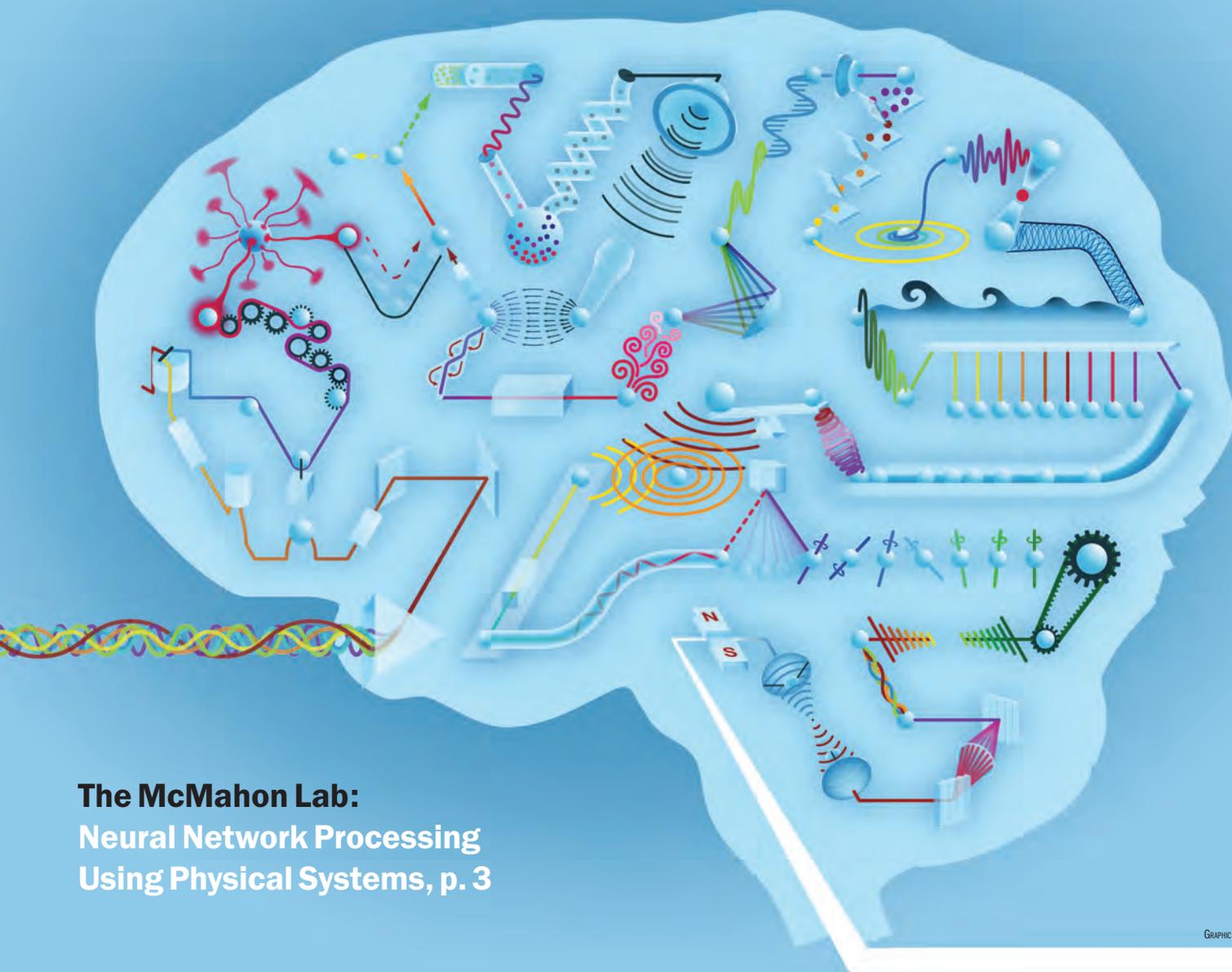


AEEP

Alumni Newsletter

Autumn 2022



**The McMahon Lab:
Neural Network Processing
Using Physical Systems, p. 3**

DEAR FRIENDS OF AEP,



I am delighted to give you a quick update about AEP. The three research areas that AEP identified in our strategic planning process—quantum information science, enabling technology for improving health, and enabling technology for energy research—were all incorporated into the college priority research directions in Cornell Engineering 2030. These priority research directions will guide our investments in people, programs, and infrastructure. We have already made major progress during the past year in some of the areas by growing the faculty, establishing new facilities, and attracting large government and philanthropic support. AEP continues to play leadership roles in a large number of interdisciplinary centers on campus, such as CHESSE, PARADIM (an NSF platform for materials innovation), CCMR (an NSF MRSEC for materials research), CABES (a DOE center for alkaline-based energy solutions), and Cornell Neurotech and NeuroNex Hub (an NSF center on technology development for brain research). With the support of Dean Lynden Archer, AEP is embarking on an ambitious plan to significantly grow our faculty numbers in the next several years, and we are running multiple faculty searches this year. AEP has done very well during the past year, and looking ahead, I see that AEP is uniquely positioned to create and implement big ideas for the future.

Please feel free to email me at aep_director@cornell.edu.

With warm wishes,

Chris Xu, Professor and Director

AEP Alumni Newsletter

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DIANE TESSAGLIA-HYMES/AEP

CHERI SIGMUND,

AEP's Assistant to the Directors, was one of the inaugural recipients for the College of Engineering's new EPICC (Excellence, Purpose, Innovation, Community, or Collaboration) award. Cheri has been a consistent and strong pillar of the AEP community for more than 20 years, serving our faculty, directors, staff and alums. Cheri continues to look for ways to make improvements, create efficiencies, think outside the box, and foster collaboration and camaraderie within our community.



DIANE TESSAGLIA-HYMES/AEP

ANN OWENS,

our new front office associate, began work in mid-July 2022. Before coming to AEP, she was the seminar and event coordinator for the department of Chemistry and Chemical Biology at Cornell. She also brings many years of experience in customer-facing and support roles with New York State Parks and the Tompkins County Board of Elections. Ann received Associate degrees in both Criminal Justice and Liberal Arts and Sciences from Tompkins Cortland Community College.

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LABORATORY RESEARCH SPOTLIGHT: THE MCMAHON GROUP

NEURAL NETWORK PROCESSING USING PHYSICAL SYSTEMS

By Diane Tessaglia-Hymes, photos courtesy of McMahon Group

“Physical systems—even those that look relatively mundane, like a piece of metal—have enough complexity in their behavior that they can do things that are actually fairly sophisticated,” said Peter McMahon, explaining the complex work that is being carried out in his lab and how it relates to our cover image.

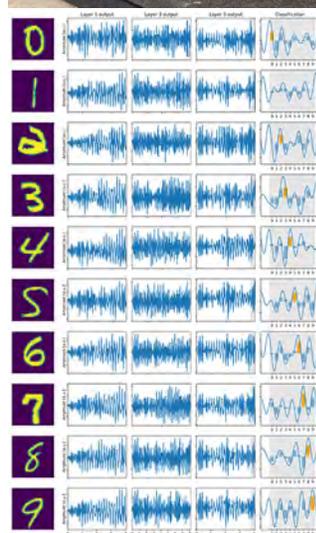
The computer science field uses the term “neural networks” to describe complex algorithms that attempt to duplicate how the biological neural networks work. As data are input, a series of equations is used to assign weights based on factors associated with the data, leading to an output. These neural networks are powerful tools for artificial intelligence, allowing machines to perform speech or image recognition, but they require extensive data and training to achieve high levels of accuracy. For some applications, when compared to manual categorization, neural networks work at scales of minutes versus hours, but often process can be excessively data- and compute-intensive.

Peter McMahon began to wonder if there was a simpler way. Were there existing physical systems that could provide more efficient calculations than computer neural networks? “How could we use an existing physical system that doesn’t look at all like it was constructed to perform a neural-network function, and turn that into something that actually does?” he asked. “For example, a wind tunnel can nearly instantaneously be used to calculate forces on an airplane wing, whereas a computer algorithm created to do this task would take far more time and computer resources. Are there other physical systems out there that can do analogous computations?”

As a proof-of-concept, McMahon’s group (post-docs Logan Wright and Tatsuhiro Onodera, and Ph.D. student Martin Stein) used a sound-based system to see if they could classify handwritten digits. They attached a piece of titanium to a speaker, vibrated it, and then identified what the digit was by the vibrations. To generate the data to send to the speaker, they scanned an image and then converted it to a linear series of values: for each pixel in the image (the x-axis), the brightness of the pixel was recorded on the y-axis. When the data were fed into the speaker, the speaker vibrated and generated a sound in proportion to what the image was, but with the x-axis as time. The sound that was emitted was then classified and used to identify the number that was input.

“This was a bit of a weird thing to do,” McMahon said. “We did this for handwritten digits, because it’s an easy example to explain. And what we managed to achieve was that we learned we can use a physical system to do some computing for us—in this case, a neural network computation like image classification.”

“It turns out,” he continued, “you can do fairly sophisticated things that the physical system clearly was not originally designed to do, although you do have to tune it so that you consistently get the expected results. But, as long as the physical system is sufficiently complex, is stable over long periods of time, and is trainable, you are able to use it to perform machine learning.”

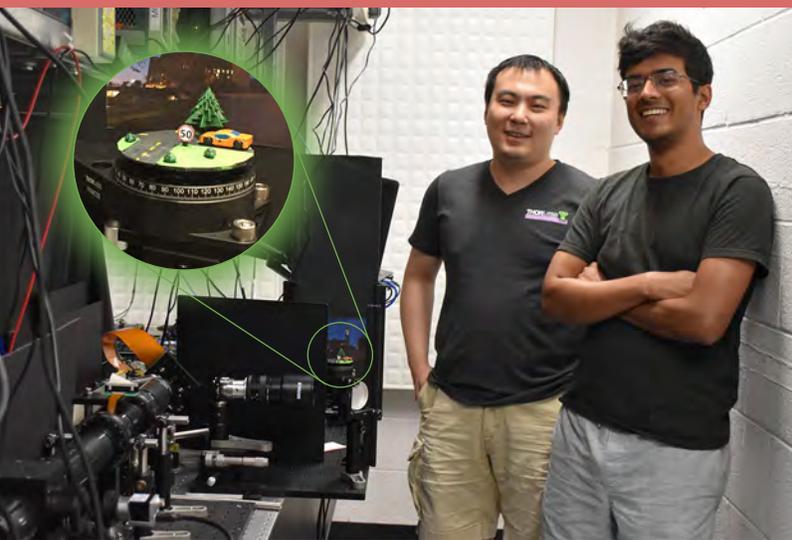


Above, McMahon’s group—post-docs Logan Wright and Tatsuhiro Onodera, and Ph.D. student Martin Stein—created an experiment to see if they could classify handwritten digits using a sound-based neural network. Stein attached a small piece of titanium to a speaker (top). Next, the digital representation of handwritten numbers was converted to an audio signal, which is then played through the speaker and the sound recorded (middle). With some concurrent tuning of the system, this physical system does a fairly accurate job of classifying the number (bottom).

McMahon’s group has also tried this technique with electronic and optical systems. By shining a laser through a crystal, the various colors of light in the laser pulse were converted in different ways by the crystal and this transformation turned out to be something that was also sufficiently complicated that it could be used to do digit recognition and vowel recognition. His team then did something similar with an electronic circuit. “You might think this sounds like this has already been done before,” McMahon said. “But, we didn’t use a gigantically large and highly complicated electronic circuit. Instead, we used one as complicated as something a middle-schooler might make for a science project, one that just had a single transistor, one resistor, one inductor, and one capacitor. This was clearly not a super-engineered, machine-learning circuit. But yet we showed that it can also do the same tasks.”

Those three systems—mechanical (acoustic), electronic (an analog electronic oscillator), and optical—were chosen to demonstrate generality. Although there are constraints on how exactly the system has to behave in order for it to work, the findings suggest that nearly any physical system can be turned into a neural network that can do complicated tasks.

Continued



AEP post-doc Tianyu Wang (l) and Ph.D. student Mandar Sohoni (r) use a miniaturized 3D traffic scene (inset) to explore an optical neural network that can compress the information from this scene to four pixels. “The difference between digital and optical neural networks,” Wang explained, “is that with optical systems—such as those used in self-driving cars—cameras take digital images and then send those images to a processor that extracts information about the image, for example, the number on a speed limit sign. That is a digital neural network, which can use huge amounts of processing power. Our setup uses an optical neural network, where the image is not stored as a digital image. Instead, the light coming in to the sensor is processed through a series of matrix calculations and reduced down to the minimum size needed, in this case, four pixels.”

“Our setup is loosely inspired by the human eye,” added Sohoni. “The camera looks at the scene, extracts information, and compresses it down. Because this is all happening optically, it happens very, very fast.”

An important outcome is the realization that the way scientists currently use neural networks to do machine learning—complex algorithms that have been designed by humans and which implement some artificial neural-network instruction—is not the only way.

What’s next?

Having developed a procedure for how to use physical systems to do neural-network processing, McMahan foresees this concept being used in systems where machine-learning and neural-network processing use immense amounts of computing resources. One example is facial recognition or queries that occur hundreds of million times a day. Can a physics-based, neural-network processor be developed that somehow is much more efficient than a standard server or neural-network-processing computer? Can a physical system be found that intrinsically does a lot of complicated calculations and is able to actually do it better than a cluster of computers performing a task like these? “This could be a path towards making replacements for high-performance computers or physical systems,” McMahan said. “But there are uncertainties about whether that kind of vision can ever be realized. We don’t know.”

What about a situation where some physical signal needs to be classified, but the data is not already in electronic form? Could a neural network be used to do some pre-processing that

would make later analysis faster or more energy efficient? An example of this situation is a self-driving car. A self-driving car needs to be able to identify anything that is in front of it. Currently, a camera on the car records digital images of what the car “sees.” These images are sent to a processor to evaluate a course of action. McMahan’s group wondered what would happen if they could bypass the process of digitization, and instead send the light through an optical processor which would directly process the scene in front of it. The entire analysis would be within the physical system. Post-doc Tianyu Wang and Ph.D. student Mandar Sohoni are currently testing this in the lab by trying to identify the objects in a model scene from any angle.

“Eventually the output needs to go to electronics, because you need the electronics to direct the car to apply the brake, or do some other task. But you no longer need to digitize the whole image. That makes this process work much faster, because it’s able to take the whole scene and immediately determine if it detects a pedestrian there or not, for example. The process is much more about *information* than creating a huge, high-resolution image.”

McMahan also foresees this technique being useful for situations where very low-power sensing or computing is needed. “For example,” he said, “imagine a sensor that needs very, very low energy consumption, such as a ‘smart dust’ sensor on the wall. You want that thing to be able to wake up when it hears something. You can’t put a microprocessor and a microphone on it, and then let it continue to run a machine-learning algorithm because it’s too power hungry to do that. Instead, you want something that can detect keywords and perform an action using very low power. Imagine these things attached to the wall and harvesting energy from sources such as mechanical vibrations from the wall. Is it possible to design that system in a way that it doesn’t just harness energy from the wall, but actually can also sense somebody speaking, and then perform some action? Low-power scenarios like this seem like something where physical or mechanical systems could actually be meaningful.”

“So, that’s the general story of how physical systems can do neural network processing,” McMahan concluded. “I think there are a lot of different directions this could take, but we can only do so much ourselves. We’re curious to see what other groups end up doing with it, too. We’re hoping that other people will pick up on this, and find ways to turn a really complicated system into a neural network.” ♦

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POLLACK NAMED ASSOCIATE DEAN



AEP Photo

Lois Pollack, John Sweet Professor of Engineering, was appointed Associate Dean for Research and Graduate Studies in the College of Engineering, a role she assumed June 1, 2022. Professor Pollack came to AEP in 2000 and served as its director from 2014 to 2020. As part of the Cornell Engineering's most research-active school, she has been a research leader in the area of biophysics. Her work focuses on the development of experimental tools that enable

novel, time-resolved studies of biological macromolecules and their complexes, as well as research on electrostatic interactions in RNA and DNA. She is also an outstanding teacher who has received the Swanson Excellence in Teaching Award (2003) as well as the Chau Excellence in Teaching Award (2012).

VALLA FATEMI RECEIVES LAHHAM FACULTY FELLOWSHIP



Diane Tessera/HMES/AEP

Professor Valla Fatemi was awarded the Aref and Manon Lahham Faculty Fellowship. This five-year fellowship recognizes his "early contributions to novel quantum phenomena that have the potential to revolutionize the next generation quantum information technology in the College of Engineering," and also provides support for research, teaching, outreach, and technology translation efforts.



Jason Koski/JUREL



bit.ly/ChronicleCHES

Senator Schumer visited Cornell on April 14, 2022, to celebrate the groundbreaking for CHES's expansion. Scan or click the QR code at left to read the full article in the Cornell Chronicle.

KOURKOUTIS WINS CANAAN AWARD

Lena Kourkoutis is a winner of the Canaan Family Award for Excellence in Academic Advising, in honor of Professor Bingham Cady. The award is given annually to faculty who have demonstrated outstanding service as faculty advisors.

"Lena Kourkoutis is an exceptional advisor to students in the College of Engineering," said Chris Xu, director of AEP. "She represents the very best that Cornell has to offer to our next generation Cornellians. Since early on in her faculty career, Lena has been an incredible resource for students. Her commanding knowledge of curricula, as well as the devotion and genuine care she offers to her advisees truly set her apart. Lena cultivates a deep personal connection to her students, empowering them to believe they belong when they are having doubts, showing them a path forward when they are frustrated, and being a wonderful role model and inspiration to all. All of us in AEP are overjoyed that Lena has been awarded the college's highest recognition for advising."



Alex Kwai/BME

Larry Jackel, Ph.D. '76, who spoke at a symposium held in memory of Watt W. Webb (professor in AEP from 1961 until 2012, and professor emeritus from 2012 until his death in 2020), talked about how Professor Webb's influence extended beyond the classroom. Read more about the event on page 16.

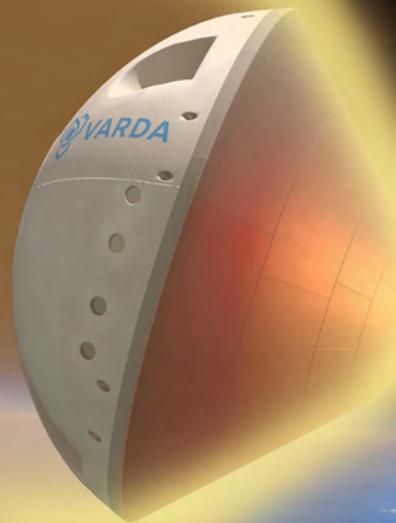
MEEHL GIFT BENEFITS AEP

Cornell University alumnus David W. Meehl '72, MBA '74 has pledged a \$10 million gift to the College of Engineering and the College of Arts and Sciences (CAS) at Cornell. A portion of this gift will be used to create two graduate fellowships, one in AEP: The James R. Meehl Graduate Student/Postdoctoral Fellowship in the School of Applied and Engineering Physics. The remainder of the gift will create The James R. Meehl Professorship in applied and engineering physics in the College of Engineering, as well as new equipment for quantum research, to be split between the Cornell Engineering and CAS. Scan or click the QR code at right to read the full article in the Cornell Chronicle.



bit.ly/ChronicleMeehl

AEP ALUM CREATES A GRAVITY-OFF SWITCH IN ORBIT



A Varda Space Industries capsule heads back to earth after completing its mission.

By Diane Tessaglia-Hymes, photos courtesy of Varda Space Industries

There's a new star in the aerospace industry and it's bringing a gravity-off switch to manufacturing. Varda Space Industries, co-founded and led by an AEP alum, is sending satellites to space, where products used on Earth can be created in a zero-gravity, dust-free environment. "We're a microgravity platform for any type of manufacturing," explains Will Bruey '11, M.Eng. '12, CEO of Varda Space Industries, a company he founded in 2020 with Delian Asparouhov. Space manufacturing has been around for decades, dating back to 1969 when Russian cosmonauts determined that the environment of space "may solve many welding problems." Starting in the 1970s, space manufacturing took the form of experimental attempts done primarily at Skylab2, and later at Spacelab and the International Space Station. Only recently has the cost to go to space fallen to a point where it can now be economical to commercially produce some products in space. This is in part due to reusable rockets that have lowered the cost of access to space and opened up a range of in-space activities. "After our satellites separate from the rocket, they perform operations such as mixing or heating chemicals," Bruey explains, "and then, after those operations are complete, we do a deorbit burn to send small capsules back to Earth with the materials produced. Our capsules—about 1 meter in diameter—survive re-entry, deploy parachutes, and land with the manufactured contents that we then deliver to our customers.

MAKING MATERIALS IN MICROGRAVITY

One such set of products serves the pharmaceutical industry: drugs formulated using microgravity. "The ideal application for our capsules is manufacturing high-value chemicals in space," says Bruey. "There are a lot of things we can do in space to create value for chemists on Earth, for example, drug molecules crystallize differently in microgravity than they do here on Earth. This can improve parameters of high interest, such as solubility. The reason we manufacture in space is because of the unique way microgravity influences chemistry." Crystal growth behavior—both morphology and growth



Will Bruey, AEP '11, M.Eng. '12, CEO and co-founder of Varda Space Industries.

rate—are different in microgravity than an equivalent setup experiencing the Earth's gravity. This is partly because as crystals grow they release heat, and that heat causes convective currents in the solution. A growing crystal that sinks due to its own weight would also create convective currents from its sinking motion. In microgravity, there is less of this convective transport. As a result, crystals grow differently, creating different geometric lattice shapes as their molecules



Ami Bhavsar works out the details of the hypersonic flow about the capsule outer mold line with (left to right) Marat Kulakhmetov, Muk Pandian, Eddie Almaria, and Larry Chan.

fit and stack together in a repeating sequence. This can also create unique ratios between their morphologies as well. “This is important because the morphology of a crystal defines many of its macroscopic properties,” Bruey says. “In the pharmaceutical world, solubility, or how fast the drug dissolves in the body, is a particularly important property. Space manufacturing in microgravity allows us to alter the outcome of crystal growth to influence properties like solubility.”

But the applications don’t stop at medicine. The International Space Station has hosted countless experiments using the unique environment of microgravity to produce unique results. Things like fiber optics, silicon wafers, and special metal alloys all have unique benefits from being fabricated in microgravity. And since gravity is a fundamental force of physics, Varda’s platform can be useful across all disciplines of engineering—just like an AEP degree.

AN INDUSTRIAL PARK IN SPACE

In the long term, Bruey wants Varda to build the first off-planet industrial park at-scale. Now that rockets are reusable and the



Varda employees integrate one of Varda’s first spacecraft.

costs have dropped accordingly, there are no significant technical or economic barriers to this goal. “We’re not really a typical aerospace company,” he says, “because our customers don’t care that we’re going to space. They only care that we can turn off gravity for them.” For Varda, that means manufacturing mostly small things like expensive chemicals or small products in the short-term as the space industry continues to grow. But as launch costs continue to drop, Bruey hopes to scale up both the range of products Varda creates as well as the size of each. Right now, the telecom and remote sensing industries are the primary users of space commercially. Varda wants to be at the forefront of the next innovation, which they’re predicting will be the first off-planet industrial park. Bruey envisions a distributed industrial park, rather than a single large “station.” Bruey envisions a set of robotic production satellites orbiting Earth, with each satellite creating a different product: drug molecules, fiber optics, etcetera.



Kris Gonzalez DeWhitt examines terrestrial versions of the chemistry Varda plans to do in orbit.

“We can bring the raw materials to those production satellites with our Varda spacecraft, and bring back finished products with our reentry capsules.” Bruey adds: “It’s hard to say what’s next in any industry, because it’s all speculation, but I think what we *can* say about Varda’s future is that it has a very real chance of benefiting people on Earth in ways that simply can’t be done any other way. If successful, we’ll end up inciting a positive feedback loop to drive human activity in space.” By manufacturing those first few products, Bruey hopes he can drive demand for launches, setting that positive feedback loop in motion to decrease launch costs and increase the economical products Varda can offer.

AEP PROVIDES PATHS TO AEROSPACE AND OTHER FIELDS TO ALUMNI

Varda Space Industries, which has so far garnered more than \$53 million in start-up capital, has approximately 50 employees and 20 interns, including AEP undergrads Nick Thomas ’23 and Sam Noles ’23 (see page 12). One of the company’s directors is AEP alum Wendy Shimata ’09. After Cornell, Shimata worked at Boeing in the guidance, navigation, and controls department for about seven years, and then accepted a job at SpaceX in the software department, eventually leading the Dragon Software team. That’s where she met Bruey, and the two worked together in mission control. After founding Varda, Bruey reached out to his fellow AEP

Continued



Wendy Shimata '09, Director of Autonomous Systems at Varda Space Industries, demonstrates that their “satellites are so small, they’re almost huggable.”

alum to bring her on the team. Both Bruey and Shimata credit AEP with giving them the skills needed to be successful, and teaching them how to narrow in on the specific problem they are facing and how to solve it. For Shimata, AEP provided a “really good fundamental basis of how everything works.” One feature of AEP that drew her to Cornell was that it not only provided her with a solid grounding in the foundations of engineering principles, it also gave her the opportunity to apply her knowledge through project teams at Cornell.

“AEP prepared me really well for all my positions: Boeing, and SpaceX, and Varda” she says. “It enabled me to approach challeng-

es in a fundamentals-first sort of way, and by doing so, allowed me to solve new and innovative problems. For example, I might not know *this subject* specifically or *that equation* specifically, but I have a solid understanding of the underlying principals, and I know I can figure it out.”

As a child, Shimata was very interested in space and astronomy, and became interested in pushing the boundary of space applications and exploration. At Cornell, most of her electives were very space-oriented: control theory, aerospace, and GPS. She was part of Professor Mason Peck’s satellite engineering project team in the Sibley School of Mechanical and Aerospace Engineering for three years as an undergraduate student.

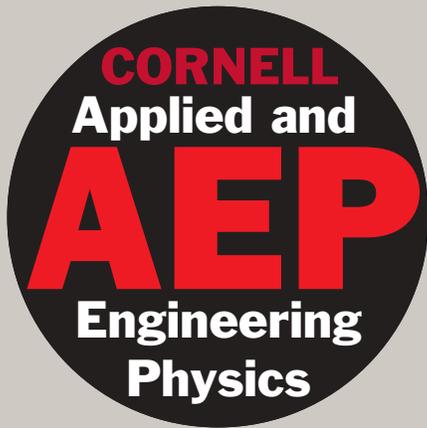
Bruey credits his AEP B.S. degree with helping him unlock the problem-solving part of his brain, while also preparing him to pursue a multitude of career paths.

“The role models for the AEP engineer are people like Schrodinger and the other physicists of the early 20th century—people who work on cutting-edge ideas. This is why I chose to be an engineer, and also why I chose to work at SpaceX. I thought it was the coolest, most cutting-edge engineering company that existed.” Most of Bruey’s undergraduate electives were in electrical engineering. That, combined with a strong fundamental physics background, plus working on Professor Mason Peck’s satellite team, gave Bruey enough preparation to contribute at SpaceX as an electrical engineer, and then later start his own company, Varda Space Industries.

“The question is, how can we be creative and innovative, because that’s what really drives our industry and pushes it to new heights,” he said. “AEP taught me to think about and understand almost any engineering problem, and it gave me a great toolbox of skills to do exactly that in my career.” ♦



In this artist’s rendering of the launch booked for April 2023, Varda Space Industries’ capsule is departing from its manufacturing satellite and heading back to Earth.



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Diane Tessier-Hoels/AEP



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Donate to The Professor Robert Buhrman AEP Faculty Startup Fund

To acknowledge and honor the contributions and memory of Professor Buhrman, AEP intends to recruit and retain current and future faculty members who embody Buhrman's legacy of expertise, leadership, and mentorship of faculty and students.

A crucial component of hiring brilliant faculty like Professor Buhrman is funding for comprehensive startup packages—which covers the cost of lab updates, state-of-the-art equipment, and graduate student funds. As such, AEP is seeking faculty fellowships to support the school's goal of hiring the most competitive candidates who promote synergistic teaching, immersive educational experiences, and collaboration. With these fellowships, AEP will have a true competitive advantage over other peer institutions in recruiting top academic talent, retaining them, and providing them with crucial equipment and lab space necessary to conduct cross-disciplinary research.

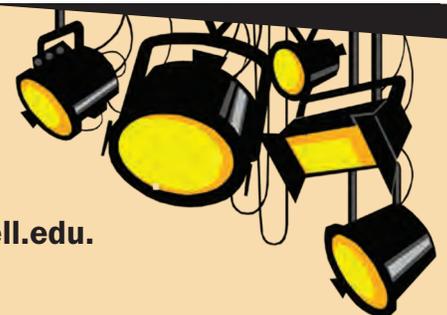
Contact Paige Onstead, po86@cornell.edu

AEP ALUMS, TELL US YOUR STORY!

We encourage you to share your story with us so we can spotlight your accomplishments on our website or newsletter.

Tell us what you have been doing by sending an email to AEPadmin@cornell.edu.

We look forward to hearing from you!



DOUGLAS CURRIE, '57

PUTTING MIRRORS ON THE MOON

by Diane Tessaglia-Hymes, photos courtesy of Douglas Currie

TWO GENERATIONS OF MIRRORS

Professor Douglas Currie, now a research scientist and professor emeritus at the University of Maryland department of physics, graduated in 1958 from Cornell with a B.S. in Engineering Physics and then continued with a Ph.D. in Theoretical Physics from the University of Rochester. He departed Cornell as an engineering physicist and the University of Rochester as a theoretician, but later evolved into an experimental astrophysicist whose significant career accomplishments have focused on developing specialized optical instrumentation as well as the applications for these instruments.

Following his Ph.D., he accepted a post-doc at Princeton University to work on quantum field theory—intending to work on designing experiments to validate and characterize the light from lasers, which were very new at the time. But soon after starting his post-doc, he learned about a lunar laser ranging project that was starting up, and soon the project to put mirrors on the moon commanded all his attention. And so, in the summer of '69, he transferred to the University of Maryland, left behind his theoretical leanings, and became an experimental astrophysicist. This move led to a research project that has lasted 55 years and spanned nearly 400,000 kilometers.

“In the late '60s, NASA had a collection of geophysics instruments called ALSEP that they planned to deploy on the moon using Apollo 11,” Currie recalled. “However, the astronauts—who had started practicing about a year before launch—were concerned that Cornell astrophysicist Tommy Gold’s prediction might be correct, and that there was a fine dust about 30 feet deep on the surface of the moon. If so, the surface would not have the consistency to support an astronaut. So, NASA put out a call for a new science package that did not require much power, or comm or ops. A national team at the University of Maryland submitted a proposal, and that’s how I became involved with the project that put the first mirror on the moon.”

The original array of mirrors that was deployed on Apollo 11 was created by a team of scientists led by the University of Maryland.



The first lunar retroreflector was placed on the moon in 1969 by Apollo 11.

Initial range measurements were performed at the University of Texas McDonald Observatory, at the Lunar Laser Ranging Station which Currie developed and directed during the early phases, and which has provided some of the best tests of the



Currie (far right) describes laser operation in 1969 to (left to right) Dr. Phillip Chapman, NASA Scientist Astronaut; Professor Carroll Alley, Principal Investigator, University of Maryland College Park; Dr. Donald Linds, NASA Scientist Astronaut. Currie developed the Lunar Laser Ranging Station at the McDonald Observatory in 1969.

properties of gravity and general relativity, as well as discovering that the Moon has a liquid core. The Apollo 11 retroreflector array contained 100 corner-cube prisms that were 38 mm in diameter and arranged in a 10x10 array that was 45 cm square.

Researchers back on Earth were able to locate the retroreflector on the moon by matching images taken from the Earth with pictures from the moon. Once the location was found, a Korad red Q-switched ruby laser was pointed at the location. The beam was collimated by the 107-inch MacDonald telescope before it was launched, expanding the diameter of the beam, but reducing the divergence to the order of an arc second, or 5 micro radians. Pulses lasting one nano-second were launched, and these provided a range estimate with the accuracy of about one foot. From a joule of photons (1,018 photons) sent to the mirror, one photon was typically returned.

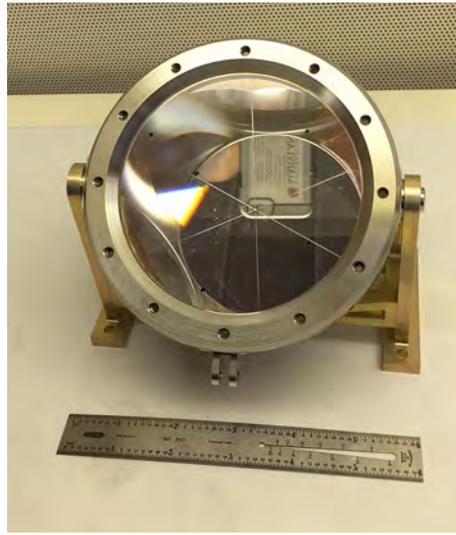
“But here’s the problem,” Currie explained. “The array on the moon is about two-thirds meter square. We only see one hemisphere of the moon, but the moon rotates about 10 degrees because of lunar libration—the wavering of the moon as seen from Earth. When the array on the moon is tilted, we don’t know whether the photon that returns was reflected from the near side or the far side. And so that’s the limitation on the accuracy and precision of a range measurement.”

Nearly 50 years later, in 2018, Currie put in a new proposal to NASA's Lunar Surface Instrument and Technology Payloads Program (LSITP) to develop Next Generation Lunar Retroreflectors (NGLRs). These NGLRs, a configuration of three mirrors, will be used to further investigate lunar physics, gravitational physics, and to test general relativity. They are scheduled to be deployed on the moon within LSITP in May of 2024. These new NGLRs are carefully designed to minimize thermal gradients across the cube corners as the array passes in and out of the sun's rays as the moon's phase changes. This prevents thermal distortions from seriously degrading the amount of light returned by the reflectors.

Why three NGLRs? "Well, the moon rotates a little bit." Currie explained. "I want to do general relativity, which is based on the motion of the center of mass, not about how one retro reflector on the surface is moving. To get the center of mass on a rotating body, I need to have three reference points. These three measurements—if things work out well—will provide a more stringent test of general relativity than has been made before and will be the best test of the weak equivalence principle. It will give us a greater-than-a-factor-of-100 improvement in these science results. And the reason we want to push hard is that quantum mechanics and the theory of general relativity are not compatible. And many people think they should be. If they are going to be compatible, there has to be a breakdown in either general relativity or in quantum mechanics. Therefore, we need to press as hard as we can on the accuracy of measurements in general relativity."

Currie experienced two technical challenges in designing and fabricating the NGLR. One was the fabrication of a corner-cube retroreflector (CCR) with tolerances of ± 0.2 arc second—1 micro radians—something that was beyond the state of the art at that time. The other challenge was managing the gradients in temperature within the NGLR.

"The best we can do on the housing is for it to be a certain temperature around 220°K," said Currie. "The housing of the corner-cube retroreflector is heated by the sun. The CCR itself does not absorb much sunlight; therefore, the CCR is cooler than its housing by almost 100°K. That means there is a strong temperature gradient across the three support tabs of the CCR, so there is a heat flow into the CCR. That produces gradients in temperature within it. The index of refraction depends upon the temperature, so we have gradients in the index of refraction. And when you have uneven index of refraction within the CCR



This prototype NGLR is very similar to the flight NGLR being prepared for the first mission.

FogEye, that would enable pilots to successfully land in foggy conditions. This project was never brought to scale because as it neared completion, it was determined that GPS could be used to land planes.

"But the problem with GPS," Currie said, "is that it is difficult to use for the last 10 feet of the landing. But FogEye would have accomplished that by using ultraviolet (UV) light—which, for wondrous, optical reasons—is not blocked by the fog. By putting UV lights in the landing strip and using special UV-light detectors, the pilot would get a picture of the lights along the landing strip, in the same manner if there was no fog.

"But the thing that I spent a lot of time on, and was a lot of fun, was the Hubble Space Telescope—which has been used to explore the solar system and outer space," he said. "In the 1970s, a group of us proposed making the main camera (the Wide-field Planetary Camera), and we were selected." Using the camera data, he extensively investigated the exploding super-massive stellar system, Eta Carinae, measuring the speed and locations of particles ejected into space when Eta Carinae exploded.

In reflecting on his long and productive career, Currie sums it up by saying, "Mostly what I have done is to find unique or undiscovered optical methods to solve problems. It's been fun." ♦



The NGLR CCR (left) is much larger than the CCR of the Apollo retroreflector array (right). The NGLRs will show improvement over Apollo 11 retroreflectors by factors of 100s.

instead of going directly back to the observatory, the beam is spread out over hundreds of kilometers. But that's a lot smaller penalty than if we put a silver coating on the back faces."

REFLECTING BACK

Besides his work on lunar mirrors, Currie received long-term support from the Office of Naval Research to tackle various astrophysical problems that were open and unmeasured at the time.

His work has ranged from developing top-secret methodologies to working on projects with wide public appeal. During the cold war, he worked on a project to develop an instrument to replace aging T4 theodolites, used to determine the best locations for placing intercontinental ballistic missiles). He also created a device, called

READ MORE

Click or scan the QR code for Professor Currie's extended CV and publication list.



AEP STUDENT SPOTLIGHTS

SAM NOLES and NICK THOMAS Interns at Varda Space Industries

Sam Noles '23 and Nick Thomas '23 are AEP seniors who both completed internships in the summer of 2022 at Varda Space Industries, a company founded and led by AEP grad Will Bruey '11, M. Eng '12 (see page 6.) "My main project at Varda was writing software to control our prototype crystallization system," Noles said. "Although that was my primary project, I had my hand in many other areas throughout my summer at Varda. I worked on ground electronics, machined parts, and conducted payload testing. My internship at Varda was a great opportunity to explore multiple different fields in industry."

Noles was drawn to AEP because of the broadly applicable physics skill set that AEP provides to its students. He believes that his B.S. in Engineering Physics will give him the foundation needed to contribute to many different fields.

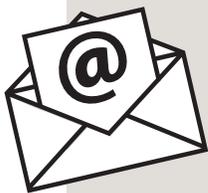
Nick Thomas, who is a problem-solver by nature, found that the best way to satisfy his curious nature and desire to develop new ideas and technologies was to create an independent major at Cornell by combining AEP with EE (electrical engineering). His major focuses on high-power energy systems along with physics associated with laser systems and nuclear reaction devices.

Thomas interned at Varda from June through August, 2022. "I worked as a thermal and recovery operations engineer on the payload-development team for Mission One," he said. "Varda is a company of cutting-edge development, single-handedly pushing the bounds of human capabilities by paving the path to space manufacturing. With my eyes set on the aerospace industry as the place to begin my career, Varda was an astronomical opportunity that allowed me to work with many of the most talented and qualified aerospace engineers in the world."

He credits the support of AEP faculty and staff with allowing him to pursue his unique major, and believes that working for Varda has developed his technical skills and spurred his growth as an engineer. ♦



Nick Thomas (left), team lead of Cornell Racing, and Sam Noles (right), team lead of Cornell Rocketry, were both interns at Varda Space Industries in the summer of 2022.



**WE WANT TO
HEAR FROM
YOU!**

Please email Cynthia at
AEP_info@cornell.edu
and tell us about your
academic experience.

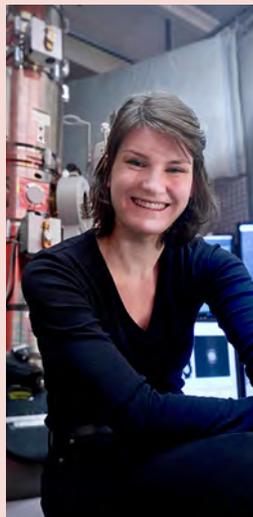


Photo courtesy of Berit Goodge

BERIT GOODGE: Schmidt Science Fellow

Berit Goodge, AEP Ph.D.'22, is one of 29 international, early-career scientists awarded a prestigious fellowship with Schmidt Science Fellows, and will be placed in the Physics of Quantum Materials Department at the Max Planck Institute for Chemical Physics of Solids in Dresden, Germany. As part of her fellowship, Goodge will be exploring new routes for synthesis and manipulation of designer quantum materials. Using atomic-resolution imaging and spectroscopy in order to stabilize new material phases and tune their functional properties, she hopes to leverage the experimental expertise at the Max Planck Institute with the insights gained during her Cornell Ph.D. research. Goodge's Ph.D. advisor was Lena Kourkoutis.

YI-HAO CHEN

“I can’t remember the exact moment when I decided I wanted to be a physicist,” mused Yi-Hao Chen, a 6th-year Ph.D. student in AEP studying with Professor Frank Wise. “I’ve been interested in physics since I was a kid back in high school, and I’ve enjoyed the feeling of over-running my brain on tough questions for as long as I can remember.” His interest in tackling the toughest questions has paid off: in October, Chen will be awarded the “Emerging Researcher Best Paper Prize” for his 2021 paper, “Starting dynamics of a linear-cavity femtosecond Mamyshev oscillator,” published by The Journal of the Optical Society of America B (JOSA B). According to JOSA B, this new prize recognizes a student or early-career researcher who is the first author of a paper that a committee of JOSA B editors judges to be outstanding. The committee chose Chen’s paper because it felt that “the thoroughness of the study, the clarity of presentation, and the significance of the work for both fundamental laser science and state-of-the-art applications of fiber lasers were particularly impressive.”

Chen received a B.S.E in materials science and a M.S. in physics from National Taiwan University. His interest in physics was solidified in high school, spurred on by teacher who encouraged his interest, and also by receiving third place in a national science competition when he was a senior. However, he first became interested in optics while at a conference in Japan during his master’s degree. There, he learned about the serial time-encoded amplified microscopy (STEAM) camera, the world’s fastest all-optical camera. Because photons can move faster than electrons, the STEAM camera is able to overcome the speed limitation set by conventional electronics with laser pulses. “I knew that I wanted to pursue the coolest research and solve the hardest problems in the world, ones that use light and fiber lasers,” Chen said, “so I decided to pursue my Ph.D. at Cornell.” ♦

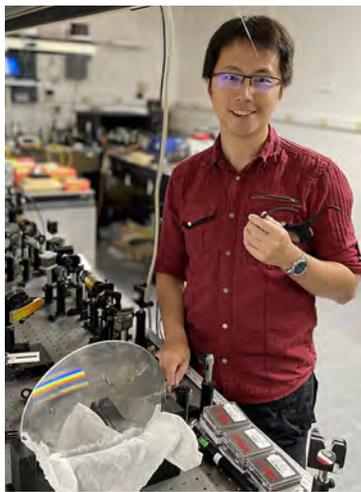


PHOTO COURTESY YI-HAO CHEN

YANDONG LI

Yandong Li, a Ph.D. student in Gennady Shvets’s lab, studies topological photonics, a new field inspired by condensed-matter physics that explores how to robustly control the behavior of light. This field is considered by many to still be fundamental research: currently in the early, theoretical stage and just starting to be applicable to real-life situations. In the last decade, some research has shown how topological insulators for photons—analogue to those for electrons—can be created. “The focus of my Ph.D. is about pushing the field of topological photonics one step further toward application,” says Li.

Li has designed several topological photonic structures, including the design of a topological cavity that was published in Physical Review Letters. This study introduced a novel way of achieving optical energy confinement: by delaying the reflection at a mirror surface. Another design, published in Applied Physics Letters, demonstrated a practical and convenient way of selectively exciting a specific topological mode. Because of the peculiar electromagnetic field distribution of topological modes, previous research often used a phased array to selectively excite one of them. Li’s experiment used only one linearly polarized dipole-like source. Most of Li’s designs can be realized with silicon photonics and integrated into photonic circuits, which may lead to more compact devices for photonic information processing and quantum computing.

In recent months, his research has extended into processing and programming light, using topological photonic logic gates. Concurrent with his Ph.D., he has pursued a minor in computer science. Believing in the great power of large-scale matrix computation, physics-informed knowledge discovery, and optimization, Li wishes to pursue a postdoctoral study where he may contribute his knowledge in photonics and computational methods to discovering novel phenomena and designing new photonic devices. ♦

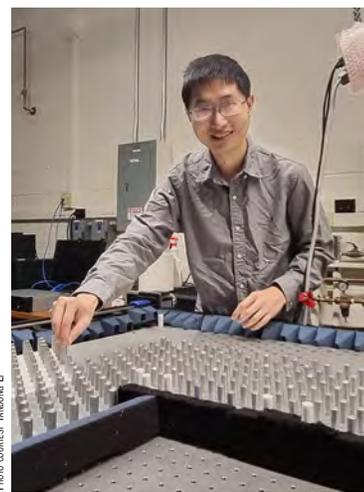


PHOTO COURTESY YANDONG LI

Read more about
Yi-Hao Chen and Yandong Li at
aep.cornell.edu/aep/spotlights.

BENJAMIN MALIA: Intelligence Community Fellow

Benjamin Malia, a postdoctoral researcher at Cornell, has been announced as one of the 2022 Intelligence Community Postdoctoral Research Fellows. The 2022 fellowships, granted by the Office of the Director of National Intelligence, began October 3 and support unclassified basic research in areas of interest to the intelligence community. Malia’s research uses materials called nonlinear crystals to generate quantum entangled photons that can be used for a number of applications. “It’s an honor to be selected for this fellowship,” said Malia, who is advised by Professor Peter McMahon. “I’m excited about this opportunity and to be working on the development of cutting-edge quantum technology.”

—Syl Kacapyr, Associate Director, Marketing and Communications, Cornell Engineering



PHOTO COURTESY OF BENJAMIN MALIA

Applied and Engineering

2022 Award Recipients

Peter J. Buckman

Leo Moon

Trevor R. Cuykendall Memorial Prize

Awarded to an Undergraduate Student for Outstanding Academic Achievement

Shake Karapetyan

Thomas J. Ugras

Trevor R. Cuykendall Memorial Prize

Awarded to an Outstanding Teaching Assistant

Erin E. Fleck (Professor Lena Kourkoutis)

Dorothy and Fred Chau Award

Awarded to an Undergraduate Student for Excellence in Research

Ran A. Gladstone

William Nichols Findley Award

Awarded to a Graduate Student for Outstanding Research

Chloe A. Washabaugh

Paul L. Hartman Prize in Experimental Physics

Awarded to an Undergraduate Student for Excellence in Undergraduate Experimental Physics

Eoin Sansevero

Henri S. Sack Memorial Award

Awarded to a Master of Engineering Student for Top Academic Performance



DMcE TESSERA-HINES/AEP

Peter Buckman (left) and Leo Moon (right) fist-bump after learning they were the recipients of the Trevor R. Cuykendall Memorial Prize.



DMcE TESSERA-HINES/AEP

Chloe Washabaugh (center front) celebrates her graduation and being awarded the Paul L. Hartman Prize in Experimental Physics with her family.



DMcE TESSERA-HINES/AEP

Graduating AEP students listen to Professor Chris Xu before receiving their diplomas.



Geir HOGESS PHOTOGRAPHY

Professor Chris Xu (left) presents the Dorothy and Fred Chau Awards for excellence in research to Erin Fleck (center) and her advisor, Professor Lena Kourkoutis (right).

Physics Commencement



2022 GRADUATES

Bachelor of Science in Engineering Physics

Pruthvi A. Banginwar
Katie Barajas
Paul R. Beck
Peter J. Buckman
Matthew J. Danbury
William R. Evans
Erin E. Fleck*
Scout H. Fronhofer
Derek C. Goss
Sophia R. Handley
Alexander M. Irwin
Brian D. Isakov

Nachiket Khambhati
Jeremy B. Kline
Jake E. Lawson
Henry F. Malarkey
Alejandro Mesa Dame*
Luke C. Meyer
Leo Moon*
Christopher M. Tyerech
Lu Cherng Wang
Chloe A. Washabaugh*
Sunny Wong
*Honors student

Master of Engineering in Engineering Physics

Maxwell C. Maloney
Najva Akbari*
Michael L. Buttolph
Kristina R. Colladay*
Phillip Dang*
Noah R. Flemens
Berit H. Goodge
Jason Hamilton*
Dylan A. Heberle*

Eoin Sansevero

Doctor of Philosophy in Applied Physics

Yunus Kinkhabwala*
ChangJoo Lee*
David Low*
Tanner G. Pearson
Josue San Emeterio
Tianhong Wang
Yang Yu*

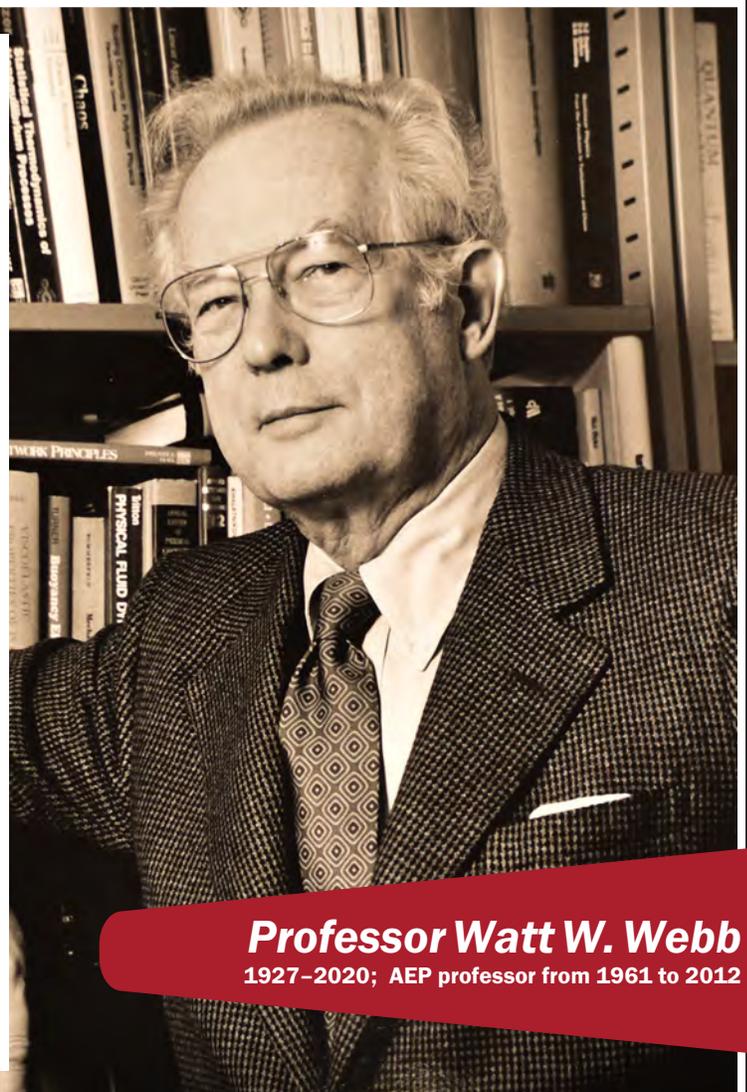
*December graduate

IN MEMORIAM WATT W. WEBB

WEBB MEMORIAL SYMPOSIUM

On August 8, 2022, friends, family, and past students of Professor Watt W. Webb gathered in the Physical Sciences Building at Cornell to celebrate his life and science. As one of his more recent Ph.D. students, it was eye-opening to meet lab alumni from decades ago who have gone on to successful careers in academia and industry. It was a testament to the breadth of interest and curiosity that drove the Webb group. Dan Dombeck, Ph.D. '05, and Sally Kim talked about their paths to pursue new optical microscopy techniques that started at Cornell. Neil Gershenfeld, Ph.D. '90, reminisced about the research freedom as a Ph.D. student that led him to eventually launch Fab Lab and head the maker movement. Joseph Schlessinger and Dan Larson, Ph.D. '04, showed their effort to apply research that can translate into potential therapies in the clinic. Lorinda Opsahl-Ong, Ph.D. '92, and Larry Jackel, Ph.D. '76, are alumni that have gone on to thrive in industry and on Wall Street. Barbara Baird and Fred Maxfield shared their perspectives as long-time collaborators. Many commented on the trail-blazing nature of the Webb group and the motivation to solve “impossible problems.” We laughed at the stories of how we initially joined the lab, and shared our lasting memories from our times in Ithaca. For me, I was inspired by his impact—both on scientific progress and on the people—that will be Professor Webb’s legacy and something that we as his former trainees will try to emulate and share.

—Alex Kwan, Ph.D., '09, Associate Professor
Meinig School of Biomedical Engineering, Cornell University



Professor Watt W. Webb
1927–2020; AEP professor from 1961 to 2012