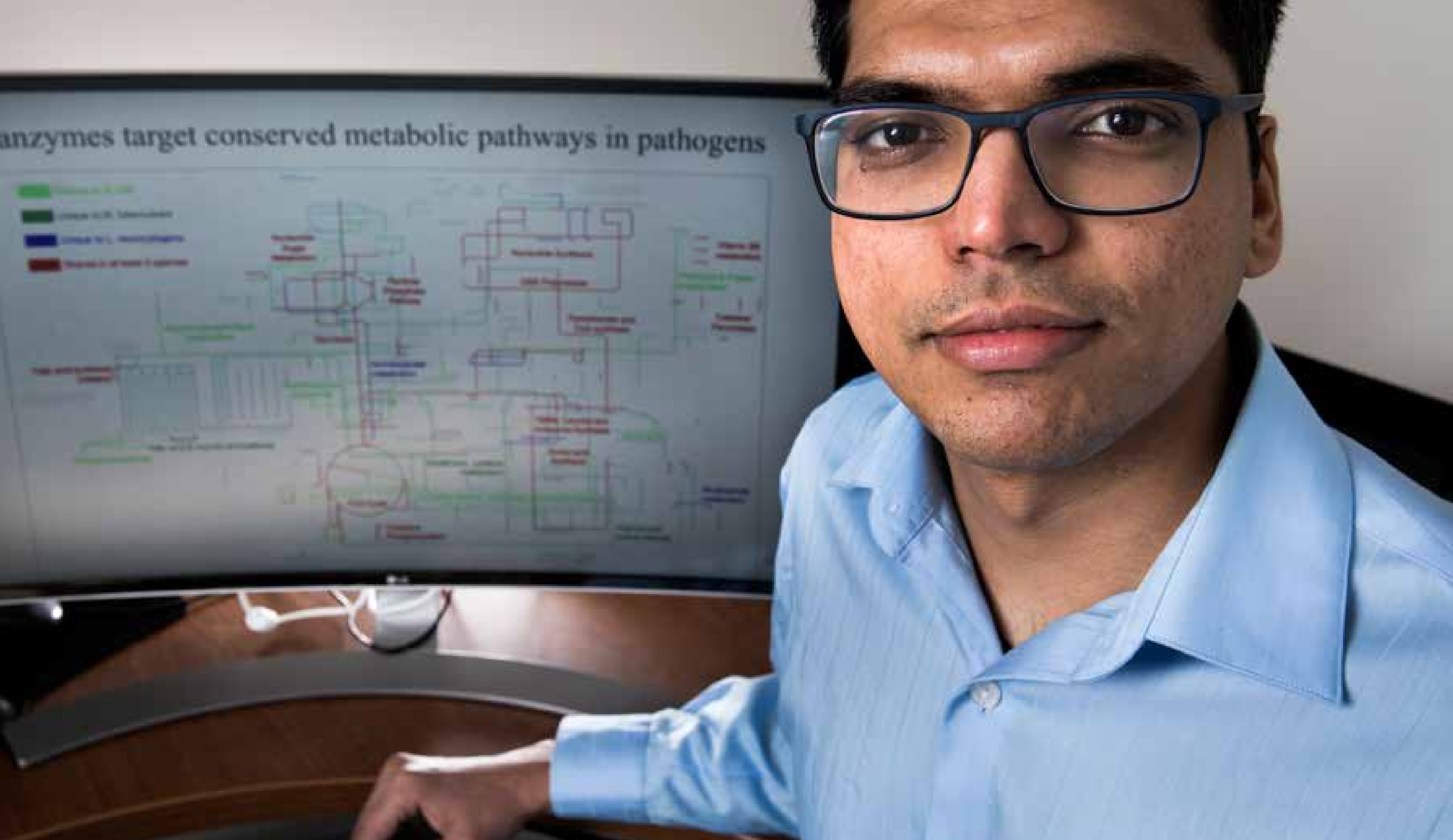
Now, go back to Tetris and its falling puzzle pieces. If you could change the shapes of those pieces, it would be simple to fit them into a neat grid below and endless high scores would follow.

The U-M trio is using nanobiotics as their "cheat code."

"Nanobiotics," a riff on nanoparticles and antibiotics, uses a particle's shape, size and chemistry to interrupt a bacterium's survival processes. Endless configurations and sizes are possible with current technology, creating new pathways for the nanoparticles to insert themselves into those key processes. Once it's there, the nanobiotic effectively disrupts and shuts down that process, causing the bacterium's death – even where there is resistance to traditional antibiotics.

Nicholas Kotov, the Joseph B. and Florence V. Cejka Professor of Chemical Engineering, makes the particles in his lab.

"These are pieces of inorganic material, a few nanometers in size,"



Sriram Chandrasekaran uses the blueprint provided by bacteria-killing T-cells and the study of proteomics to design drugs and treatments to combat drug resistance. Knowing which proteins the body naturally targets informs how new drugs or new combinations should work to be most effective.

he said. "What we've learned along the way is how to use the biomimetic natural design of nanoparticles and attribute to them some biological functions."

Angela Violi, a professor of mechanical engineering, as well as chemical engineering and biophysics, lays out the pathway for Kotov's work via computer simulations. She probes the defenses of cell walls, known as the lipid bilayer, to find the best paths for a manufactured nanoparticle to find its way in.

"We try to change the size, shape and chemical composition of the particle to control how it interacts with a target's biological systems and interferes with its processes," she said. "Then the question becomes: can we fine-tune the design enough to achieve our goal?"

In one example, the team fashioned nanoparticles into pyramid shapes with long points. Those pointed ends interact with bacterial enzymes.

"Those enzymes also have shapes," Kotov said. "Some have a hole in them, or grooves. Their geometry fits well with the sharp apexes of our nanoparticles."

Bacteria, however, don't like to leave themselves vulnerable. They dig in, setting up defenses. They'll bunch and adhere to any surface they can find in the body. And it's easier for them to hang on to a medical implant than living tissue.

In this strength-in-numbers approach, the bacteria grow in layers and produce a protective gel as a barrier between themselves and immune cells. That gel also keeps antibiotics at bay.

"Even if you assumed a perfect world going forward, one where you weren't seeing this increase in resistance to antibiotics, biofilms would still be a major problem because regular antibiotics don't work on them," said Scott VanEpps, a biomedical engineer and ER doctor at Michigan Medicine. "But in reality, the mechanisms inside biofilms foster the development of antibiotic resistance because you have bacteria in close proximity transferring genes."

VanEpps takes the materials provided by Kotov's lab and tests them to see not only if they work, but how. He has seen firsthand what drug-resistant bacteria can do. For patients, it can create a painful cycle of surgeries to implant devices, remove them once they cause an infection, and replace them with new ones. "Ultimately, taking the devices out of people, that winds up being the solution," he said. "I can't kill the bacteria infecting the device because it's in a biofilm. So it has to come out, often repeatedly."

Other nanoparticles can be designed to attack biofilms specifically. Graphene, a single layer of carbon atoms Kotov describes as "chicken wire," can be designed at the microscopic level, two to five nanometers in size.

"We can coat the edges of the particles with some chemistry and it turns out these graphene particles have a different type of activity in connection with bacteria," Kotov said. "It turns out they can prevent and destroy the formation of biofilms."

That discovery has led the research team to wield nanobiotics in a different way – preventing the formation of biofilms in the first place. By coating medical implants in graphene nanoparticles prior to implantation, researchers are arming them with bacteria repellant that could block infections from taking hold.

But nanobiotics have years of experimentation and clinical trials ahead of them. New options for challenging drug resistant bacteria are needed now. And for that, our own immune systems may show the way.

"WHAT IF THIS ONE BACTERIUM MUTATES SO IT'S NO LONGER SUSCEPTIBLE TO A DRUG OR LESS SUSCEPTIBLE TO A DRUG?"

MULTI-PRONGED ATTACKS

Cricket didn't bring Sriram Chandrasekaran fame as a bowler or batsman the way he imagined growing up in Chennai, along India's southeastern coast. Yet somewhere, in the sport's ranking systems and statistical analyses, it still nudged him toward his future.

Early on, cricket's numbers – particularly odds, probabilities and averages – spoke to Chandrasekaran in a way other youthful interests did not. Today, he is an assistant professor of biomedical engineering, and the numbers tell a different story. They hint at strategies in a struggle more important than anything played on the pitch.

In his North Campus lab, Chandrasekaran and his team are harnessing numbers via the large-scale measurement of proteins – a field given the name proteomics two decades ago. Their work takes place not under a microscope, but on the backs of microprocessors.

Computer simulations predict the impact of changing protein levels in cells before and after stimuli are introduced. Applied to bacteria, these simulations can identify which proteins to disable if you want to kill the cell.

Chandrasekaran's early work in the arena provided our closest look to date at how the body's defenders – killer T-cells – target and destroy bacteria. When the immune system recognizes the presence of harmful bacteria, killer T-cells deploy the protein perforin, which opens up holes in the bacterium's protective membrane. With that door opened, Chandrasekaran's team found that T-cells simultaneously attack multiple processes in the bacteria with protein-degrading enzymes to kill it.

That contrasts with how antibiotics work. For example, amoxicillin, among the most widely-used antibiotics on the market, halts a single process – the bacteria's formation of cell walls.

Mirroring the body's approach, Chandrasekaran said, could aid the battle against drug-resistant bacteria. His proteomics research creates a roadmap for combining drugs already on the market in a regimen that recreates the multi-pronged approach of T-cells.

But roadmaps, while a help, do little to shorten the journey by themselves. And in many ways, researching treatments for drug-resistant bacteria is a race against time.

Technological advances within the last decade have accelerated what researchers like Chandrasekaran can accomplish. And that's key because they face a mountain of variables in their search for better drug formulations.

"Twenty years back, researchers normally measured just one protein at a time," Chandrasekaran said. "You would see papers come out saying, 'We measured the level of Protein X in something like E. coli, and we observed its levels change over time.' That would be a whole study in itself."

"Because E. coli has something like 4,000 proteins, just measuring one protein doesn't tell us much – doesn't give us the big picture."

In recent years, proteomics technology and improved computational methods have allowed for this kind of deep dive. The experimental tech identifies what proteins T-cells target in the bacteria and the computer modeling helps show why specific proteins are attacked and what the outcome is.

And the data generated creates all kinds of possibilities.

"We can now expose different bacteria to immune enzymes in simulations and track what proteins the enzymes go after," Chandrasekaran said. "This gives us a huge amount of data to work with and it's allowing us to develop computer models of the bacteria before and after T-cells attack.

"When data shows that the enzyme from T-cells blocks a specific protein, I should be able to predict what happens to the cell."

That includes being able to simulate how the enzymes impact key cell processes bacteria need to survive. Chandrasekaran likens the work to using route-finding software. Ask those apps to get you home and they'll sort through all of the possible routes to settle on the one most likely to get you there the quickest.

With drug-resistance treatments as the destination, sorting through the options via conventional means of trial and error under the microscope is daunting. Computer simulations point Chandrasekaran's team in the right direction.

"The system of equations we've built mirrors Google Maps; we create a map of how all the proteins within a bacterium interact with each other," he said. "This can tell us if the bacteria has a backup option when a protein is blocked, which they usually do for important proteins.

"So when a drug or enzyme blocks the backup protein, I can now say confidently that blocking that protein is a way to slow the bacteria down or, possibly, kill it."

While Chandrasekaran brings this approach to fighting bacteria in general, one ancient bug is already getting the multi-pronged treatment. And that research may be giving us a look at the future of fighting bacterial infections.

VETERAN OF THE DRUG WARS

They'll tell you tuberculosis can be harmless. On initial infection, it may not produce symptoms at all, or it can remain in the body for years in its latent form.

But its innate tenacity has put it ahead of the game in drug resistance, requiring combinations of antibiotics for treatment as a matter of course.

And when it kicks into its highest destructive gear, it still demonstrates the ferocity of earlier centuries when it was referred to as "captain of the men of death." In 2006, the disease's power was on full display in the small South African town of Tugela Ferry.

An "extensively drug-resistant tuberculosis" (XDR-TB) took hold among the population of roughly 3,000. Early on, the local hospital reported 53 cases. All but one died.

A year later, 314 cases had been reported, eventually resulting in 215 deaths.

Tugela Ferry's region of South Africa is essentially the backyard of Elsje Pienaar's youth – a long way from her current life in America's Midwest. Her academic path wound from a university in Pretoria to a research team headed by Jennifer Linderman, a professor of chemical engineering.

Linderman has spent years examining cell behavior and internal processes such as diffusion, the movement of particles in the body, and chemical kinetics, with a particular interest in immunology. With collaborator Denise Kirschner, a Michigan Medicine researcher in microbiology and immunity, the team has painstakingly crafted a computer simulation of the disease as a means of studying it and, it is hoped, finding new ways to treat it.

With the introduction of tuberculosis, Linderman said, a "battle" begins in the body. One of the hallmarks of that confrontation is the creation of granulomas – dense groupings of immune cells surrounding the bacteria to protect the host. But they also protect the bacteria.

"In some cases, the body's immune system can eliminate the bacteria there completely, sterilizing the granuloma," Linderman said. "That's if you're lucky.

"If you're not so lucky, the bacteria are growing and dividing and the immune system is fighting them, keeping the levels of bacteria low and in check within the granulomas. Or worse, the immune system is not able to keep the bacteria in control and you develop active tuberculosis."

That constant battle in the body has been a focus of Linderman's research group in recent years. Quickly, basic questions came to the fore, like: Why doesn't the immune system simply wipe out every last bacterium? Which cells and molecules of the immune system are most important to keeping the bacteria in check?

To get to the heart of such questions, the team developed computer simulations of the immune response. A powerful resource for such work lies in data collection, and Linderman uses everything she can get her hands on.

Studies of how bacteria behave in a petri dish? Got it.

Animal studies, from mouse to macaque, of tuberculosis progression? Check.

In fact, the team collaborates with JoAnne Flynn, a professor of microbiology and molecular genetics at the University of Pittsburgh, and Veronique Dartois of the Public Health Research Institute at Rutgers University, who examine the disease in animals.

"We were developing simulations where we'd take a piece of lung tissue and start with an infected cell, or infected macrophage and see the bacteria dividing," Linderman said. "We could watch a granuloma grow in simulation.

"Then you start working with variables. What if the immune system came in later? What if the bug didn't divide as well? You can play around with all of the different parameters."

With a detailed simulation of tuberculosis in hand, Linderman's group put together simulations of two antibiotics – isoniazid and rifampin – which are among the most widely used to treat the disease.

> "I AM ALWAYS ATTRACTED BY INTELLIGENCE IN NATURE, AND BACTERIA HAVE CLEARLY SHOWN THEY CAN OUTSMART HUMANS."

And most recently, the team has factored in drug resistance to their tuberculosis simulations.

"Now that we've built a model that has the bacteria and the antibiotics in it, we can start asking 'What if this one bacterium mutates so it's no longer susceptible to a drug or less susceptible to a drug?'" said Pienaar, who continues to collaborate with the team after taking a post at Purdue University last year. "We can change the bacteria's susceptibility to the drug and its growth rate."

The work has given researchers a glimpse of tantalizing treatment possibilities, as well as an idea of the Herculean task ahead.

"The problem is that when you treat tuberculosis, you use combinations of drugs," Linderman said. "Let's say there were 15 drugs that could be of use. Each can be given in multiple ways – once a week, twice a week, over a month or several months, or in multiple concentrations.

"We're talking zillions of combinations. And you cannot test them all. It's impossible to test all of the possible drug combinations, dosage combinations and regimens – from animal models through to human testing."

Jennifer Linderman's team utilizes highly-detailed computer simulations to wade through the "zillions" of drug combinations and treatment variables that can impact the progression of tuberculosis. In recent years, the team has focused on TB's drug-resistant forms.

Even high-powered computer simulations can't slog through every potential combination. But they can point researchers in promising directions – toward the drugs and drug combinations that are most likely to produce results.

It's the general area of the haystack to look in to find that needle.

"Using these simulations, we can predict which direction we should be moving in," Linderman said. "We're not only looking at existing therapies, including immunotherapy options, but we're thinking what drugs – new, repurposed or existing – could be used in different combinations that might be effective."

There's a sad familiarity to many of the conferences Pienaar attends on drug resistance. Inevitably, a presenter will pull up a heat map of areas where resistance crops up most often.

South Africa and its surrounding countries always stand out.

"It's a huge problem back home," she said. "That's why I kind of can't let it go."

THE ROAD AHEAD

The threat of the problem at hand – and its truly global implications – has some of the best minds pivoting from other areas and bringing their talents to bear on antibiotic resistance. Angela Violi's previous work centered on the chemistry of combustion. Scott VanEpps was, at one point, heading down the path of vascular biomechanics. And Sriram Chandrasekaran's work on proteins could have led him anywhere.

"I am always attracted by intelligence in nature, and bacteria have clearly shown they can outsmart humans," Violi said. "They are tiny and yet they understand that if they work in unison, they can launch attacks we can't stop.

"If this work is successful, we can make a real difference and impact lives."

From his doctor's vantage point, VanEpps sees that the research being done at U-M is a vital cog in what will need to be a much larger machine.

"I can't expect Congress to go up to a drug-maker like Merck or GlaxoSmithKline and order them to start developing and making new antibiotics," he said. "There needs to be a diverse portfolio approach."

A real solution, he said, lies in a convergence between philanthropic groups, university support and private investment.

It's a sentiment echoed by undersea explorer and medicinal chemist David Sherman.

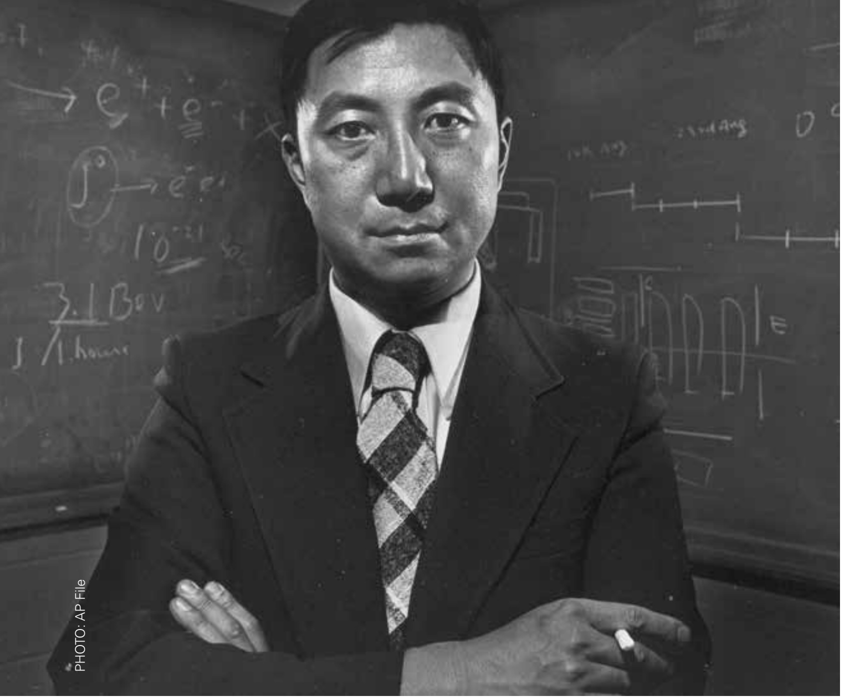
"There is a lot of discovery underway that is seeing promising success,"he said. "The next phase is the really hard part – getting these discoveries to a point where we can decide if a big investment in the next step is worthwhile."

Q&A

with Samuel Ting

Nobel Laureate and Michigan Engineer

STORY BY: KATE McALPINE



Samuel Chao Chung Ting is shown at the Massachusetts Institute of Technology on Nov. 1, 1976. Ting, a longtime MIT professor, was co-winner of the Nobel Prize for physics that year. (Previous page: Image of matter distribution in the universe from the Millennium Simulation Project, Max Planck Institute for Astrophysics)

Samuel C.C. Ting received the Nobel Prize in 1976, with Burton Richter, for discovering the subatomic J/psi particle. He is the principal investigator for the Alpha Magnetic Spectrometer experiment on the International Space Station, a $2 billion project installed in 2011. Here, Ting (BS '59 Eng Phys, Eng Math, MS '60 LSA, PhD '62 LSA) talks about his time at Michigan, the discovery that brought the November Revolution in physics and the most sophisticated particle physics experiment in space.

HOW DID YOU END UP COMING TO MICHIGAN?

I was born in Ann Arbor, Michigan. And three months after I was born, war between Japan and China broke out. My parents decided to return to China.

So I grew up during wartime in China. I never had a chance to go to school. In 1948, we went to Taiwan. Then, my father was a professor of engineering, and my mother was a professor of psychology. Both of them had come to graduate school in Michigan. My mother was very active in the University of Michigan alumni association. I think she was the president.

One day, I think the trustees of Michigan, together with the dean of engineering, visited Taiwan. My mother arranged the program for them, and that's how I met G.G. Brown [George Granger Brown, Edward DeMille Campbell University Professor of Chemical Engineering and Dean of the College of Engineering]. It must have been my sophomore year in high school.

After I graduated from high school, I returned to Michigan. So I went to pay my respects to G.G. Brown. He said, "Well, you don't have a place to stay. Why don't you come stay with us?"

I stayed in their house, and I learned a lot of things from the Browns. The most important thing I learned, I think, was football. They said, "You need to go to a football game with us!"

I had no idea what they were talking about, but I vaguely remembered when I was in Taiwan, my parents were describing football, and they showed no interest. Now, I said to myself, "Now that I am a student at the University of Michigan, I want to be what everyone else is."

So I went to the game. It was University of Michigan versus UCLA. It took me a very short time to figure out the rules. In my six years at Michigan, I probably did not miss any games. I always went to the games.

But more important, because G.G. Brown was the dean of engineering, many accomplished scholars came to visit. So I had the chance to meet many people. I am very grateful to the Browns. George and his wife were very kind to me. At that time, I really didn't understand what was going on.

HOW WAS YOUR ENGLISH?

Practically nonexistent.

WOW. HOW DID YOU GO THROUGH SCHOOL WITHOUT UNDERSTANDING ENGLISH?

That's very interesting because in 1956, the University of Michigan was quite different from the University of Michigan today. There were very few foreign students.

I decided now that I'm here in the United States, if I want to stay here, it's better I learn all the customs and the language. In order to try to accomplish something, you really have to assimilate yourself to the society. So that's why I made an effort to learn English.

The first week, because of the time change, I normally fell asleep in class. And the teacher would call my name, and everybody would laugh because I was asleep. But after a month, people began to take notice of me.

WHY?

Every month, there was a blue book exam. Even at that time. Students, my classmates, began to notice: Well, there's this guy, hardly speaks English, but somehow he always gets his blue book back first. Which meant I was the guy who got the highest grade. And people began to borrow my notes and talk to me, and I made an effort to talk to them. That's how I gradually learned English.

But of course, the courses I took were mostly physics, chemistry and mathematics, and those are somehow easier for me. You don't really need to know the language to figure that out.

YOU'VE SAID THAT THE UNIVERSITY OF MICHIGAN HAD A GREAT INFLUENCE ON YOUR CAREER. CAN YOU EXPAND ON THAT A LITTLE BIT?

I had very good teachers in physics and mathematics. The six years I was at Michigan were really the happiest moments of my life – when I was free, and I could take whatever courses I wanted. It helped me to learn to think freely. And the university was very supportive. They gave me a scholarship.

Before Michigan, I had a very limited education. Six years of high school in Taiwan. I didn't have any grade school in China.

THE REVOLUTION

The discovery of the J/psi caused such a shift in thinking that the period is called the November Revolution. Here's how we built up to that moment.

THE BACKGROUND

Accelerator physics. Einstein predicted that mass and energy are actually interchangeable, but it takes a lot of energy to produce a little bit of mass. So physicists started smashing particles into other particles, concentrating the energy to make new particles. These particles are not normally seen because they give up their mass in the form of energy, downsizing into ordinary particles – such as protons, neutrons and electrons. They typically do so very quickly, in just a nanosecond or less.

THE BREAKTHROUGHS

1947: The "pi meson" is discovered, kicking off the accumulation of a "particle zoo." These particles, discovered with accelerators, were thought at first to be elementary particles – the smallest particles, from which everything else is made. But as the community closed in on a hundred of them, researchers doubted that they were truly elementary.

1964: Physicists first propose the "quark" model of matter: the particles in the zoo are actually combinations of quarks. The three quarks, as well as their antiquarks (which are like the negatives of the quarks – opposite in electrical charge and other characteristics), could explain the known particles: they were called "up," "down" and "strange."

1970: The existence of a fourth quark, the charm quark, is predicted.

Monday, November 11, 1974:

Sam Ting, a physics professor at MIT, and Burton Richter, a physicist at the Stanford Linear Accelerator Center, make a joint announcement. In two different experiments, they had discovered the same particle. Ting's group called it the J particle. Richter's named it ψ (psi).

THE NEW MODEL

The weird thing about the J/psi is its very long lifetime combined with a high mass. It didn't fit any predictions. Eventually, the community realized that the J/psi was made up of a fourth quark, dubbed the charm quark, and its antiparticle. The quark model officially took over. Ting and Richter were awarded the Nobel Prize in physics in 1976.

I went to the University of Michigan on September 6, 1956. And I enrolled in the school of engineering – in mechanical engineering. After the year was over, I had an advisor. Actually it was a very well known professor, Robert White. He took a look at my grades and he said, "You are no engineer."

At that time, there were no computers. So you had to look at a mechanical object from the top, from the front, and from the side. You had to do a three-dimensional drawing, and I was absolutely no good at that. I also couldn't draw a line straight. You know, a line is supposed to have uniform thickness, and I never seemed to be able to do that.

And then Professor White said, "Well, why don't you go to physics and math? Why don't you try to get two degrees at the same time? And why don't you take courses in graduate school? I'll help you to skip some requirements such as sociology and social science."

So that's how I started taking courses in physics and math, and that turned out to be quite easy for me. I got my degrees rather quickly. Entered in '56, I think I got my degrees in engineering physics and engineering math in '59.

At that time, there was still a draft for the war in Vietnam. I was classified as 1A, ready to be drafted. Fortunately, the Atomic Energy Commission had a national competition to select a few physicists and mathematicians and give them a full scholarship and a live-in stipend of $2,000 a semester – at that time it was worth quite a bit of money.

So I participated in the test. Luckily, I was selected. Then the Atomic Energy Commission wrote a letter to my draft board claiming that I'm important to national defense, so I was exempt, and I was able to go to graduate school at Michigan.

Because I had good grades, I started working with George Uhlenbeck. He was the one who discovered that an electron spins – it rotates around itself. So I studied with him.

After about a month, he had a tea with me and a few other of his students. He remarked that, if he were to do his life over again, he would rather be an experimental physicist than a theoretical physicist. I was quite surprised because he was one of the great theoretical physicists of the early 20th century.

So I asked him why and he said, well, an average experimental physicist is very useful because you always measure something. An average theoretical physicist is not. Look at the early 20th century. You have Einstein, you have Dirac, you have Heisenberg, and so forth, you can count them on your fingers how many really made a contribution.

After this little conversation, I decided to leave theoretical physics. I was wondering what to do. Then I met Professor Larry Jones, who is retired but still living in Ann Arbor, and Marty Perl, who recently passed away as a professor at Stanford [and who received the Nobel Prize in 1995 for his 1975 discovery of the tau lepton particle]. They mentioned their experiment in the Lawrence Radiation Laboratory at Berkeley [now the Lawrence Berkeley National Laboratory]. If you join us, they said, you get a trip to California. And I had nothing else to do, so I joined them.

At first, it was really quite difficult. I had no idea what they were doing. But after a while, I begin to learn things. So that's how I became a particle physicist.

SPEAKING OF PARTICLE PHYSICS, CAN YOU TELL ME ABOUT THE IMPORTANCE OF THE J/PSI PARTICLE?

When you break the atom apart, you have a nucleus. And if you break the nucleus apart, there are some things that we thought were elementary particles. Pions, protons, kaons, rho mesons, omega mesons, and so forth. There are a few hundred of them.

All of them have a very short lifetime. In 1974, I discovered this J particle. Soon after this, a family of similar particles were observed by many, many groups worldwide. Their unique feature is their lifetime is 10,000 times longer than all the known existing elementary particles. The significance of which you can visualize as follows.

Everybody lives on Earth to about 100 years. But you find some village in the Upper Peninsula where people live one million years. And then these people are somewhat different from ordinary people. And this discovery means our understanding of physics is totally incomplete. New models had to be made. That is why I received a Nobel Prize – mainly because the J particle changed the basic concept of physics.

HOW DID YOU FEEL WHEN YOU REALIZED THAT YOU'D SEEN SOMETHING THAT WAS REALLY GROUNDBREAKING?

Basically, you have a feeling that you are really very small. There are so many things you do not know. You thought you understood everything. Not the case at all.

DID IT MAKE YOU MORE INTERESTED IN TRYING TO BE THE FIRST TO FIND SOMETHING ELSE?

Yes. I am now doing an experiment on the International Space Station. The idea is very simple. You have heard of the Big Bang origin of the universe. Now, at the beginning of the Big Bang, there is a vacuum. So then suddenly you have a big bang. The universe begins to expand. After 14 billion years, we have the University of Michigan, we have a football team, we have you and me.

Now the question is, at the very beginning of the Big Bang, there must be equal amounts of matter and antimatter because otherwise it would not have come from a vacuum. Nothing exists in a vacuum. So once you have a big bang, the positive and negative must be the same amount.

CAN YOU TELL ME MORE ABOUT ANTIMATTER?

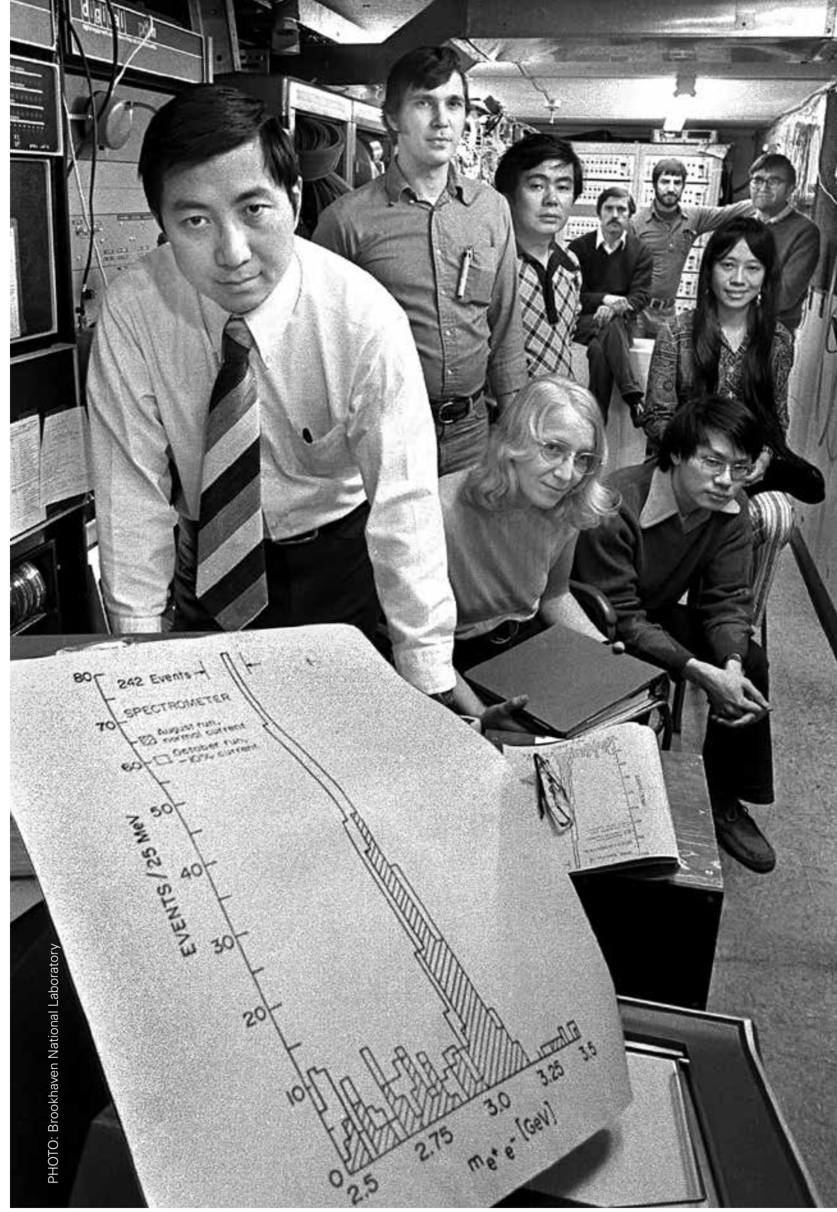
Antimatter exists on Earth. If you go to the hospital, you have a PET scan. That's Positron Emission Tomography. That positron is a positively charged electron, that's the antimatter of the electron.

You also have protons and antiprotons. You have neutrons, you have antineutrons. So every particle has an antiparticle. So the existence of antiparticles is not a question. The question is: If the universe comes from a big bang, where is the universe made out of antimatter? And that's the question I'm asking on the International Space Station.

HOW ARE YOU DOING THAT?

Matter and antimatter have opposite charges. Protons have a positive charge, antiprotons have a negative charge.

To distinguish charge, you need a magnet. So when particles go through a magnetic field, positive bends one way, negative bends the opposite way. So you need to put a magnetic device on the space station. This is a difficult thing because, as you know, a magnet always points north, the other end points to the south. If you're not careful, the space station will spin like a magnetic compass.



Ting (front) gathers with members of his experimental team at the Alternating Gradient Synchrotron at Brookhaven National Laboratory, where he discovered the J/psi particle independently from Burton Richter working at the Stanford Linear Accelerator.

For many years, nobody can put a magnetic detector in space. And then one day, I figured out a way, together with a group of collaborators at MIT. A magnet that doesn't turn. All the magnetic field stays inside the magnet. It's a very simple idea, but it took us 40 years to figure out. And so after we figured it out, we put it in space. So now we can detect matter going one way, antimatter going the opposite way.

DARK MATTER IS ALSO A TARGET OF THE ALPHA MAGNETIC SPECTROMETER, RIGHT?

Yes. What is dark matter? If you look at a galaxy, there are thousands of galaxies that have been examined, every galaxy has a closed orbit. A closed orbit means it is a balance of gravitational force and centripetal force. Only when you have forces that are balanced do you have a closed orbit.

Gravitational force is the product of the mass of the galaxy and the mass of the entire universe. Centripetal force is the mass of the galaxy and the speed. And so if you put all this together, you examine the galaxy, you find out the amount of material – the amount of matter

In 2011, the Alpha Magnetic Spectrometer was delivered to the International Space Station aboard the Space Shuttle Endeavor, clearing the way for Ting's ongoing experiment to try to solve the mysteries of antimatter and dark matter.

you need in the universe – is ten times more than what you see in the universe. In other words, 90 percent of the universe you cannot see.

This is not only true for our galaxy, it's true for thousands of galaxies that have been examined. That's why it's called dark matter. It's called dark matter because you cannot see it. Nobody knows what dark matter is like. But the collisions of dark matter become energy. Energy can change into matter from relativity. And so you can produce positrons and antiprotons. So by measuring these particles, you can try to get a hint of what is going on with the origin of dark matter. In fact that's what we're doing now. We are measuring cosmic rays, particles shooting through space.

AND THIS SHOWS UP AS AN EXCESS OF ANTIMATTER IN YOUR DETECTOR? AS IN, MUCH MORE THAN YOU WOULD EXPECT?

Huge excess! Enormous excess of positrons and antiprotons. Much more than from ordinary collisions of cosmic rays. So something new – some new phenomena is there.

It will take some time for us to pin it down. But up to now, we have collected more than 100 billion cosmic rays, up to an energy of a trillion electron volts [in other words, a particle with the same kinetic energy as a flying mosquito]. And all this phenomena, all the things we have collected, cannot be understood by the knowledge of existing cosmic ray physics.

WHY HADN'T OTHER COSMIC RAY EXPERIMENTS CAUGHT THIS?

Before us, there have been many experimental measures of cosmic rays by balloons and small satellites. Balloons, you can send to space, but not to 400 kilometers above earth. They normally fly to about eight kilometers. So you still have atmosphere above.

Also at night, when the temperature cools down, the balloon tends to fall to the ground. Balloons tend to stay aloft for a few days to a maximum of a month or two. So you cannot make a precise measurement.

Small satellites normally do not carry a magnet. If you don't carry a magnet, you cannot distinguish positive charge and negative charge. So this is the first time you have a very large particle physics type detector in space. So basically we open the door into a new territory. There are now hundreds of theories to explain what we have observed.

WHAT ARE YOUR FAVORITES?

Oh, when they ask me, I always tell them they are all correct. Some people say, oh, it's because the origin of the positrons or antiprotons come from a different form of supernova explosion. Some people say it's because of the propagation through space, some of them have been accelerated. There are many, many theories.

But to me, that's really not important. The important thing is to do the measurement very accurately. This is a very precise experiment, so we need three or four more years to finish all the measurements.

So far, though, we have made measurements of positrons, antiprotons, helium, lithium, elements across the periodic table. These measurements are very, very accurate. I run a collaboration of about 600 physicists. We normally have two teams, sometimes four teams, to analyze the same data. Only when all agree within one percent, we will publish.

SOUNDS STRINGENT.

Yeah, because it took us nearly 20 years to put this device in space. And in the foreseeable future, there are probably no similar detectors in space. So we have an obligation to get it right because nobody else can perform the same measurements.

This is the same data, same detector. But to achieve an accuracy of one percent, a judgment call is needed. What is a real particle signal, what is background from the detector itself? There is always a human element. Most of the time people don't agree. But I want to understand why. Eventually, people reach agreement.

HOW DID IT FEEL WHEN YOUR EXPERIMENT LAUNCHED AND WAS INSTALLED ON THE SPACE STATION?

I was quite scared because before that, I used to do experiments in accelerators. And in accelerators, if you have something you're worried about, you can shut down the accelerator and go in and take a look. I remember when the space shuttle took off, I was quite, quite concerned. Because suddenly, I could not check anything.

Fortunately, most of the elements are redundant. The electronics and the computers sometimes have fourfold redundancy, and the minimum is two-fold redundancy. So if one goes bad, another one can switch and replace it.

AND FINALLY, FOR THE FOOTBALL FANS, WHAT ARE YOUR FEELINGS ABOUT OHIO STATE?

When I was at Michigan, the first thing I learned was not physics – the first thing I learned was, "Beat Ohio State!"

I remember one year, Michigan did not do well. The Michigan-Ohio State game was always the last game. The stadium had a capacity of 100,000 people, but that year, because Michigan had done so badly, and it was raining hard, there were only about 5,000 people in the stadium. And I was one of them.

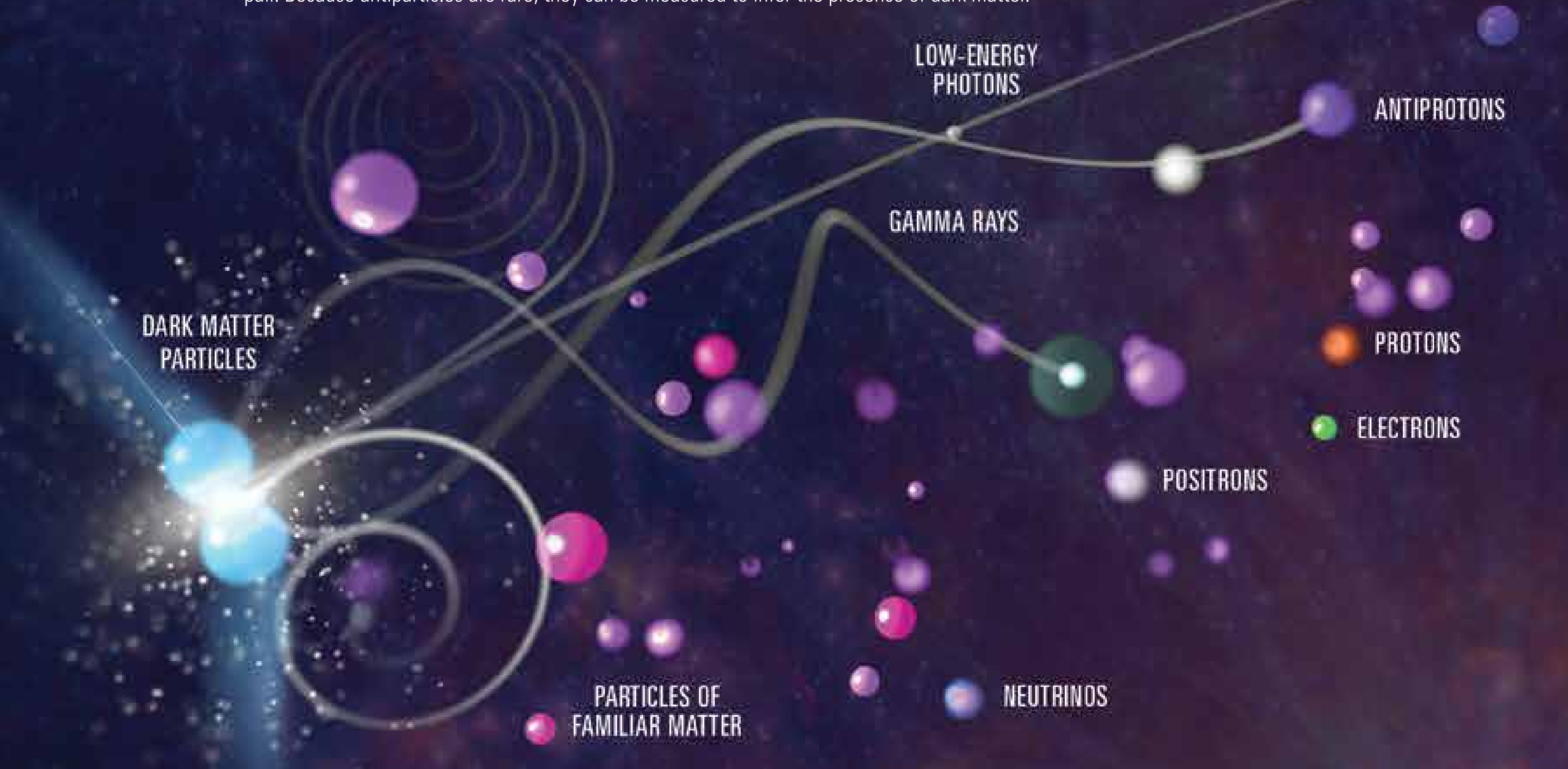
A few years ago, I went to visit Ohio State. They invited me to give a speech about my experiment. They announced I was from Michigan, and I heard this "Booooo" noise. When it was my turn to do the talk, I told them I came from Michigan, and today is the first day I actually realized that Ohio State has classrooms on its campuses!

WHAT IS DARK MATTER?

Galaxies are spinning too fast. At least, if you consider the amount of matter in them – there isn't enough gravity to hold them together. They should contain about five times more matter to produce that gravitational force. This is why scientists believe there is "dark" matter floating out in these galaxies, helping to hold the stars together.

DARK MATTER IS ITS OWN ANTIMATTER

Dark matter particles are their own antiparticles. If they bump into one another, they'll revert the energy, a process called annihilation. This energy can then become any kind of particle-antiparticle pair. Because antiparticles are rare, they can be measured to infer the presence of dark matter.



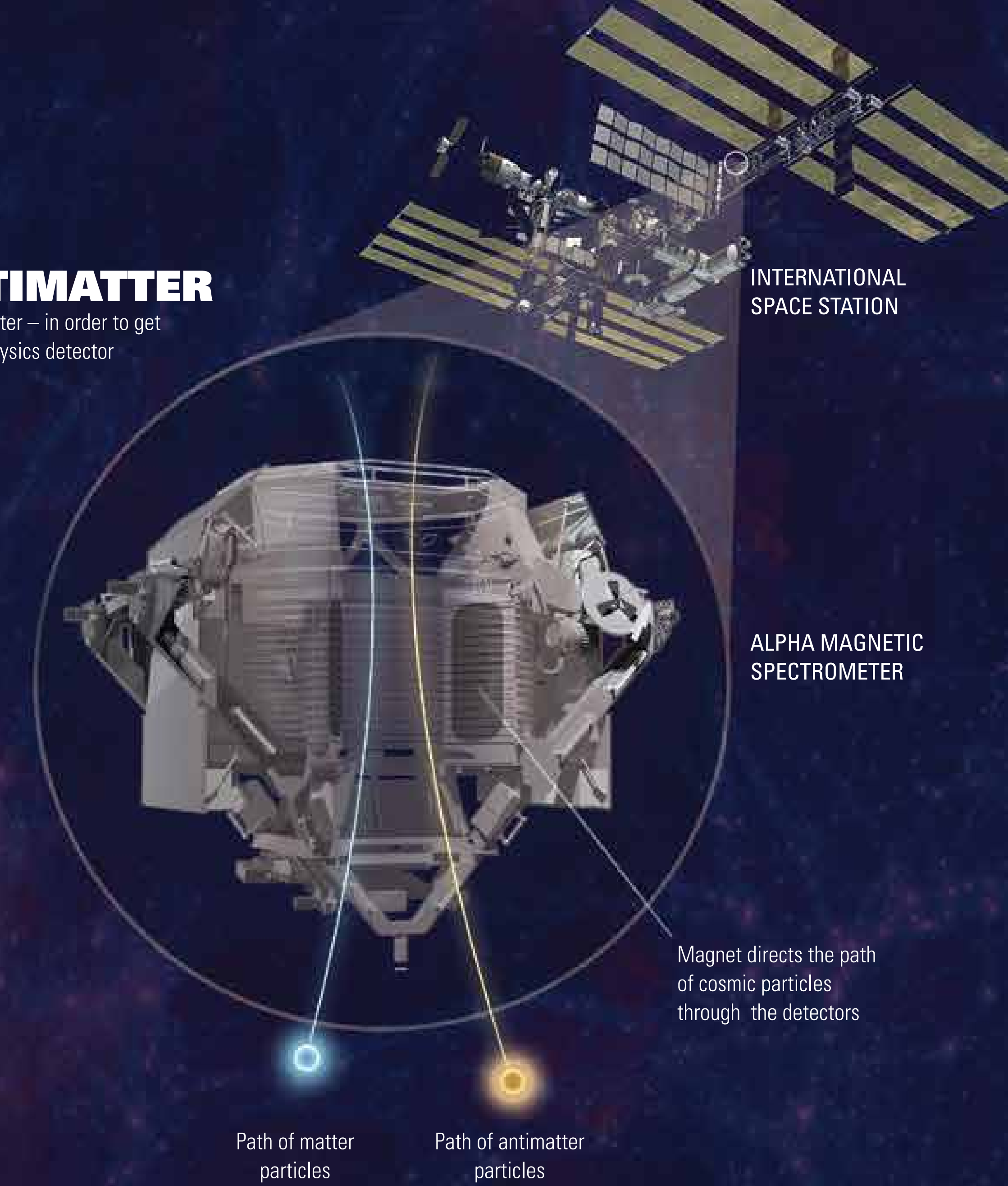
INFOGRAPHICS: Steve Alvey

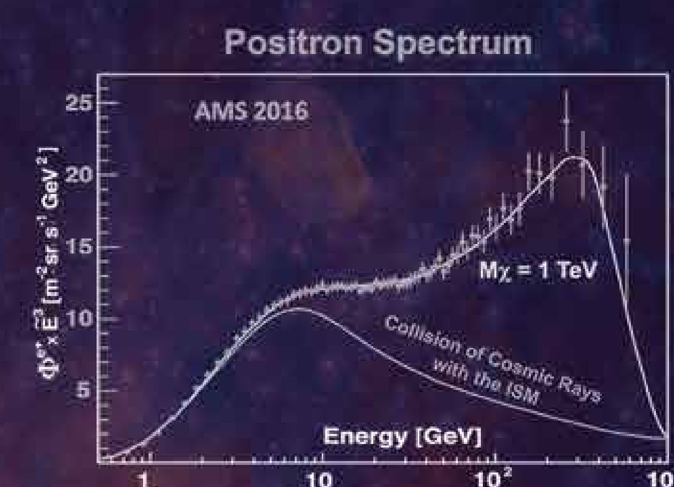
MEASURING ANTIMATTER

Ting and his colleagues are looking for antimatter – in order to get hints about dark matter – through a particle physics detector on the International Space Station.

The central component of the detector, called the Alpha Magnetic Spectrometer, is a large magnet. When particles pass through this detector, positively charged particles curve one way and negatively charged particles curve the other way. The scientists combine this information with a measure of the mass to determine a particle ID. Some are regular matter, such as electrons. Others are the corresponding antimatter, such as positrons.

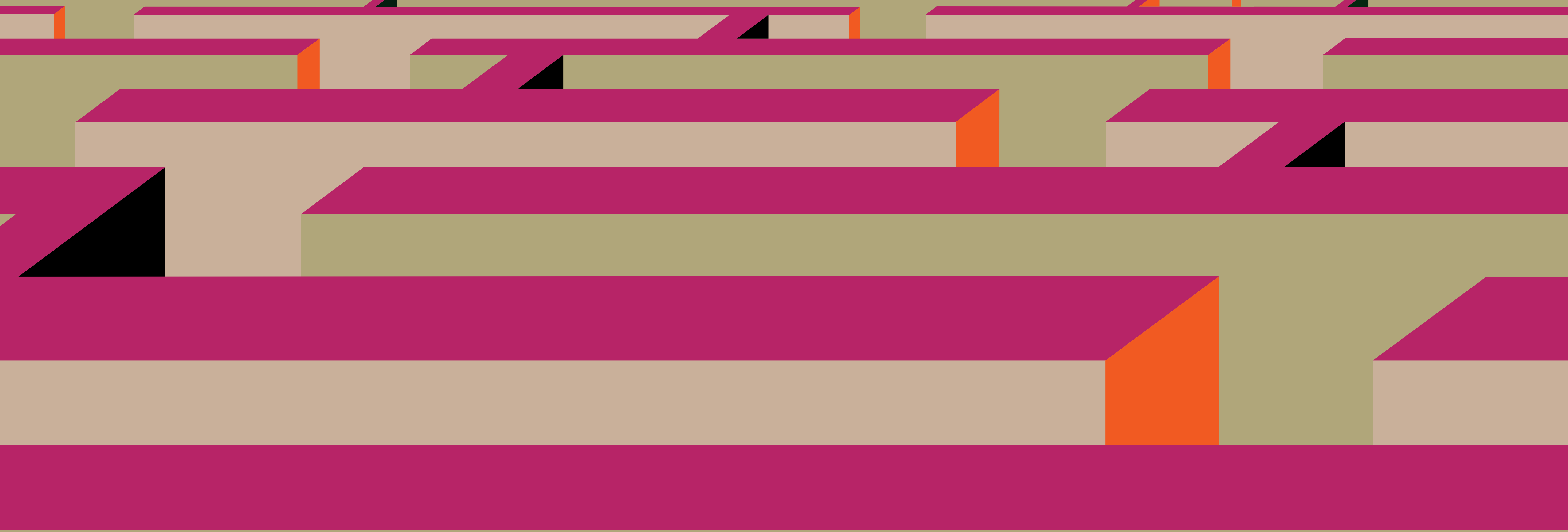
A certain amount of antimatter is expected from cosmic ray collisions (particles that are catapulted out of exploding stars), but if dark matter particles are running into one another, we should see more.





SO HAS THE DETECTOR FOUND DARK MATTER?

It has measured a suspicious trend in the positron spectrum – or how the frequency of positron detections changes at higher and higher momentum measurements. The curve resembles what you'd see if there were dark matter particles with masses of about one teraelectronvolt – roughly 1000 times more massive than a proton. But it doesn't qualify as a smoking gun – this pattern could also come from proposed physics related to exotic post-supernova stellar remnants known as pulsars. Still, by the end of the experiment in 2024, Ting is optimistic that we could have an answer.



MAPPING THE GAPS

Why do smart students fail and how do social systems influence their success? Understanding mentorship and community to create engineers.

STORY BY Cara Gonzalez

PHOTOS BY Joseph Xu

Joi Mondisa, assistant professor of Industrial and Operations Engineering (IOE) and engineering education, in her office on North Campus.

Mondisa (right) discusses research with Seth Guikema (center), associate professor of IOE, and Mark Daskin, IOE chair.

"I really believe we need a diverse group of engineers if you want to have good engineering practice in this country."

IN one of her first engineering classes, Joi Mondisa encountered a problem – one that would lay the foundation for her life's work as an engineering education researcher.

In the late 1990s, she had graduated at the top of her class at a multicultural high school in suburban Chicago. She had always excelled in math and science and worked well with other students. A college major in engineering seemed a perfect fit.

But at university, it was different. In one of her very first class discussions, she attempted to contribute to the group discussion. However, her ideas were ignored.

"It was like" – she mimes tapping a microphone – "'Is this thing on?'"

Mondisa noticed that some of her classmates chose not to sit next to her. And while classmates would work together on the homework, no one collaborated with her.

She grew uneasy. What was she doing wrong? She confided in a trusted faculty member – someone who would become one of her most influential mentors. But he had a hard time understanding Mondisa's experience. He is a white man. She is an African-American woman.

This situation was not unique – not for her, or other underrepresented minority (often referred to as URM) students. A steady stream of studies from the 1990s to today has shown that many African-American students experience a "chilly" campus climate at predominantly white institutions. In a challenging major like engineering, this lack of connection provides, at best, little support for the student, and at worst, withdrawal from the field. Scholars say it's partially to blame for the low numbers of URM students in engineering.

Mondisa got through both her undergrad and grad school. In 2014, she attended Michigan Engineering's NextProf, an annual workshop for women and URM early career scientists and engineers who are contemplating careers in academia. Today, Mondisa is at Michigan Engineering as an assistant professor of Industrial and Operations Engineering (IOE) and an engineering education researcher.

From this unique perch, she is analyzing systems within engineering education. She's taking a quantitative approach to answering one of the most complicated questions in engineering education research: What is the role of social community in the retention of engineering undergrads, especially URMs?

"The curriculum for engineering is hard already. On top of that, an intimate knowledge of the higher education system is required to be successful," says Mondisa. "Learning to navigate the system can be extremely difficult."

Industrial and operations engineers analyze and optimize some of the most complex systems known to humans in areas such as health care, ergonomics and disaster planning. From her uniquely valuable position at the intersection of engineering and engineering education, and informed by her life's experience, Mondisa aims to illuminate what mentoring methods, approaches and programs actually work – and why. She began by studying the mentors themselves.

The work could have implications not just at U-M but across engineering.

"I really believe we need a diverse group of engineers if you want to have good engineering practice in this country," said Mark Daskin, the Clyde W. Johnson Professor and chair of the Department of Industrial and Operations Engineering. "To design anything, you want a very diverse group of engineers and potential users."

Mondisa's engineering education colleagues agree. "Mondisa works alongside her IOE colleagues, teaches IOE classes, and her research is in alignment with the department, but it's outside of the scope of what they've normally done," said Cindy Finelli, director of the Engineering Education Research Program and associate professor of Electrical Engineering and Computer Science. "So here at U-M, the work that Joi is doing is directly tied to IOE."

LOST POTENTIAL AND REVENUE

Mondisa earned her bachelor's degree in engineering in 2001 from the University of Illinois at Urbana-Champaign. She worked in industry for ten years and completed an MBA during this time. Then she returned to school and earned her master's in industrial engineering and PhD in engineering education. In 2016, she accepted a tenure-track position at U-M.

Then why are success stories like hers still so rare? The engineering workforce is no more diverse now than it was when Napster debuted and Y2K was a looming concern. In 2001, when Mondisa graduated, 1.74 percent of engineering bachelor degrees were awarded to African-American women. In 2015, almost fifteen years later, the number had fallen to below 1 percent. In fact, African-American and Hispanic students are more, not less, underrepresented at top universities than they were 35 years ago.

Both academically and professionally, the representation of women and minorities in engineering has either plateaued or started to backslide for the past two decades. In 2014, women accounted for 24 percent of the engineering workforce, down from 25 percent in 2001. And at the same time, African-American and Latino workers represent 29 percent of the general workforce, but just 16 percent in advanced manufacturing, 15 percent in the computing sector and 12 percent of engineers.

That's years of lost potential for diverse engineers. It could also add up to lost revenue for the entire industry. McKinsey researchers in 2015 found that companies in the top quartile for racial and ethnic diversity are 35 percent more likely to have financial returns above their respective national industry median. And companies in the top quartile for gender diversity are 15 percent more likely to have better financial returns.

Engineering is a career with high status, big paychecks, and opportunities to contribute to society. It's an elite program of study that can break cycles of generational poverty. Engineering degrees are prized across cultures. This exceptionalism has created a system of educating engineers that many believe is calibrated to allow only a certain variety of student to survive. It can be cutthroat and competitive. And that might push out students who don't exactly fit the mold.

Valerie Washington, an IOE PhD student, and Mondisa discuss a potential project in Mondisa's office.

Not everyone sees that as a problem. In a 2016 nationwide survey of engineers co-sponsored by the Society of Women Engineers, 16.8 percent of male engineers expressed the view that diversity is threatening the quality of the profession and that women now have unfair advantages. Compare that to 3.6 percent of male lawyers in a similar survey.

U-M, as well as other engineering education researchers like Mondisa, are working hard to shift this attitude for the sake of the profession, and in support of the common good.

ENGINEERING EDUCATION: THE NEXT FRONTIER

Engineering education research is an emerging field, a discipline that came to prominence in the 1990s. Concerns were mounting: the supply of engineers wasn't adequately meeting the demands of a nation facing increasing global competition and an appetite for technology.

In 1995, the National Research Council, part of the U.S. National Academy of Sciences and the U.S. National Academy of Engineering, published "Engineering Education: Designing an Adaptive System," which outlined the steps to address the "needs and realities" of the United States and the world in the 21st century. The council imagined the world would need a bigger, more diverse pool of engineers to address the global challenges facing humanity.

Purdue University, where Mondisa completed graduate studies, established the nation's first school of engineering education in 2004. Michigan launched its own engineering education program in 2017 and the Engineering Education PhD program launches in fall 2018. Michigan's program is unique in that it embeds engineering education researchers in traditional engineering departments as a way to bridge the gap between theory and practice. No other large research university takes this approach. "Sitting side by side with our engineering colleagues means we have an immediate way to implement our research findings into practice," said Cindy Finelli.

"We really have an opportunity to improve society by helping develop better engineers," Finelli said. "We're applying research methods and practices from education and sociology to study questions in the context of engineering. It spans the entire engineering ecosystem – how can we encourage K-12 students to explore STEM concepts? What can we do as faculty to help support a broader group of undergraduates? What mentoring practices would be the most effective at helping grad students? Or what we can do on a policy level?

Engineering education research departs from the traditional view of engineering: Math and science are driven by right answers, so shouldn't it be possible to graduate the best engineers simply by fostering competition for the best scores?

"It's usually the first thing people say when you ask them why they chose this field," Mondisa says. "'I went into engineering because I was good at math and science.'"

She opens her palms, a little apologetic. "Even I say it. What we really should say is, you need to have strong science and math skills. You have to be willing to work hard at it and enhance your skills."

She's not saying anyone should make engineering easier. "We want to change how we talk about engineering so that it's more inclusive, but at the same time, be truthful. Engineering is a tough curriculum."

So what's needed beyond math and science skills? Engineering education researchers point to three traits previously identified by psychologists: grit, resilience and persistence. Grit is a deep commitment, or an ability to continue even in the face of adversity and inevitable failure. University of Pennsylvania psychology professor Angela Duckworth, who has popularized the concept, found that grit is a better predictor of success than talent. Resilience is the ability to bounce back from failure, like from receiving a bad grade, and persistence is the ability to stay focused, like completing a semester-long project.

Mondisa and other engineering education researchers are examining how to help engineering students develop these critical character traits. Students with these traits will be more likely to survive engineering's rigorous curriculum. Those without them, even top talent from the competitive high schools, are at risk of failing, especially in their first year.

One of the keys to this, Mondisa believes, is community. And one of the crucial benefits of community is mentorship – from both peers and faculty members.

A MECHANISM FOR SUCCESS – MENTORSHIP

Mondisa believes that mentorship matters. Research shows that mentoring minority college students makes them twice as likely to stay in school as their non-mentored peers, and to have higher GPAs.

When she launched into her engineering education PhD program, Mondisa, like many researchers, was interested in studying protégés. But as she reflected on her own experience, she flipped the model to examine the mentors themselves, why they're effective, and what mechanisms help students develop the toolkit they need.

"I saw mentorship as the mechanism that needed to be studied. Protégés are the benefactors of mentoring."

Mondisa smiles when she remembers that first college mentor. "He really is a great mentor," she said.

Throughout the rest of her undergraduate career, he shared with her what she describes as "social capital." He illuminated the internal structure of higher education and how the world of research worked, unlocking key pieces of information that she needed to keep reaching for the next step.

> "I saw mentorship as the mechanism that needed to be studied. Protégés are the benefactors of mentoring."

In her research, she is examining how and why mentoring works – in the context of engineering.

In her current research, she uses mixed methods – both qualitative and quantitative approaches. In a qualitative study, Mondisa interviewed underrepresented minority STEM mentors. Results from this study indicated that mentors share coping strategies and knowledge about their experiences with their protégés. Mentors also use cultural and social capital to motivate and connect. In addition, she found that some mentors take a holistic approach to mentoring their protégés and they encourage them to advocate for themselves.

THE SAVING GRACE OF COMMUNITY

Mondisa knows firsthand how social factors can loom over an undergraduate experience.

During her undergraduate career, some people went out of their way to let her know they didn't think she belonged. For example, they asked her if she was admitted into the program under the university's affirmative action plan. These social roadblocks began to stall her upward trajectory.

Mondisa found what she called "her saving grace" in a group of students who were experiencing similar phenomena in their classes.

Mondisa teases Washington about her long list of ideas on where to focus her graduate studies. As Washington's co-advisor, she understands the need to help Washington direct her passions.

A portrait of a black female dressed in a graduation gown hangs in Mondisa's office. It comes from a community workshop that she and her engineering education cohort attended while at a conference, and serves as a reminder of the role her own community has played in her life.

"In higher education, having a support system can be crucial for people of color, who may face additional obstacles and challenges."

They were her fellow Merit Scholars at the University of Illinois at Urbana-Champaign. The program provided a social community for Mondisa, where she could find the support she needed to get through. "We'd say, 'We all got into this program. We're all graduating,'" says Mondisa.

They became a tribe who helped each other survive. They met for study groups, exam prep and an occasional movie.

"That community was critical for my survival. We were all from different backgrounds – black, white, city and suburban kids, as well as kids from farms and rural areas. What was also important is that we were not remedial students," Mondisa said. "We were the high-achieving, 'cream of the crop' students from our high schools, but we were at risk of not graduating from university because of environmental factors."

Mondisa knew from her experience that the social community played a big role in completing her engineering degree. She held onto the idea that this saving grace could be studied and replicated. "I'm an industrial engineer. I want to understand systems," she explains. There is a system at work, and it can be empirically studied, she reasoned.

Now this work has begun in earnest, even if it is in the early stages. She is a new U-M professor in a young field. Her research contributions include a "social community scale" and a "social community model" to begin empirically assessing social communities, environments where like-minded individuals engage in dynamic, multidirectional interactions that facilitate social support.

The scale makes the connectedness of a community measurable. Mondisa and Sara A. McComb from Purdue University used it in a study published in March about the role of social community in minority mentoring programs. The study surveyed 179 current and past members of the Merit Program for Emerging Scholars at the University of Illinois at Urbana-Champaign. Participants were asked to answer a series of questions about how connected they feel to others on campus and how satisfied they are, in general, about their school. The study analyzed how people experience social community differently based on demographic factors such as being male or female, undergraduate or graduate, and white or non-white.

One of the findings of the study was a significant relationship between connectedness and race: The connectedness mean for whites was 3.75 out of 5 and 3.47 out of 5 for non-whites.

Based on the findings, the study called for more research about why non-whites feel less connected, in order for universities to improve the effectiveness of mentorship programs for these populations. Overall, the research reveals the underpinnings of social community. The more we understand it, the better we will be at fostering it. This research can help colleges identify sources of a lack of social community, as well.

The Social Community Model was used in this research. The Social Community Model is a framework that can be used to examine participants' program experiences and outcomes and empirically assess engineering mentoring programs like the Merit Scholars Program.

Such programs have been successful in promoting student retention and many engineering schools have similar programs, including the University of Michigan's M-STEM program. Mondisa studies the social mechanisms within these programs. She pays close attention to the participants' outcomes, such as their ability to be resilient, engage in communities of practice and build social capital.

In a social community, group members need to share a similar mindset. They don't necessarily have the same ethnicity, socio-economic status or other demographics. But they are a part of a community because they share values and goals like becoming an engineer or passing a class. Mondisa noted that people in such a community tend to experience a reduction in friction and an increase in cooperation. They work toward similar ends and share that knowledge with everyone in the community – no matter their demographic differences.

The model offers a way of understanding the costs and rewards for all members who create social support through the back-and-forth of their interactions. It can be as simple as spending time solving problems they understand and receiving help from other individuals about problems they cannot solve. But they also gain social capital, which they can "spend" in their community – for example, trading chemistry notes for a bit of tutoring on last night's calculus homework.

When you're an outlier, you will need an extra-strong social support system because you're going to have additional pitfalls to handle. Mondisa says, "In higher education, having a support system can be crucial for people of color, who may face additional obstacles and challenges."

HIGHER ED, HIGHER STAKES

Mondisa points to a painting that hangs in her office. On a background of deep red – her favorite color – stands a black woman holding her diploma proudly. It's a reminder of the importance of her own communities. Several women of color in her PhD program helped form Mondisa's social community.

In reflecting on her experiences as part of this community, Mondisa says she received the support she needed. "We're all in this together. Knowing you're not in a situation alone helps you to continue." Mondisa continues to contribute to and access her support resources. "I keep going back to my community. I talk to friends and colleagues as well as mentors. I continue tapping into my support system."

Perhaps one of the most important intangible assets that students receive from their social communities is how to value and work in what is called "communities of practice." She's found that the communities don't end when the mentoring program does. Participants can seek out new communities of practice or even create them.

It's happening around her at U-M, as she holds up a mirror to an institution charged with building the next generation of engineers. Using data, she's showing what's required to achieve the vision of a global, diverse and collaborative workforce of the future. It's not enough for engineers to build mentoring programs and methods based on what's going on in social and behavioral sciences – they want the schematics, they want to build it, test it, and they want to make it better.

At U-M, Mondisa serves as an informal advisor for a fledgling support program, a student-faculty partnership between her department and the National Society of Black Engineers student chapter at U-M. They meet monthly to discuss undergraduates' needs and concerns and to cultivate relationships between URM IOE undergrads and IOE faculty. At a recent meeting, a student said, "I feel pretty good about the campus climate here."

Mondisa put her hand on her heart. She was relieved and elated to hear that comment.

VICTORS STEP UP

MICHIGAN ENGINEERS ARE STEPPING FORWARD TO TRANSFORM THE COLLEGE – AND THE WORLD – IN OUR $1 BILLION RESOURCE-GENERATION EFFORT

ALL IN THE FAMILY

The Nuclear Engineering Laboratory, home to the Glenn F. Knoll Nuclear Measurements Laboratory.

The late **Glenn F. Knoll**, a highly esteemed professor of nuclear engineering and radiological sciences, spent more than 50 years at U-M from his PhD onward. In such a close-knit department, his wife, **Gladys Hetzner Knoll** (BSN '78, MSN '80), is a part of the NERS family.

Now, Gladys Knoll has established the Glenn F. and Gladys H. Knoll Department Chair of Nuclear Engineering and Radiological Sciences, tying their legacy to the position that Glenn Knoll held from 1979 to 1990. The endowment creates a discretionary fund for the chair. Ron Gilgenbach, current NERS chair, is the first to hold the new title.

"I am supremely grateful to Gladys for her generosity. Glenn set the standard as chair and professor of NERS. I am deeply honored to be the inaugural chair to have this distinction."

Gladys has her eye on the future of the department, as NERS is in the midst of a search for the chair who will take office in September when Gilgenbach steps down after eight years.

"My hope is that this endowment will be an inducement for a top-notch candidate to come to U-M NERS. After all, it's important to maintain that number-one ranking," she said.

Gladys also has endowed the Glenn Knoll Scholarship Fund and the Glenn F. Knoll Lecture, and has provided resources to name the Glenn F. Knoll Nuclear Measurements Laboratory in the Nuclear Engineering Laboratory.

BETTER MATERIALS, BETTER PRODUCTS

There is a lot of science in the products we use every day. For example, take a diaper. Expectations are high for the fibers inside.

Stacks of the baby care items are compressed in their packages for what could be months at a time, and when the package is opened, the fibers must absorb moisture and odor as well as they did on the day they were made.

This is a seemingly simple example in a range of everyday products that benefit from engineering expertise. And it's one of many ways that Procter & Gamble is partnering with U-M researchers to improve its products.

P&G has a strong history in recruiting and classroom engagement at U-M, but in recent years, U-M has also emerged as one of the company's leading university partners in research and development. The Cincinnati-based company currently has 21 active research projects across seven U-M schools and colleges – and a third of them are with Michigan Engineering.

This includes the Materials Innovation Collaborative, a partnership launched in 2015 that examines how soft materials like diapers and shampoos behave, leveraging Michigan Engineering's strengths at modeling and simulation to find new possibilities.

"Three years ago, we declared our strategic partnership between P&G and the University of Michigan and since then, we have been able to have focused and fruitful collaborations leveraging the strong multidisciplinary innovation ecosystem that the university has to offer," said Kathy Fish, Chief Technology Officer, Procter & Gamble Company.

To date, between R&D and philanthropic support, P&G has supported nearly 40 different units on all three U-M campuses.

CONNECTION TO CHINA

Although the reasons for investment in Michigan Engineering vary, there are a growing number of examples of donors with connections to China. Sometimes the connection is based on the deeply personal experience of an alum; other times it is based on the promise of mutual learnings from opposite sides of the globe. A common thread, however, is how they often benefit students.

SUPPORTING JOINT INSTITUTE STUDENTS

Students from the Joint Institute between U-M and Shanghai Jiao Tong University are eligible for need-based support when they enroll at Michigan Engineering, thanks to an endowed fund from **Jackson** and **Muriel Lum**. Jackson Lum was a professor in QCC of the City University of New York and an electrical engineer. The husband and wife originally emigrated from China. Jointly they built up an electronics business in New York.

BUFFER FOR NEW PhD STUDENTS

When doctoral students start at U-M, they immediately need to find a project that will provide funding. For international students in a new culture, this can be challenging. Thanks to an endowed fund established by **Liming** and **Zhenhuan Yu**, first-year international doctoral students are eligible for fellowships that provide a buffer. The funds will cover their first- or second-semester tuition, stipend and health care costs.

Liming Yu established an auto supply company in China. His son, Zhenhuan (MSE IOE '17), earned his master's degree at Michigan Engineering after the family learned about U-M through the Joint Institute.

BUILDING A BME CURRICULUM

Biomedical engineering is an emerging field in China. To spur its development, the **Li Ka Shing Foundation** is investing in a partnership with the Biomedical Engineering Department (BME) at U-M to develop a BME program with Shantou University in China.

This joint effort is expected to enrich the BME programs at both institutions. It brings together people from each university to share in curriculum development. In addition, Michigan's BME department – which lies at the interface of Michigan Engineering and Michigan Medicine – is innovating its novel teaching practices and experiential learning modules. These will be adapted by the two universities to meet the specific opportunities at Shantou.

The Li Ka Shing Foundation, which seeks to inspire societal improvement through supporting education and health care initiatives, is the philanthropic foundation of Hong Kong businessman Ka-shing Li.

THUNDERX GETS ROLLING

A new partnership between U-M and Cavium Inc., a San Jose-based provider of semiconductor products, will create a powerful new big data computing cluster available to all U-M researchers.

The $3.5 million ThunderX computing cluster will enable U-M researchers to, for example, process massive amounts of data generated by remote sensors in distributed manufacturing environments, or by test fleets of automated and connected vehicles.

"U-M scientists are conducting groundbreaking research in big data already, in areas like connected and automated transportation, learning analytics, precision medicine and social science," said Eric Michielssen, associate vice president for research-advanced research computing, the Louise Ganiard Johnson Professor of Engineering, and professor of electrical engineering and computer science. "This partnership with Cavium will accelerate the pace of data-driven research and opening up new avenues of inquiry."

Syed Ali, Cavium's founder and CEO and a U-M alumnus (MSE EE '81), added, "I know from experience that U-M researchers are capable of amazing discoveries. Cavium is honored to help break new ground in big data research at one of the top universities in the world."

Along with applications in fields like manufacturing and transportation, the platform will enable researchers in the social, health and information sciences to more easily mine large, structured and unstructured datasets. This will eventually allow, for example, researchers to discover correlations between health outcomes and disease outbreaks with information derived from socioeconomic, geospatial and environmental data streams.

Cavium is a leading provider of semiconductor products that enable secure and intelligent processing for enterprise, data center, wired and wireless networking.

– Dan Meisler, Advanced Research Computing

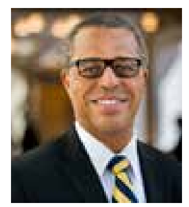
ON STRATEGY

Four questions for members of the Leadership Advisory Board

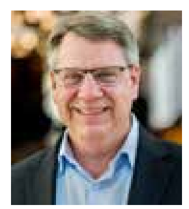
How can Michigan Engineering gather the best ideas to improve its strategic direction? One of several ways is through its Leadership Advisory Board (LAB). It has tapped an impressive array of leaders for this group. The board's charge is to provide strategic insight, guidance and assistance to the dean to execute the College's vision and mission. Members, many of whom are alumni, are selected based on a demonstration of outstanding professional achievement, commitment to the long-term vitality of Michigan Engineering and enhancement of the LAB's breadth and diversity.

We checked in with these thinkers to see what resonates with them about the direction of Michigan Engineering.

Susan J. Schmitt
Sr. VP of H.R.
Rockwell Automation



Kenneth Washington
VP & CTO of Research & Advanced Engineering
Ford Motor Company



Richard I. Lesser (BSE ChE '83)
President & CEO
Boston Consulting Group

OUR FOUR QUESTIONS:

1. You've heard a lot from the Dean and other College leaders about the development and meaning of the vision and mission. What excites or impresses you about it?

Schmitt: I love the vision's focus on being a thought leader of engineering research and education for the benefit of the common good for the 21st century! This statement is powerful, long-term-oriented and inspiring.

Washington: I am both impressed and excited about their commitment to cross-disciplinary research, where they clearly recognize that big innovations and discoveries happen at these cross-disciplinary intersections.

Lesser: A big challenge for any organization is how to create momentum for continued change, innovation and improvement – to avoid complacency, to not stand still. This plays extremely well to the ambition of the College of Engineering. As good as it is, I am really energized by the goal to take it to the next level in terms of research contributions, community involvement and investment in the next generation of engineers and leaders.

2. What's a key strength or opportunity for Michigan Engineering?

Schmitt: Students at Michigan Engineering are encouraged to pursue bold ideas. Faculty and researchers, among the top leaders in their fields, are guided by a desire to create a long-term, tremendously positive impact for the College. Their goal: work together to create a diverse and welcoming community that expands opportunities for everyone.

Washington: Their proximity to the heart of the U.S. automotive industry is an important strength and opportunity for Michigan Engineering. They have a unique opportunity to help drive the reinvention of the automotive industry in areas like electrification, autonomy and connected smart vehicles more than any other university in the world.

Lesser: Michigan has great opportunities and strengths to build upon. A key opportunity is its location in the industrial heartland of the U.S., where there are amazing companies to collaborate with to drive breakthrough innovation. A core strength is the world-class quality in many disciplines: medicine, business, LSA and the engineering college itself, which has so many departments on the leading edge. Meaningful breakthroughs in today's world really require leveraging a truly interdisciplinary approach.

3. How about something to be careful about?

Schmitt: Focus on the biggest leverage actions that will make the most significant impact versus becoming too activity driven.

Washington: Michigan Engineering should be careful about the intensity of competition in hot technology fields like robotics, deep learning and cybersecurity, and how competition for talent will place pressure on their best professors to leave academic life. They should think carefully about how to incent these professors to stay in academia while still participating in this important revolution.

Lesser: Technology is dramatically changing the way work is done, and at an accelerating pace. This is true for companies, governments and universities. For Michigan to remain one of the top engineering colleges in the world, it must be ready to continuously challenge how it operates and builds new capabilities across the university. It's never been truer that standing still is falling behind in today's world.

4. What person or book has most influenced your ideas about strategy or success? In one sentence, explain why.

Schmitt: Dr. Elliott Jaques most influenced my ideas about strategy and success because of his substantial work during which he studied large and small organizations, both for-profit and not-for-profit, all over the world, and the people in them for 50+ years and identified several important things that must be in place to ensure high organizational performance and effectiveness. His research and conclusions significantly shape my views about leadership, organization design to drive the strategy and managerial practices that must be in place.

Washington: Jim Collins's book "Good to Great" flags the importance of getting the right people on the bus and having the right culture to drive success; getting these right will make everything else so much easier, productive and enjoyable.

Lesser: The book I recommend most often is "Give and Take" by U-M grad and Wharton professor Adam Grant. For me, it is a very different business book than others I've read, challenging some of our traditional assumptions around what makes people successful in business and in life. Creating environments that encourage "givers" strengthens cultures, promotes creativity, and allows everyone to achieve higher levels of success. That's true for businesses and for academic institutions.

Bonus question for alumnus Rich Lesser: What's something you learned at Michigan that you view as connected to your success?

Lesser: The combination of great problem-solving, creativity, persistence and strong teamwork are the foundations of making real change happen, driving progress and building both individual and collective success.

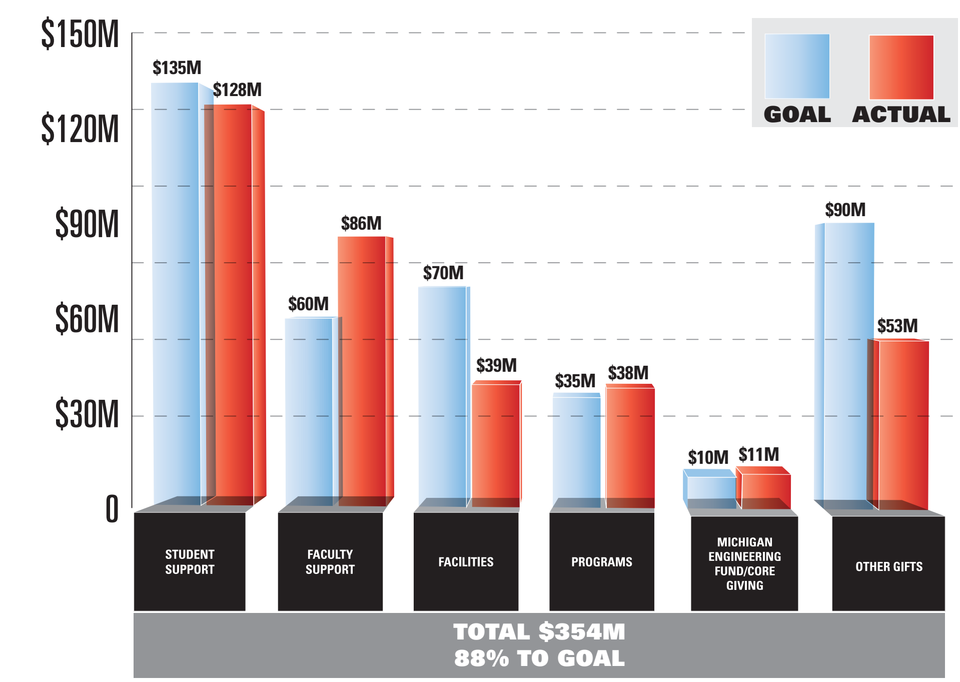
*Gallimore is the Robert J. Vlasic Dean of Engineering, Richard F. and Eleanor A. Towner Professor, and Arthur F. Thurnau Professor.

STATUS OF THE VICTORS

Michigan Engineering set its goal high in Victors for Michigan, a U-M fundraising campaign in recognition of the 200th anniversary of the university in 2017. The College is on track to meet its $1 billion goal, including the $400,000 goal for philanthropic support.

HELP US FINISH STRONG!

The leading objective of the Victors for Michigan campaign is to make a difference in the lives of students. Contribute to the future of Michigan Engineering. Visit: engin.umich.edu/giving



*As of January 2018

STOP, HEY, WHAT'S THAT SOUND?

As several Michigan Engineer readers correctly pointed out on Facebook, this is an anechroic chamber. All those spikes and pads are made of horsehair and rubber, meant to soak up radio waves.

While a similar chamber still operates on North Campus, this one was located in the Theater Building at Willow Run Research Laboratories in Ypsilanti. Built in the 1960s, it remained in use until 2015, when the remaining Willow Run facilities were demolished to make room for a new autonomous and connected vehicle facility.

The man in the chamber is Ralph Hiatt, EECS professor. One of only a few chamber experts in the world at the time, he helped design this one. The PUSH, EXIT and oh-so-1960s NO SMOKING signs were added because designers worried that users wouldn't be able to find the door in the event of an emergency.

PHOTO: Bentley Historical Library

PHOTOS: Courtesy of nuTonomy

NOVEL APPROACH

Every engineer learns by reading books. Far fewer learn by writing them. But then, Karl Iagnemma (BSE ME '94) has always followed his own path. After graduating first in his class at U-M with a mechanical engineering degree and earning a PhD in philosophy and robotics from MIT, it seemed that he could set his sights on whatever he chose. He chose to write.

"At Michigan, I had taken an English elective from a professor named Charles Baxter, who was a revered personality on campus. He had a big influence on me, he taught me to love writing and make it a part of my life."

Iagnemma did just that, publishing "On the Nature of Human Romantic Interaction," a collection of short stories, in 2003 and "The Expeditions," a novel, in 2007. The books were successful in their own right, but Iagnemma says the experience of writing them also informed the success of nuTonomy, the autonomous vehicle software startup he co-founded in 2013 and recently sold to Delphi.

While the path from fiction writer to autonomous vehicle entrepreneur might not seem obvious, it was a natural progression for Iagnemma.

"Writing a novel was incredibly difficult. And when you tackle a project like that, you learn to empathize with people who are doing hard things," he said. "Writing books felt like the first act and this company has been the second act, and they're similar in that they were both very difficult things that I didn't know how to do when I started."

The company grew out of work he was doing as a scientist at MIT. The company develops what Iagnemma calls the "brains" of autonomous vehicles, a portable software solution that can be factory-installed on any vehicle. It uses a rules-based system that teaches cars to make the thousands of decisions that we humans make behind the wheel.

"We're applying motion planning, deep learning methods that are among the absolute state of the art," he said. "And we're putting them on cars and testing them on the road every day to create a product that could save hundreds of thousands of lives. That's exciting."

For Iagnemma, working in the auto industry is about more than safety. A metro Detroit native, he has the car business in his blood.

"My father worked in the auto industry and I interned at GM during a period when the auto industry was not a hotbed of innovation. Getting into a car felt like travelling ten years back in time. Today it's the opposite – when you get into a driverless car, you're experiencing some of the most state-of-the-art research in the world."

As part of Delphi, nuTonomy plans to add more than 100 new employees. Its expertise will power Delphi's planned launch of autonomous mobility services in cities worldwide.

Iagnemma's success in the autonomous vehicle space hasn't dulled his urge to write – in fact, he says the process of starting the company has given him plenty of new material.

"It has been interesting to see the difference between the myth and the reality of starting a company," he said. "There's this fascination with the founder, this idea that they can see into the future. The reality is a little different – anyone can be a founder, but the actual work of building a company is really hard. It has been an interesting experience and I've met a lot of characters along the way. And hopefully, I have at least one more book in me."

PHOTO: Courtesy of Kristine Svinicki

NUCLEAR KNOW-HOW

While engineers earn plenty of titles and accolades, "The Honorable," isn't usually one of them. But Hon. Kristine Svinicki (BSE NE '88) has earned that distinction by bringing her nuclear engineering chops to the sometimes-contentious field of nuclear safety.

As chair of the U.S. Nuclear Regulatory Commission (NRC), her depth of understanding of the real and perceived risks of nuclear energy helps to shape U.S. nuclear policy, ensuring that safety concerns are rationally addressed.

While she started out doing technical work at Idaho National Laboratory immediately after earning her degree, she quickly recognized that the work done at the lab was driven by policy decisions. She pursued that avenue, moving on to Capitol Hill to advise U.S. senators on topics such as nuclear energy and national security. She was first appointed to the NRC in 2008 by then-President George W. Bush.

In recognition of her extraordinary achievements and distinction, she is the 2017 recipient of the Michigan Engineering Alumni Medal, the highest award offered by the Michigan Engineering Alumni Board.

"I'm very honored the College would consider a recipient in the policy space rather than someone who took a more technical path," said Svinicki. "It shows that there are a lot of different visions of the contributions one can make with a valuable engineering degree, and it sends a powerful message to the rising generation."

PHOTO: Joseph Xu

UNICORN VS. CYBER-PIRATES

Dug Song (BS, '97) has called cybersecurity "the biggest geopolitical issue of our time." And he and fellow U-M graduate Jon Oberheide (BS CS '06, MSE CSE '08, PhD '12) have devised a billion-dollar solution: Duo Security. The Ann Arbor-based information security and software-as-a-service (SaaS) company that Song and Oberheide co-founded recently reached $1 billion in valuation – a unicorn, in tech parlance.

The newly minted unicorn cements Ann Arbor's status as a tech hub to watch according to business magazine VentureBeat. The publication also called the company's recent $70 million Series D "the largest round of venture capital raised by any company in Michigan history."

Used by clients like ProQuest, Yelp, Kayak and U-M, Duo's cloud-based two-factor authentication app was developed in Ann Arbor. And Song has no intention of leaving town as the company grows.

Song has long been a proponent of Ann Arbor as a great place for tech companies. In an interview about the startup community in the state of Michigan for The Michigan Engineer in 2014, he outlined his hopes for the area.

"I'd like to see a shift in the culture of the community where we're not so afraid to try big things – to see them work or see them fail," he said. "Startups are the punk rock of business. You go out to start an industry or do something great."

Duo Security now ranks among the world's most valuable private SaaS companies with total funding of $119 million, and a company post-money valuation of $1.17 billion. It has more than 10,000 customers and protects more than 300 million logins worldwide every month.

MICHIGAN MADE

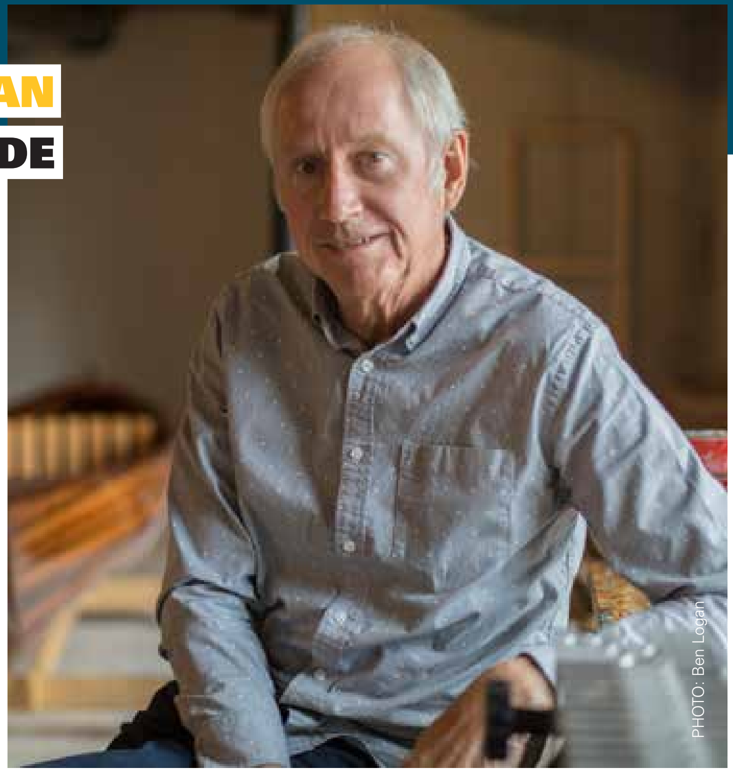


PHOTO: Ben Logan

Engineering can be elegant. But drop-dead gorgeous? U-M alum Randy Torno's (BSE ME '73) handmade boats fit solidly into both categories. And perhaps that's no surprise, since he has always considered himself an artist first and an engineer second.

Torno has dedicated much of his life to creating things that are both beautiful and functional: airplanes, furniture, ceramics, stained glass, and these days, custom wooden boats. Together with his wife, Janet, he founded Torno Boat Works in 2014, using his engineer's grit and artist's eye to fashion gliding, glistening works of art.

He's meticulous about every detail, right down to the Dutch varnish he uses to give them just the right smell. He hand-picks every stick of wood, using local sources when he can.

"Design and composition make my boats unique," Torno said. "I like hand-working things. I feel that has value. I think people appreciate [my boats] because it's not one out of a hundred."

Torno has mastered an impressive variety of historical and modern boat styles: English birding canoes, kayaks, scale models, even a reproduction of a 1930s boat called a Gentleman's Runabout.

"I have always liked to design and build functional things in my career and for myself. Building allows me to use my engineering knowledge and skills as well as my artistic background to create something that is superior in design and performance. However, the best part is that they are great to use."

Torno worked for several years as a model builder at Ford Motor Company until teaming up with fellow U-M alum Phil Jenkins (BSE ME '47) at Jenkins Equipment Company, which later became part of International Equipment Solutions. These days, he spends much of his time in his home workshop in northwest Ann Arbor. And, of course, out on the water, where he and Janet often canoe together.

Torno has been involved with boats all his life, racing three-point hydroplanes in high school and sailboats as an adult.

He also admits to another, nerdier passion: spreadsheets, which he has used to hone his boat-building process to a science. It takes him about 50 hours to put a boat together from start to finish. When he's not building boats, Torno builds furniture for friends, and he has also helped develop an educational curriculum in patents and copyrights for students at Washtenaw Community College.

His lifelong passion for art and engineering is a combination that lends a special quality to the work he does, and Torno takes great pride in it. That passion hasn't slowed down, and Torno doubts that it ever will.

PHOTO: Patrick Young

Have a story you'd like us to consider for the next issue's Alumni Notes? Let us know by sending an email to MichiganEngineer@umich.edu with "Alumni Notes" in the subject line.

THINK INSIDE THE CUBES

PHOTO: Meredith Bruckner; All About Ann Arbor/ WDIV

What has three cubes, weighs seven tons and sways like a tree in the breeze? That would be "3 Cubes in a seven-axis relationship," the 25-foot tall Philip Stewart sculpture that was recently installed in front of the George G. Brown Laboratories. In many ways, the piece is the ultimate brain hack.

"I want it to raise the hair on the back of your neck," explains Stewart. He went through 68 design iterations, and it shows. Not only does each cube rotate, but the whole structure sways slowly, leaning into impossible-looking angles only to bend back the other way when the wind turns.

To make it happen, he combined classic sculpture with modern engineering. He loaded the top two cubes with tunable gas struts that give them just the right resistance to the wind. They're attached to two axles that work like balance scales, held on with a system of exotic alloy spindle and transfer bearings built to last centuries. Stewart did the math himself with an elaborate system of spreadsheets.

"I got to the point where I could see the motion of the cubes in the numbers on the spreadsheet," he said. "But when they took the ropes off the final sculpture, I still jumped out of the way. That was when I knew it was a success."

CUBE CONUNDRUM

While the 14.000-pound sculpture's three cubes look identical on the outside, they're very different on the inside. Their weights were carefully calibrated to keep the sculpture in perfect balance. Can you guess the approximate weight of the bottom cube? Is it:

A: 3,000 pounds
B: 6,000 pounds
C: 9,000 pounds

Answer: B
6,000 pounds. The bottom cube contains a massive rotating lead counterweight made of thousands of recycled bullets.

IN MEMORIAM

1940s

’41	Mitchell J. Zolik	8/31/17
’42	Filadelfo Panlilio	7/24/17
’42	John W. Anderson	9/10/17
’42	Arne I. Johnson	12/22/17
’43	Glen A. Nelson	7/22/17
’43	G. Stewart Johnson	8/6/17
’43	Robert F. Desel	10/24/17
’43	John B. Hadley	11/22/17
’43	Chester A. Bruner	1/30/18
’44	David B. Mahler	8/2/17
’44	Caleb Warner	8/24/17
’44	Yung C. Hu	10/5/17
’45	Richard L. Dreher	8/18/17
’47	Harry R. McEntee	9/2/17
’47	Paul F. Werler	9/2/17
’47	Douglas G. Knight	9/9/17
’47	Robert G. Allen	9/22/17
’47	Jerome A. Prizlow	9/26/17
’47	Robert W. Hornbeck	11/2/17
’47	Kenneth M. Zemke	11/7/17
’47	Stanford H. Arden	11/18/17
’47	George A. Kozloff	12/9/17
’47	Ralph W. Gibert	12/17/17
’47	Charles W. Donahey	12/24/17
’47	Morris Rochlin	1/1/18
’47	William Seymour	1/12/18
’47	Charles M. Miller	1/24/18
’48	Harry E. Bailey	7/17/17
’48	Douglas H. Aldrich	7/24/17
’48	Feyyaz Berker	8/22/17
’48	John D. Kennedy	9/28/17
’48	Harry M. Baxter	10/5/17
’48	Ralph W. Woodhead	11/19/17
’48	Jal N. Bharucha	1/16/18
’48	Frederick H. Meeder	1/21/18
’48	James F. Magness	1/29/18
’49	Marlin L. Sheridan	9/2/17
’49	Arthur F. Pears	9/20/17
’49	Claude S. Farrell	10/31/17
’49	Maurice A. Goff	11/8/17
’49	Kenneth A. Stone	11/23/17
’49	Eaton V. Kelly	12/7/17
’49	Leo H. Barbour	12/20/17
’49	Robert Cohrs	1/31/18
’49	Kenneth L. Smith	2/21/18

1950s

’50	Robert R. Lewis	7/7/17
’50	Richard L. Kirby	8/1/17
’50	Robert M. Murphy	8/12/17
’50	Philip M. Allen	8/27/17
’50	Vincent S. Haneman	8/29/17
’50	James R. Christiansen	9/20/17
’50	Richard F. Schults	9/24/17
’50	Robert L. McCulfor	10/5/17
’50	Sabatino Petrilli	11/8/17
’50	Robert E. Wester	1/27/18
’51	John C. Baker	7/6/17
’51	John J. Miller	7/28/17
’51	Paul D. Hodges	9/16/17
’51	Andrew J. Kloiber	10/2/17
’51	Lawrence H. Yount	10/5/17
’51	James F. Hood	10/8/17
’51	William O. Heyn	10/17/17
’51	William W. Akers	11/5/17
’51	Robert W. Price	12/9/17
’51	Richard T. Seeger	1/26/18
’52	John T. Reeves	7/22/17
’52	Arthur L. Bergey	9/4/17
’52	Alex E. Mansour	9/20/17
’52	Saul Hershenov	10/12/17
’52	David R. Reitz	10/25/17
’52	Albert A. Patrosso	1/9/18
’52	John D. Willison	1/20/18
’52	Russell D. Harrison	1/24/18
’53	Nooraldeen M. Ridha	8/13/17
’53	Melvin L. Peden	10/31/17
’53	Donald E. Tackett	11/13/17
’53	Robert A. Shetler	1/10/18
’53	Bernard White	1/20/18
’53	Martin Fruitman	1/23/18
’54	Pravin G. Bhuta	7/20/17
’54	Hubert B. Probst	9/7/17
’54	Daniel E. Eesley	1/7/18
’55	Gerald D. Pruder	8/30/17
’55	Richard B. Graver	9/13/17
’56	Merrill W. Nelson	9/1/17
’56	Robert E. Wesel	9/2/17
’56	Eugene L. Pickett	10/19/17
’56	Robert T. Marsh	12/28/17
’57	Robert W. Rowley	7/22/17
’57	Richard A. Tyler	8/28/17
’57	Roger F. Seymour	1/8/18
’58	Robert J. Warrick	7/21/17
’58	Francis E. Hauke	9/2/17
’58	John J. Ahrens	9/11/17
’58	David L. Hilderley	10/4/17
’58	Carl P. Tresselt	10/8/17
’58	William D. Olmsted	12/13/17
’58	Ahmet R. Akman	1/21/18
’59	David J. Vargas	7/21/17
’59	John D. Joyce	7/27/17
’59	Kevin Giffen	8/7/17
’59	Marvin D. VerSchure	10/10/17
’59	Richard E. Anderson	10/22/17
’59	Harrison P. Quirk	10/24/17
’59	Robert J. Mack	10/24/17
’59	Charles M. McDowell	11/6/17
’59	George J. Klett	11/15/17

1960s

’60	Edward C. VanDeventer	9/28/17
’60	John M. Noerr	10/15/17
’60	Phillip L. Andreas	10/19/17
’60	Donald T. Check	10/30/17
’60	Herman F. Russell	12/8/17
’60	Laurence E. Wexler	1/25/18
’60	Robert H. Morris	1/28/18
’61	Thornton W. Zeigler	7/10/17
’61	Howard C. Richards	7/20/17
’61	Frank P. Cartman	10/30/17
’61	William R. Weimer	11/3/17
’61	George H. Johnson	12/5/17
’61	Gerald N. Goldberg	2/2/18
’62	Gary K. Grim	11/3/17
’62	Alan W. Morton	12/23/17
’63	John B. Woodward	9/22/17
’63	Mahmoud Ghaneei	10/19/17
’63	Robert L. Swadner	1/21/18
’64	John J. Enright	8/4/17
’64	Anthony B. Walker	9/4/17
’64	Jack R. Nothstine	12/1/17
’64	Jerry W. Gerich	12/23/17
’64	John A. Leese	1/12/18
’65	Leo A. Legatski	7/15/17
’65	DeWitt C. Seward	8/5/17
’65	Frederick W. Knopf	9/25/17
’65	William W. Moss	12/20/17
’65	John C. Reilly	1/20/18
’65	Jorge R. Polo	1/28/18
’66	Clarence B. Givens	8/22/17
’66	David L. Simpson	9/9/17
’66	Robert M. Olree	10/19/17
’66	William E. Chatfield	1/1/18
’66	Neal A. Gehring	1/14/18
’67	Herbert E. Palmer	7/2/17
’67	Frank E. Hibbard	7/13/17
’67	Howard M. Brilliant	9/23/17
’67	D. Jack Donaldson	9/30/17
’67	Albert R. Fillion	10/23/17
’67	Eugene W. Lewis	10/28/17
’67	Donald B. Thornton	12/10/17
’68	Leonard R. West	9/6/17
’69	David A. Kline	8/2/17
’69	Martin W. Herbenar	11/19/17
’69	Richard K. Jones	12/23/17

1970s

’70	Charles S. Merriam	7/24/17
’70	Terry A. Tarte	1/14/18
’71	Herbert J. Schlachter	10/4/17
’72	James R. Warner	11/18/17
’73	Melvin L. Goss	7/30/17
’73	Michael J. Vukelich	10/29/17
’74	Bruce E. Banyai	9/6/17
’74	John A. Lommel	11/10/17
’75	Meng-Sing Liou	9/29/17
’75	Dean V. DeGalan	12/13/17
’76	Robert F. Anderson	11/2/17
’76	James V. Benaglio	2/1/18
’78	William J. Engle	8/25/17
’78	William J. Donakowski	10/15/17
’79	Patrick J. Meyers	8/28/17

1980s

’80	Nicholas Dragiewicz	7/28/17
’80	David J. Vanderveen	9/30/17
’82	R. Barton Wright	1/8/18
’84	Terry R. Ostrom	9/11/17
’84	Paul M. Polries	9/21/17
’86	Daniel Gadawski Callam	11/8/17

1990s

’98	Nathan L. Binkert	9/21/17
’98	Robert C. Thompson	1/15/18

2000s

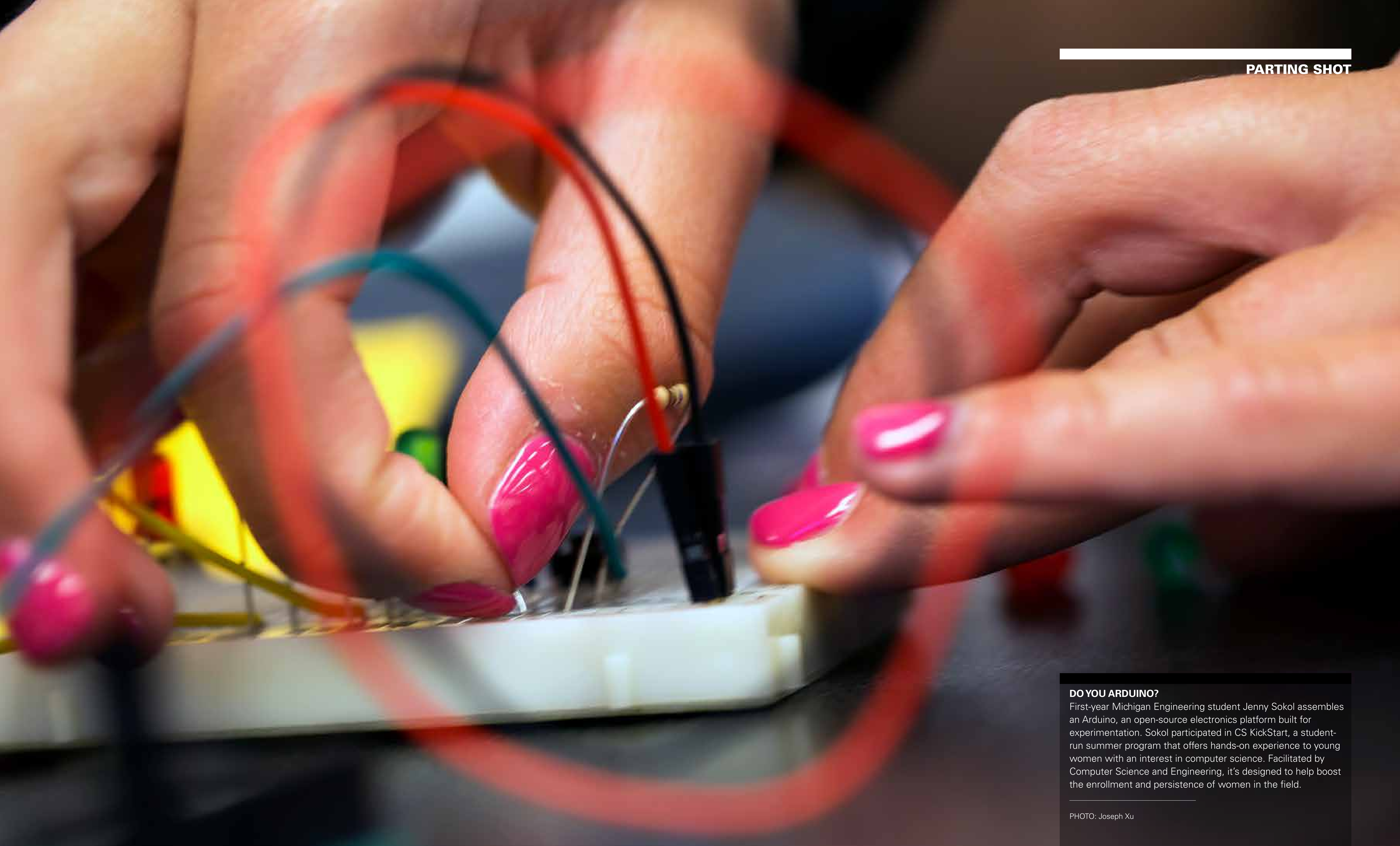
’08	Eileen R. Clemens	1/20/18
’09	Daniel R. Hohs	10/14/17

2010s

’11	Christopher W. Charnow	7/29/17

Faculty

David K. Felbeck	10/4/17
Thomas B. Senior	11/24/17
John B. Woodward	9/22/17



DO YOU ARDUINO?

First-year Michigan Engineering student Jenny Sokol assembles an Arduino, an open-source electronics platform built for experimentation. Sokol participated in CS KickStart, a student-run summer program that offers hands-on experience to young women with an interest in computer science. Facilitated by Computer Science and Engineering, it's designed to help boost the enrollment and persistence of women in the field.

PHOTO: Joseph Xu

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