ENGenious

ISSUE 13, 2016

A PUBLICATION FOR ALUMNI AND FRIENDS OF THE DIVISION OF ENGINEERING AND APPLIED SCIENCE
of the California Institute of Technology

Caltech

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We invite you to learn more about the Division through our website, *eas.caltech.edu*.

ENGenious

ISSUE 13, 2016

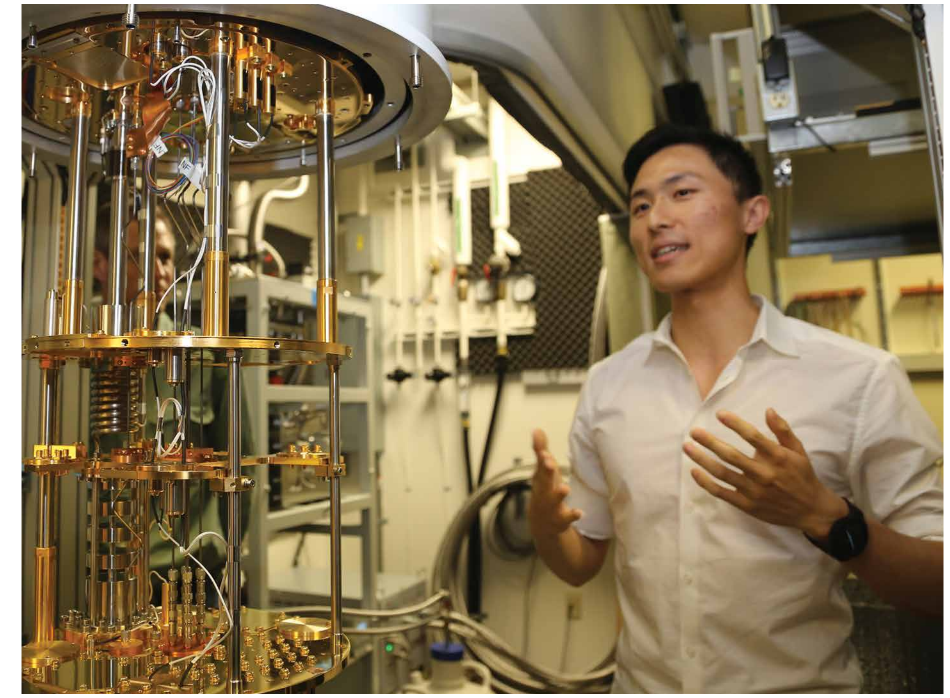
The Caltech Division of Engineering and Applied Science consists of seven departments and supports close to 90 faculty who are working at the leading edges of fundamental science to invent the technologies of the future.

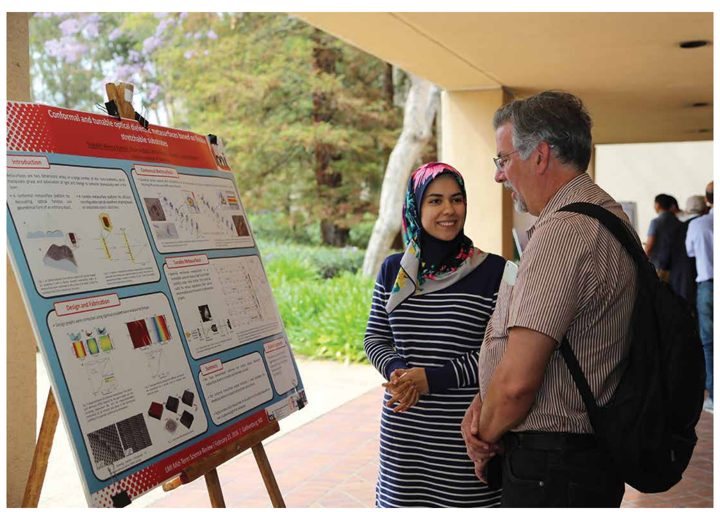
Sparks of Inspiration

The cover of this year's issue is inspired by the many ways in which the Division of Engineering and Applied Science both supports highly individualistic research and fosters cross-disciplinary connections.

The cover also contains hidden eggs. See if you can catch all of the eggs, or hatch a new idea in the process. (Answer on the inside back cover. Tip: Do not count partial shapes.)

MESSAGE FROM THE CHAIR





Dear alumni and friends of the Division,

Just over one year has passed since I began serving as the Otis Booth Leadership Chair of the Division of Engineering and Applied Science (EAS). My goal has been to enhance the Division's resources and strategies so that we continue to move forward as an intellectually vibrant, diverse, and inclusive destination for the top engineering scholars in the world and maintain our leadership in undergraduate and graduate education, research, mentoring, tech transfer, and outreach. I hope you will see some of the fruits of these efforts in the pages of this issue of *ENGenious*.

It is my pleasure to report that we are continuing to attract the best minds in the world, with five new faculty members joining us this year. Our faculty are unique in that they drive advances that benefit humanity through basic engineering research that addresses deep challenges, and our new hires continue in this tradition. Three of the new faculty are joining EAS as Bren Professors: Aaron Ames (Mechanical and Civil Engineering), Andrew Stuart (Computing and Mathematical Sciences), and Lihong Wang (Medical Engineering and Electrical Engineering). The Bren Professorships have been established under Caltech's initiative to explore new territory through interdisciplinary approaches to the biological and information sciences, including approaches that have roots in engineering fields. We also welcome Soon-Jo Chung to our Aerospace Department (GALCIT), and the new director of the Jet Propulsion Laboratory, Michael Watkins, to GALCIT as well.

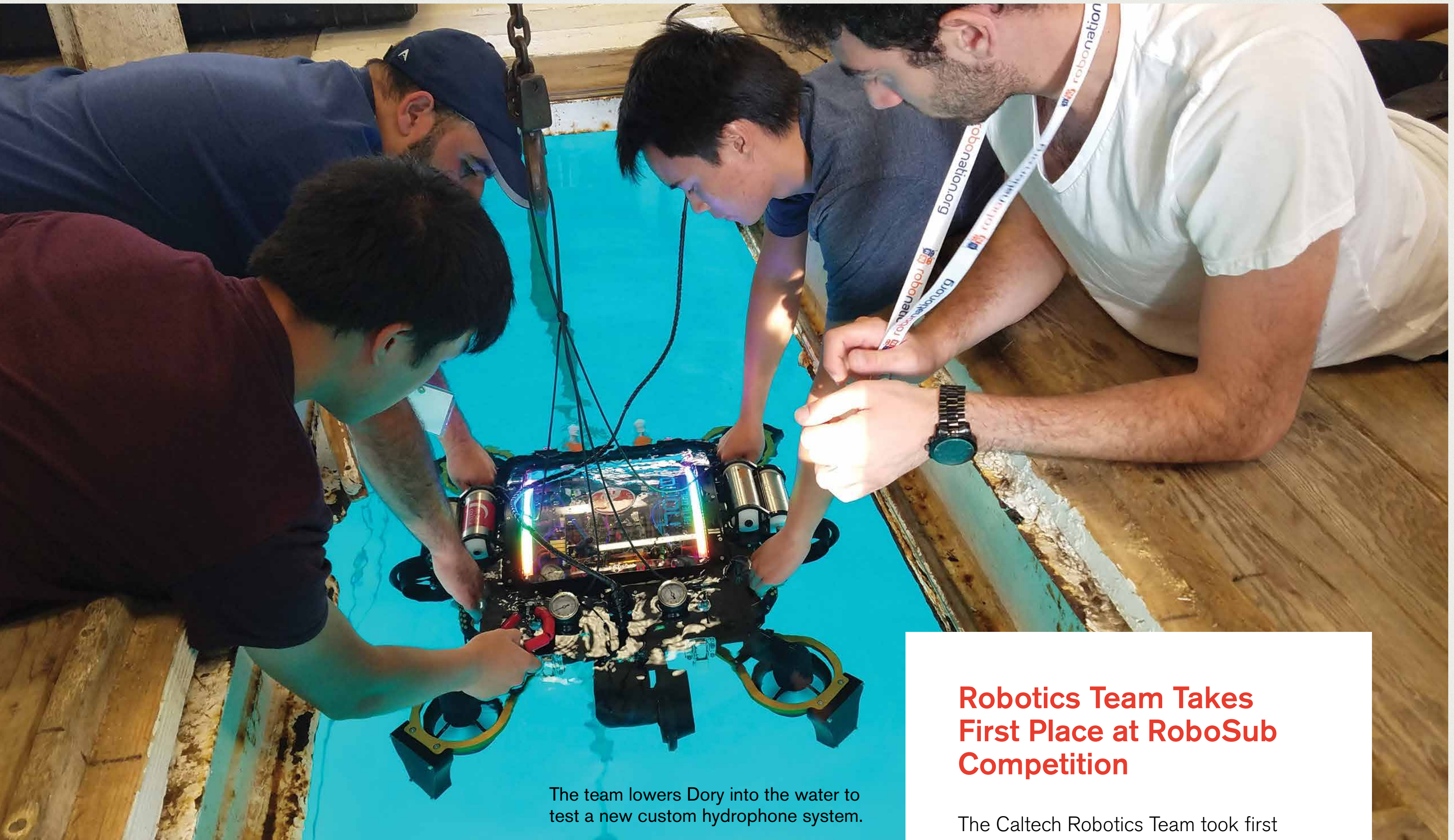
Attracting the best minds in the world means we bring exceptional students to Caltech, and this issue of *ENGenious* features the adventures and accomplishments of 14 current EAS students. As you might expect, they are embedded in research groups that are pushing the limits of engineering education and research, but they are also applying their talents to endeavors that range from school leadership activities to mentoring students from underserved communities.

Covering research in depth, we offer two progress reports in this issue. The first looks at advances in nano- and micro-technologies related to the human eye, and the second considers silicon photonics, which, although still in its infancy, is the basis for the next revolution in communications. In both of these areas, the Kavli Nanoscience Institute (KNI) at Caltech plays a vital role. In conversation with the directors and staff of the KNI, we discover how the KNI supports myriad research efforts at Caltech, helps push the frontiers of quantum science and engineering, and also plays a crucial educational role in motivating and nurturing students.

Finally, as many of you know, I firmly believe that EAS alumni play a key role in our success and are our best advocates and champions. In this issue, we profile two alumni whose Caltech education has propelled them into becoming influential players in their respective fields, financial services and the construction industry. Their stories illustrate just two of the infinite ways our alumni are shaping our society and the world.

I wish you the greatest success personally and professionally, and, as always, I look forward to receiving your thoughts and comments.

G. Ravichandran
Otis Booth Leadership Chair, Division of Engineering and Applied Science



The team lowers Dory into the water to test a new custom hydrophone system.

Robotics Team Takes First Place at RoboSub Competition

The Caltech Robotics Team took first place at the 2016 International RoboSub Competition. The team's robot, nicknamed Dory, successfully navigated an obstacle course with tasks that required it to touch buoys, fire torpedoes at targets, and rescue an object under water—all autonomously. Dory has seven thrusters, two grippers, a hydrophone, and other sensors. She took nine months and about $75,000 to build. This was the third year Caltech undergraduates entered the competition. In the first year, they placed seventh out of 39 teams, winning the "best newcomer" award. The following year, the team's ranking climbed to fourth out of 37. This year they came in first out of 47 competitors from around the world. It is noteworthy that, each year, the team has chosen to build the sub from the ground up—even though teams are allowed to re-enter subs, tweaking them to build on past successes.

Watch a video of the team in action at *www.robonation.org/competition/robosub.*

CMS Partners Program

The Computing and Mathematical Sciences (CMS) Department launched a new CMS Partners Program this year. It provides opportunities for individuals, start-ups, and companies to engage with CMS faculty, researchers, and students in order to strengthen academic–industry ties and initiate research collaboration. The Partners Program provides ways for companies to meaningfully engage with undergraduate and graduate students through course projects, collaborative research, and mentorship. The program encourages members to actively engage with students and faculty through a variety of channels, including TechFest, the annual Meeting of the Minds event, student clubs, and events such as Hacktech, Caltech's coding competition for high school and college students.

To learn more and get involved with the CMS Partners Program, visit *www.cms.caltech.edu/outreach/partners_program.*

Autonomous Systems and Technologies

The Center for Autonomous Systems and Technologies (CAST) was recently established at Caltech to promote interdisciplinary research and the exchange of ideas in the exploding area of autonomous systems. These systems include drones and robots for use in science, industry, and medicine. The research conducted by the center addresses sensing, control, vision, and other emerging areas. The center also promotes a synergic environment where machines and humans share the workplace. In addition, it serves as an arena for ideas to translate into reality and be demonstrated to academic researchers as well as to the general public through educational outreach. This center was funded through the generous support of Foster and Coco Stanback.

For information about ways to get involved, contact *cast@caltech.edu.*

Partnering to Diversify the STEM Workforce

Students and faculty from the Graduate Aerospace Laboratories of the California Institute of Technology (GALCIT) have been partnering with a workforce and entrepreneur accelerator called Base 11 to help create the next generation of leaders in STEM (science, technology, engineering, and mathematics). The program brings together GALCIT students and high-potential, low-resource community college students who have expressed interest in aerospace engineering. During the fellowship, the Base 11 students receive mentoring, attend conferences and lectures, and participate in GALCIT research projects. One such student was Alina Rai, who was mentored by Professor Beverley J. McKeon and her graduate student David Huynh. Rai worked on a drag-reduction experiment focusing on flow-induced motions of elastic gelatin membranes. She had the opportunity to build an experiment from the ground up and experience the challenges and thrills of aerospace research.

Learn more by watching this video: *bit.ly/2aUL6cW.*

WHO'S NEW

New Faculty

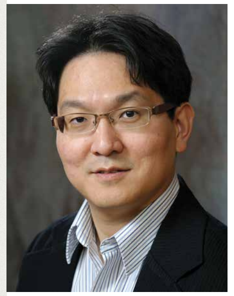
Aaron D. Ames

Bren Professor of Mechanical and Civil Engineering

Aaron Ames develops fundamental theory bridging the areas of robotics, nonlinear control, and hybrid systems, with a heavy emphasis on applications to bipedal robotic walking—both formally and through experimental validation. His lab designs, builds, and tests novel bipedal robots, humanoids, and prostheses with the goal of achieving human-like bipedal robotic locomotion and translating these capabilities to robotic assistive devices. The application of these ideas range from increased autonomy in legged robots to improved locomotion capabilities in the mobility impaired.

He received a BS in mechanical engineering and a BA in mathematics from the University of St. Thomas and his MA in mathematics and PhD in electrical engineering and computer sciences from UC Berkeley. He was a postdoctoral scholar in control and dynamical systems at Caltech and then began his faculty career at Texas A&M University. Prior to returning to Caltech as Bren Professor, he was at the Georgia Institute of Technology as an associate professor in the Woodruff School of Mechanical Engineering and the School of Electrical and Computer Engineering.

To learn more about our new faculty's research and accomplishments, visit eas.caltech.edu/people.



Soon-Jo Chung

Associate Professor of Aerospace

Soon-Jo Chung's research focuses on nonlinear control and estimation theory as well as motion planning and flight control, with application to spaceborne interferometry, spacecraft swarms, and robotic spacecraft systems. Other areas of research include aerial robotics, bioinspired flight, and vision-based navigation. At Caltech, he is establishing a research and education program in distributed spacecraft systems and aerospace autonomous systems.

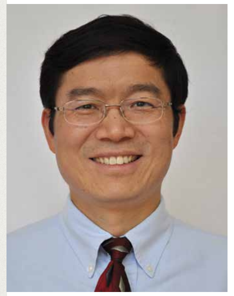
He received his BS in aerospace engineering from the Korea Advanced Institute of Science and Technology (KAIST). He then went to the Massachusetts Institute of Technology (MIT) to earn his MS in aeronautics and astronautics and ScD in estimation and control with a minor in optics. Prior to joining Caltech, he was on the faculty at Iowa State University and the University of Illinois at Urbana-Champaign. He has a strong collaboration with the Jet Propulsion Laboratory on distributed small satellites.

Andrew M. Stuart

Bren Professor of Computing and Mathematical Sciences

Andrew Stuart's research is in applied and computational mathematics—in particular, in the analysis and development of effective algorithms and the creation of mathematical frameworks within which to further the analysis and development of those algorithms. His current research focus is on the interfacing of mathematical models with data, and more specifically the solution of inverse problems and data assimilation. He has developed foundational mathematical frameworks for the formulation of statistical inverse problems, where both model and data are uncertain, and for filtering of high-dimensional systems; guiding applications for this work include subsurface geophysics and atmospheric modeling.

He graduated in mathematics from Bristol University and then obtained his PhD from the Oxford University Computing Laboratory. After a postdoctoral appointment in mathematics at MIT, he held permanent positions at Bath University in mathematics and at Stanford University in the computer science and mechanical engineering departments before joining the Warwick University Mathematics Institute.



Lihong Wang

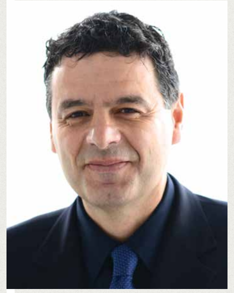
Bren Professor of Medical Engineering and Electrical Engineering

Lihong Wang's primary research interest is in the development of novel biomedical imaging technologies. His laboratory was the first to report functional photoacoustic tomography, 3-D photoacoustic microscopy, photoacoustic endoscopy, photoacoustic reporter gene imaging, the photoacoustic Doppler effect, the universal photoacoustic reconstruction algorithm, microwave-induced thermoacoustic tomography, ultrasound-modulated optical tomography, time-reversed ultrasonically encoded optical focusing, nonlinear photoacoustic wavefront shaping, compressed ultrafast photography (100 billion frames/second), Mueller-matrix optical coherence tomography, and optical coherence computed tomography.

He obtained his BS and MS from the Huazhong University of Science & Technology in Wuhan, China, and his PhD from Rice University. Prior to joining the Caltech faculty, he held the Gene K. Beare Distinguished Professorship of Biomedical Engineering at Washington University in St. Louis.

Moore Scholar

The Moore Distinguished Scholar program was established by Gordon and Betty Moore to invite researchers of exceptional quality who are distinguished at both the national and international levels to visit the California Institute of Technology for three to six months. There are no teaching or other obligations during the appointment, allowing Moore Scholars to focus on research.



Petros Koumoutsakos

Chair for Computational Science, ETH Zurich

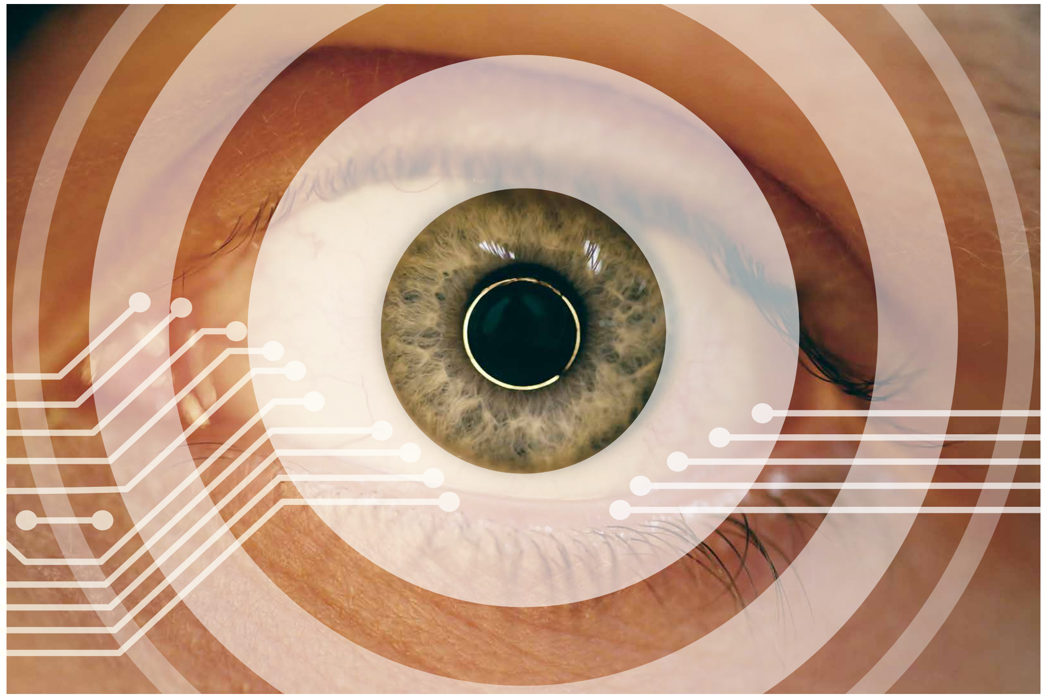
Petros Koumoutsakos conducts research at the interface of simulation and data sciences with an emphasis on fundamentals and applications in the areas of fluid mechanics, life sciences, and nanotechnology.

He received his diploma from the National Technical University of Athens, Greece, and his first MS from the University of Michigan in naval architecture. He also received an MS and PhD in aeronautics and applied mathematics from Caltech. He joined ETH Zurich as Assistant Professor of Computational Fluid Dynamics and was then named Professor of Computational Science. Later, he became the founding director of the ETH Zurich Computational Laboratory and the Zurich Graduate School for Computational Science. In addition to being a Caltech Moore Scholar, he is a fellow of the Collegium Helveticum and of the Radcliffe Institute at Harvard University.

Michael M. Watkins

Professor of Aerospace and Geophysics; Vice President and Director of the Jet Propulsion Laboratory

Before being appointed as the JPL director, Dr. Watkins was the Clare Cockrell Williams Centennial Chair in Aerospace Engineering and Director of the Center for Space Research at the University of Texas at Austin. Prior to his time at the University of Texas, he worked at JPL for 22 years. He served as mission manager and mission system manager for the Mars Science Laboratory's Curiosity rover, led review and development teams for several missions, including the Cassini, Mars Odyssey, and Deep Impact probes, and was the project scientist leading science development for the GRAIL moon-mapping satellites, the GRACE Earth science mission, and the GRACE Follow-On mission. He also served as manager of the JPL Science Division and the chief scientist for the Engineering and Science Directorate. He holds a BS, MS, and PhD in aerospace engineering from the University of Texas at Austin.



New Sight for Sore Eyes

A formidable team of Caltech and University of Southern California (USC) investigators has geared up to understand, protect, and repair a critical living system outside the usual gamut of engineering research. Their investigatory target is a complex, delicate structure consisting of a membrane enclosing a ball of liquid in which precisely shaped gelatinous bodies are arranged to control and respond actively to light, a system designed to turn the incoming light into data for neural information processing—a system known as the human eye.

Eyes, fragile but crucial for human and almost all other animal life, pose difficult challenges, both for basic research and for effective solutions to the medical problems that such research investigates. Caltech professors Yu-Chong Tai and Hyuck Choo work with students and postdocs along with distinguished USC faculty and medical professionals on a range of these challenges, using multidisciplinary approaches spanning nanotechnology, electrical engineering, biomedical engineering, physics, optics, photonics, and optomechanical engineering.

Meeting these challenges offers the potential for significant human rewards. While the most widely feared disease is cancer, as Tai notes, next on the list is blindness. And there, he says, the medical bar is high: "People usually don't make enough effort to maintain their eyes until it's too late. On the other hand, for the blind, having their vision even partially restored would represent a major advance."

New tools are changing the game—tools that have the potential to diagnose eye conditions, to restore vision to the blind, and to make state-of-the-art medical eye-examination technology available much more widely around the world, even in places with limited health systems. The Caltech and USC teams hope to deliver revolutionary new systems that may soon enable patients in remote areas around the world to be examined rapidly, without having to have their eyes chemically dilated and then be immobilized for many hours in clinics. If these new systems succeed, many more patients will receive full eye exams instead of brief looks.

For example, the measurement of pressure within and around the eye's liquid center illustrates one of the unique Caltech and USC medical engineering approaches. Intraocular pressure has long been recognized as a critical diagnostic parameter for ophthalmology. Higher pressure is a symptom and warning of glaucoma, a common cause of blindness and other pathologies.

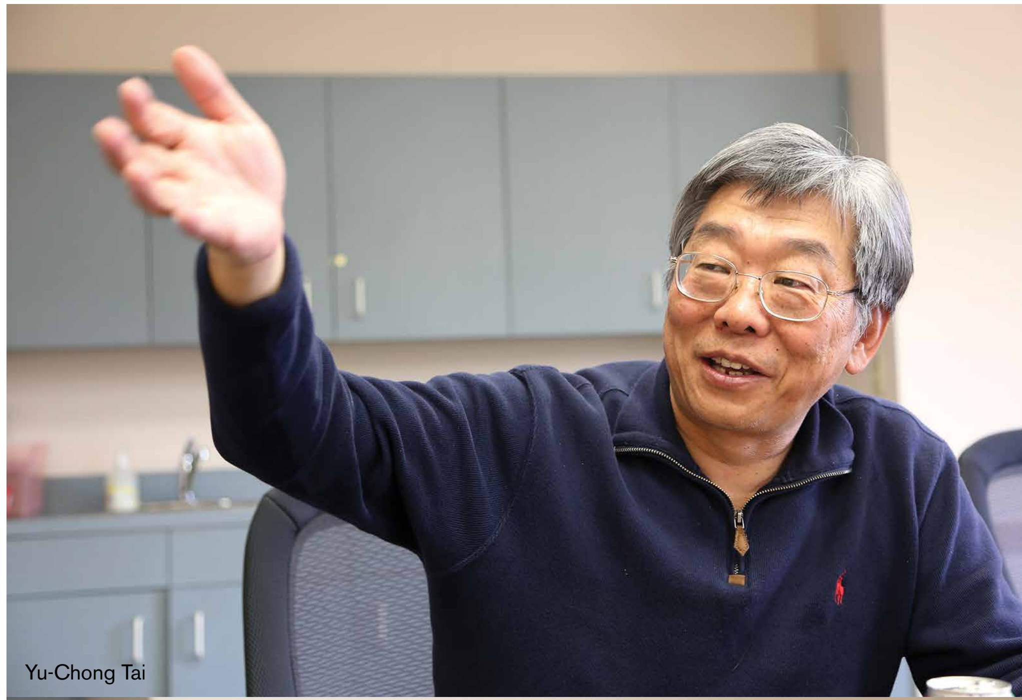
But pressure measurements and diagnoses have been almost exclusively done in medical offices several times a year and sometimes late in the game, long after pressure buildup has started. Thus either the pressure may not be at dangerous levels the day of the exam or treatment, or abnormally high pressure will have gone undiagnosed before extensive, irreparable damage has been done.

Doctors have discovered—by exhaustive (and exhausting) marathon tests—that ocular pressure varies a great deal over time, going from normal to high and back again. These changes may be associated with the progression of disease. This has led, as ophthalmologists have long noted, to late or incomplete diagnoses—less than half of the patients who have glaucoma are diagnosed early enough for optimal treatment.

Modern medical technology now allows blood pressure, blood sugar, and many other medical variables to be monitored virtually continuously by portable devices, including modern smartphone apps. Work using very different approaches and on separate paths by Professors Tai and Choo at Caltech is leading to similar modernizations in the realm of eye measurements.

Tai has been working on the problem the longest, consulting for more than a decade with a neighbor who happens to be a prominent ophthalmologist and biomedical engineer—Mark Humayun, an MD and PhD who is director of the USC Institute for Biomedical Therapeutics and co-director of the USC Roski Eye Institute.

"We have elected," says Humayun, "to collaborate with engineers at Caltech because they have some specific knowledge that we need and we think it very important for the medical application—and, well, because they're just nice people."



Yu-Chong Tai

Hyuck Choo

Eye-implantable microelectromechanical systems (MEMS) are potential ophthalmological game changers in many ways, says Humayun. "The eye is a great spot for MEMS because it's small, and so it's constrained by size, and the tissue is very delicate and also often transparent. So all those things make it a specific challenge that MEMS is able to address."

Tai and Humayun have been developing a new pressure sensor to make the monitoring process easier. Nine years ago, they reported the first prototype of an "implantable micromechanical parylene-based pressure sensor for unpowered intraocular pressure sensing"—that is, a fitted and flexible plastic device that can be implanted within the eye and activated externally to report pressure.

Armand R. Tanguay (left) and Mark Humayun

This device has been continually improved for use in high-risk patients.

Pressure monitoring remains critical. Choo is collaborating with University of San Francisco (UCSF) colleague David W. Sretavan on perfecting an optomechanical system designed to report intraocular pressure continuously for hours at a time. "Other than the time that the patient is asleep, we can monitor the pressure pretty much around the clock, during all activities," whenever the eye is open, he says.

The research involves studies that, Choo explains, "followed a [glaucoma] patient's pressure for a week or two, 24 hours a day, to see how the pressure changes. The study found that the patient's pressure actually changed over the course of a day. Furthermore, there's a particular time of the day that the pressure spiked. Clinicians believe that this pressure spike is what causes the damage to the optic nerve."

Glaucoma research is also aimed at discovering exactly what causes the spikes and investigating possible cures for the disease. Intensive work is already being done on rabbit eyes, says Choo. "It involves a sensor that has a wireless electronic or optical automatic readout capability to understand the relationship between the pressure and optic nerve damage as well as other immune responses that occur in the eye. To put all of this into a single package is a very efficient approach. It really speeds up the progress."

On the horizon is an implantable device that not only measures intraocular pressure but also responds to it. "If we can develop a device that controls the pressure by draining a little bit of fluid, it would be really revolutionary!" Humayun says.

For human medical care, facilitating internal ocular monitoring of other variables can change the game in a number of other ways. For example, a new surgical procedure can repair retinal tears and restore vision in a damaged eye by using a bubble within the eyeball to hold together the pieces of a retinal tear. However, it can only do so if the patient maintains a specific head position for more than 12 hours so that the bubbles will be properly positioned against the retinal tear and will push against the wall. At present, this can only be done with a patient immobilized face down in a hospital.

However, new electronic equipment developed by Choo and Professor Robert Grubbs is opening up a new possibility: an external device that actually tracks the position of the bubble inside the eye. The new system consists of a headband that is wirelessly connected to an iPhone. It actually tells the patient whether his or her head is properly positioned. If it's even slightly out of position, the system warns post-op care workers right away. Choo reports that a prototype is due for trial in summer 2016. It will be tested by UCSF collaborators Dan Schwartz and Frank Brodie.

These and other new and emerging technologies will not only change medicine in state-of-the art hospitals but may also change it in third-world settings. This is one of the attractions for the members of the Caltech and USC medical engineering team, which also includes Armand R. Tanguay of the USC Viterbi School of Engineering.

For example, Professors Humayun and Tanguay at USC, in collaboration with Professor Choo at Caltech, are harnessing ultra low light level imaging technologies to develop both improved surgical microscopes and ophthalmological imaging devices. "We're always trying to figure out different ways to measure and image the eye," says Humayun. "Our current cameras and imaging equipment are very sophisticated, but if you're in a rural area of China, India, or Africa, it is currently very difficult to bring these instruments into the field to perform screening and testing. Therefore, we've been thinking about an easy-to-use technology that one could take to the Serengeti, a device that anyone can use to upload images to the doctors in a clinic hundreds of miles away. We're really working at the edges of medicine, physics, and engineering to be able to do this."

Tanguay takes up the thread. He explains: "I don't know if you've ever had your eyes dilated, but it's a long process. Chemicals are used to expand the iris. There's a long waiting period before the ophthalmologist can actually do the examination. People are also very sensitive to light for a long time afterwards. But everyone's eyes naturally dilate rapidly at night, or in the dark," which provided an opening for the new technology.

Tanguay continues, "Because image sensor arrays are far more sensitive now than they were 20 years ago, we thought that we might be able to use ultra low light level imaging of the retina to allow a full ophthalmological examination in a darkened office without any chemistry at all. So then you could have very rapid examinations of many subjects with maybe even a handheld device or a small ophthalmoscope that would be inexpensive and hence far more accessible. This new idea got us at Caltech and USC really excited. We patented the concept at USC a few years ago, and we've been continually working on developing it further."

The eye pressure sensor is only one example of Humayun's work with Tai. In collaboration with Tanguay, the multi-university research team is also working toward developing an intraocular retinal prosthesis that is capable of restoring partial sight to the blind.

Humayun notes that, with Tai, "we've worked on a retinal implant technology that is very novel, very different than what currently exists. It potentially allows the manufacturing to be simpler, and therefore the cost of the eventual product to be lower. It also allows the implant to be smaller but with more resolution, and therefore to potentially provide better vision." Tanguay and Humayun have collaborated for a number of years on visual psychophysics experiments to better understand the natural coupling between head and eye movements, and they are developing an ultraminiature camera to implant directly into the eye in order to restore this natural coupling and replace an external camera that is typically mounted on a pair of glasses. Taken together, these advances could provide a retinal prosthesis that is so well integrated that the entire apparatus can be implanted directly into the eye.

Other members of the collaboration also have innovations approaching the market. Robert Grubbs, Caltech's Victor and Elizabeth Atkins Professor of Chemistry, is part of a team developing the targeted microbubbles that are used in retinal replacement for application in other body areas. Azita Emami, Professor of Electrical Engineering, is developing ocular microimplant technology for units that can remain in the eye for 10 years or even longer. Morteza Gharib, Hans W. Liepmann Professor of Aeronautics and Bioinspired Engineering, has patented a design for carbon nanotube microneedles for drug administration.

Graduate students are also picking up the threads and the unique perspective offered by the collaboration. "Our program relies on very deep engineering," says Tai. "Our students are recruited from engineering backgrounds, but for their graduate research, they need to solve medical problems. This is very different, because we believe that in order to solve a real-world medical problem, you need to have a really deep understanding of engineering."

But academic silos can interfere with the process—and both Caltech and USC are consciously avoiding the trap. "There's no lack of students who want to work on medically related projects, especially no lack of engineering students. But many engineering students don't have the opportunity to acquire the range of medical skills needed for research in this field," says Tai.

The students admitted to the Caltech medical engineering program have the opportunity to build on their engineering strengths and learn in a uniquely multidisciplinary environment that rewards original thinking and innovation. USC has implemented a novel Health, Technology, and Engineering (HTE) program that integrates engineering and medical students in a highly interactive curriculum and research environment that even includes hospital rounds.

The results may someday save the sight of you or someone you know.

ENG

Yu-Chong Tai is the Anna L. Rosen Professor of Electrical Engineering and Mechanical Engineering and Executive Officer for Medical Engineering at Caltech. Hyuck Choo is Assistant Professor of Electrical Engineering.

ALUMNI PROFILE

Eduardo Repetto: Communicating Difficult Concepts

Eduardo Repetto (PhD '98, aeronautics) is the Co-Chief Executive Officer and Co-Chief Investment Officer of Dimensional Fund Advisors LP. The Dimensional firms manage over $400 billion for investors worldwide, with 12 offices around the globe. Repetto has oversight across the investment, client service, marketing, and operational functions of the firm. *ENGenious* sat down with him to learn more about his time as a graduate student at Caltech and his unique career path in the financial industry.

***ENGenious*: How has your Caltech education influenced you?**

Repetto: You become humble very fast when you go to a school like Caltech. You realize that there are a lot of talented people around you who can add to your own experiences. I recognized that what other people bring to the table is very important; the group can bring something that you cannot do on your own. As a graduate student at Caltech, I was able to interact with mathematicians, engineers, computer scientists, and many others as part of my courses and research. I learned how to work and communicate across groups with different sets of expertise. This experience has been extremely useful in my current working environment. I interact with people from many backgrounds, including investors, boards, lawyers from different countries, employees from each one of our offices, marketers, data managers, portfolio managers and traders, computer scientists, etc.

***ENGenious*: What were some of the lessons you learned at Caltech?**

Repetto: You don't realize what you've learned until you have to apply that knowledge or those lessons. We all learn great technical skills in our own field of study that can be transported to other disciplines, but there is much more. As Caltech students, when we spoke with professors, we realized their ability to communicate extremely complex and technical topics to us in easy and understandable ways.

That was a big lesson by itself! It applies to all aspects of business. It is very relevant in the financial industry because we need to communicate technical and complex topics in a manner that reaches a wide range of audiences. In many cases there is no time to negotiate and agree on how technical the language should be. We need to adapt to the language used by our audience without sacrificing the accuracy of the content.

At the end of the day, communication is trying to make our audience understand what we are trying to convey. We have to distill the information so it can be assimilated, trusted, and repeated. This is one of the lessons my Caltech mentors, including professors Michael Ortiz, Guruswami Ravichandran, Ares Rosakis, Kaushik Bhattacharya, and Wolfgang Knauss—among others—taught me.

***ENGenious*: Why is building trust so important in the financial industry?**

Repetto: People's savings often represent years of life committed to work and sacrifices made to put aside earnings to fulfill future aspirations or manage future life uncertainties. Speaking about savings is the same as speaking about people's lives, so people need to trust that you bring expertise that can help them and that you understand their needs. Investors will not commit their savings without trusting the company or the strategy.

It is a big responsibility, helping people with their investments. In order to gain their trust, we need to have a sound investment process but also have a good understanding of people's needs and the ability to communicate how we can help in a trustworthy and straightforward way. Some investment concepts are very technical, so the manner in which we communicate matters.

I see a big similarity in how Caltech professors are able to communicate very difficult concepts. They have such a deep understanding of the subject that they are able to simplify the communication but still keep it meaningful and preserve the integrity of the concept. As a Caltech student, you get the technical knowledge, but your group meetings, your conference presentations, and your posters force you to find ways to communicate your ideas efficiently, and that's important, too. All of us are in the business of marketing something—our products, our expertise, or our ability to help or to teach. Caltech is not a business school, but it taught me many of the skills I apply on a daily basis in business.

***ENGenious*: What was it like being a foreign student at Caltech?**

Repetto: I was very lucky to be mentored by Caltech professors that really care about their students. As a foreign student, even though we study English and have tests in English as a second language, it can be difficult to order a sandwich, let alone speak up in class! The professors helped us create a network that made us feel at home, which is extremely important when you are on your own, far from your home country and your family. Professors Ortiz and Knauss would even invite us to their homes, allowing us to interact with their families.

***ENGenious*: Why was it hard to order a sandwich?**

Repetto: When I first came to the United States as a student, I was at Brown University. One day, I went to order a sandwich in a coffee shop. I was used to ordering sandwiches in Argentina, where when you order a ham-and-cheese sandwich and you just get a ham-and-cheese sandwich. In the United States, I asked for a sandwich and then the guy, who had a line of 50 people waiting to order sandwiches, starts speeding through the selection of cheeses—Swiss, American, white, yellow. I felt like he was bombarding me with it all and then, once he finished with the selection of cheeses, he started with the selection of bread—white, wheat, rye. I didn't know the difference among the types of bread or even what the names meant. I remember just saying "yes," because I didn't know what else to say without delaying everyone behind me!

***ENGenious*: How is the Caltech approach unique, and has it helped you overcome barriers?**

Repetto: Caltech taught me the discipline to try to find the right answer, to iterate and work until all the different aspects needed to understand that a solution is the right solution are taken care of.

When I was doing research at Caltech, first I tried to understand the problem at hand and the work done by others in the same or similar fields. This process included reading papers, speaking with professors and fellow students, and performing multiple iterations. Then I tried to push the current state of knowledge and be innovative while focusing on finding the right solution. I became disciplined in being critical of my work and my knowledge in a systematic way—recognizing its weaknesses and trying to find ways to overcome them or find alternative solutions. Caltech teaches this very well! Caltech brings you together with extremely talented and approachable people from all over the world, who are always willing to speak about interesting problems and possible ways to solve them. This is very similar to my current work environment; we are always searching for the right solution and always debating ways to improve it.

***ENGenious*: Is a Caltech education valued by your colleagues in the financial industry?**

Repetto: Being a Caltech alumnus and being associated with Caltech is a very strong endorsement, no matter where you are. Caltech has a reputation outside the main scientific environment for the rigor that it imposes on every process that it is involved with. There are many Caltech graduates who are dispersed around the world in very important positions and are highly recognized for what they have done in science and in other fields. I work very closely with one such Caltech PhD, Gerard O'Reilly. He's one of the smartest people I've met. He's Irish, from Trinity College, a clever guy, very approachable, always willing to take an extra step to help and able to communicate very difficult concepts with great ease. Another Caltech mathematics alumnus that I know and admire is Luis Reyna. Luis showed me that you can succeed in finance with a PhD from Caltech. He was the one that told me that a Caltech education and work ethic are highly desirable in the financial industry.

***ENGenious*: What made you decide to support graduate fellowships at Caltech?**

Repetto: It was not just me. It was also my wife, Carla, who grew up in this area and whom I met at Caltech's Dabney Hall. Coincidentally, we now live across the street from where she grew up. Caltech has done a lot for me, and we decided we should do something for the next generation. We have been very lucky. One's studies, knowledge, constant willingness to try to learn enhances his or her chances of doing well when opportunities show up, but you also have to be at the right place at the right time. Hopefully, Carla and I can enable other students to be lucky like we have been.

***ENGenious*: What advice do you have for the next generation of Caltech students?**

Repetto: Take advantage of all that Caltech can give you. And it's not only the courses; it's also the interactions with professors and other students. Learn the communication skills you need to convey difficult concepts to different kinds of audiences. Take advantage of learning from different people who come from different backgrounds. Enjoy every moment. Enjoy every opportunity. I always tell people who are looking for a job: Don't find the job that pays you more. Find the one that you can do for a long time, and have fun and enjoy it, because the rest happens. Enjoy what you're doing. That's the most important thing. ENG

Pushing the Limits of Engineering Education and Research

A key ingredient of the celebrated Caltech culture is the student body. To gain insight into the current student experience at Caltech, *ENGenious* sat down with 14 students who have chosen to get their degrees from the Division of Engineering and Applied Science. Two were selected from each of the seven EAS departments. For the three departments with the largest number of undergraduate students, Computing and Mathematical Sciences, Mechanical and Civil Engineering, and Electrical Engineering, one of the students chosen was an undergraduate and the other was a graduate student.

All the students shared a passion for research and excitement about the unique opportunities in the EAS division to work closely with faculty and interdisciplinary research groups. The students are involved in a broad range of research, including packaging big antennas into small satellites, designing color-splitting optics, modeling the behavior of large groups in social media, developing ultra-low power systems for medical devices, studying the critical moments when earth structures move, understanding the role of single-cell eukaryotes in climate change, building new oxygen-delivery systems for hypoxic cells, and using carbon nanotubes in seawater desalination.

Caltech has also created many opportunities for the students to contribute to companies and startups, including hedge funds, a Japanese company making spider-fiber composites, SpaceX, and Northrop Grumman. This experience has encouraged some to become entrepreneurs and others to join larger and more established companies where they can push the limits of technology and innovation.

Furthermore, the intense yet intimate Caltech culture has allowed the students to get involved in an equally diverse set of activities. Several are advocates for STEM education in underserved communities, some are engaged in science policy at the state and national level, and others are contributing to the arts as members of the Caltech orchestra and chamber music society.

As you read the following student profiles, we encourage you to share your thoughts and impressions with us at engenious@caltech.edu.

Arnold Durel Deffo Nde

Graduate Student: Aeronautics

Advisor: Michael Ortiz, Frank and Ora Lee Marble Professor of Aeronautics and Mechanical Engineering

Arnold Durel Deffo Nde grew up in Central Africa, and studying at Caltech was a longtime dream. While still in high school in Cameroon, he met a JPL fellow from Mali who told him about JPL and Caltech.

The connection stuck. When Deffo Nde went to the United States for college to study aeronautical engineering, he began at Wichita State University in Kansas. "But I always wanted to go to grad school," he says, "and when it came time to apply for grad school, Caltech was the first school that came to mind. Thankfully, I was admitted. So here I am today."

Deffo Nde, who is now conducting research in materials science and specifically in dislocation dynamics with Professor Michael Ortiz, learned a crucial lesson early in the talent-rich Caltech environment. "You have to accept the fact that other people at Caltech are better than you in some aspects. And instead of looking at it in terms of competition, you must accept it and go to them if you need help. Caltech also made me realize that science is usually done as a collaborative effort."

The Caltech engineering approach was also different, he found. "At Caltech it's still engineering, but engineering at the more fundamental level. Caltech prides itself in dealing with fundamentals. The depth to which professors go is something that makes Caltech quite different from the experience I had as an undergrad."

The professors are only part of the Caltech difference. "In grad school, it's all from within," Deffo Nde says. "You must be willing to make that effort, because no one is forcing you to go read those extra papers. This not only makes research very rewarding but also makes you a better-rounded person, because you have knowledge of all the other aspects."

Deffo Nde had critical help in getting from his city of Douala in Cameroon to the United States. As a senior in high school, he placed first in the Cameroon national graduation examination, which led to a newspaper article that brought him to the attention of a nearby entrepreneur and philanthropist, Bernard Fokou, who gave him a scholarship to go abroad for his education.

He is still grateful, and he is giving back by working with Base 11 students interning at Caltech. The nonprofit partners with Caltech to train the next generation of leaders in STEM (science, technology, engineering, and mathematics) from underserved communities. Deffo Nde finds this work very gratifying, and he is proud to report on the progress of one of the Base 11 students he has worked with: the student is now headed for the University of California, Riverside. ENG

What languages do you speak?
Besides English, I also speak French and Bansoa, the latter being my mother tongue.

What is your favorite online activity?
Playing the soccer video game FIFA online with friends.

What is your favorite story?
L'Enfant Noir by Camara Laye. It's an autobiography by an African writer that reminds me of my own story in many respects.

What is your favorite destination?
Douala, Cameroon (of course)!

What languages do you speak?
English and Russian

What is your favorite online activity?
Browsing travel photography

What is your favorite story?
"The Rocket" by Ray Bradbury

What is your favorite destination?
New Zealand

Maria Sakovsky

Graduate Student: Aeronautics
Advisor: Sergio Pellegrino, Joyce and Kent Kresa Professor of Aeronautics and Professor of Civil Engineering; Jet Propulsion Laboratory Senior Research Scientist

Maria Sakovsky engineers twenty-first-century origami structures. She works in Professor Sergio Pellegrino's lab on components that can unfold from compact packages to form large space structures of complex shapes. She is also a Keck Institute for Space Studies graduate fellow.

Her research is developing novel deployable antennas for small satellites. The idea is to pack big, very-high-performance antennas into very small volumes. Elegantly folding them up stores strain energy so they unfold themselves autonomously. "We're able to get a lot more data back, and this is a very efficient way to get into space, so everybody's excited about the technology," Sakovsky says. "We are pushing the communications envelope."

Sakovsky has had the opportunity to work with prototypes in numerous venues. "I actually got to go to Albuquerque last year to take one of these antennas into their anechoic chamber, where we measured the performance of the antenna. We put the antenna on one end and the receiver on the other end. We then attached the antenna to a CubeSat and rotated it to measure its performance in all directions."

Sakovsky, who was born in Russia and later lived in Israel and Canada, came to Caltech from the University of Toronto, where she became passionate about aerospace. When she arrived at Caltech, she needed to deepen her understanding of electrical engineering. "At first I was terrified, because circuits and any electrical engineering was outside of my comfort zone, but I was pleasantly surprised to learn more about the interaction between electrical engineering and structural engineering, and that's now what I do," she says.

When not folding and unfolding antennas, Sakovsky reaches out to an extended Caltech community. "I really love working with the Caltech Y on the Rise tutoring program for high school kids," she says. "I get to work with students who are struggling with math and science. I find this work to be a lot of fun because the students ask very good questions, and they get so excited when they hear that a tiny little math equation that they're working on can be applied to building spacecraft. Then they start asking even more questions." ENG

EAS STUDENT FEATURE

Evan T. Miyazono

Graduate Student: Applied Physics
Advisor: Andrei Faraon, Assistant Professor of Applied Physics and Materials Science

Evan Miyazono is a graduate student in applied physics and spent multiple summers as an intern at Northrop Grumman before coming to Caltech. He has worked on various electrical engineering, data processing, and hardware testing problems, as well as on the setup for thin-film research. He explains, "I learned a lot about how engineering is done in industry, and to a large extent, it motivated me to apply to PhD programs."

His research with Professor Faraon at Caltech centers on optical storage of quantum information using rare-earth atomic dopants, a complex problem that requires wide-ranging expertise, including software engineering, nanofabrication, optics, vacuum systems, and even, occasionally, plumbing. To Miyazono's surprise, he has found all of this expertise among his own group members. He recently scored a breakthrough in this cooperative environment while working with his graduate student mentee, Ioana Craiciu. Miyazono says, "We have made devices for coupling to rare-earth dopants using electron beam lithography techniques. This allows us to scale our coupling platform to easily make arrays of interconnected devices. Our previous work used focused ion beam devices, which were individually sculpted by what could be described as sandblasting with gallium ions. Our new devices are a big step forward!"

He has an anecdote to share about the Caltech attitude toward learning: "I had a friend who told me that they absolutely loved getting the book for a class, opening it up to almost the last page, and just staring at what was basically incomprehensible and thinking: I'm going to understand this book in 10 weeks or a year. I love that. I love that classes are really a great excuse to better yourself without any sort of external metric for success."

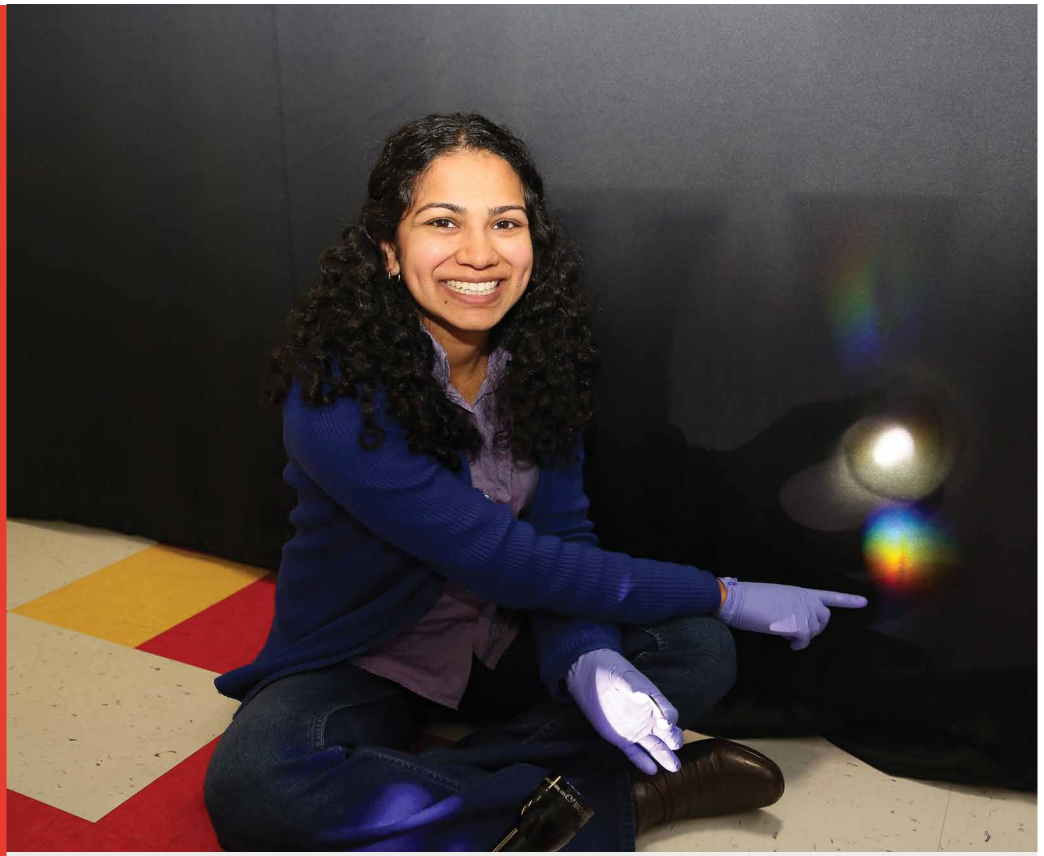
Miyazono also enjoys STEM outreach, and he fondly recalls a recent trip funded by the Institute for Quantum Information and Matter (IQIM) to the Navajo Preparatory School in Farmington, New Mexico. Between his planned lectures to physics classes, Miyazono visited some of the school's math classes. "I just sat at the front of the room and answered the age-old math student's question, 'When will I ever use this?' And I had answers! This led to an impromptu lecture about the properties of ellipses and parabolas and the applications of conic sections from orbits to optics. It was really fun to improvise and get the students enthused about the subject. I will try to go back before I graduate from Caltech." ENG

What languages do you speak?
I'm a native English speaker, can read and hold a slow conversation in Spanish (took four years in high school), and have been recently trying to learn German, because I thought it would be fun.

What is your favorite online activity?
Reading articles on politics, economics, sociology, and the occasional popular science article from a variety of sources, ranging from the *Guardian*, the *New Yorker*, and the *Economist* to *Wired*, *Medium*, and *TechCrunch*.

What is your favorite story?
God's Debris by Scott Adams or *The Martian* by Andy Weir (honorable mention to Andy Weir's short story "The Egg"). I'm convinced stories are one of the best tools humanity has to foster empathy, and I also love optimistic stories that show potential worlds that people actually want to live in; the first step in engineering an improvement is believing that things can improve.

What is your favorite destination?
The nearest uncrowded beach with clear water, sunny skies, and good surf.



Sunita Darbe

Graduate Student: Materials Science

Advisor: Harry Atwater, Howard Hughes Professor of Applied Physics and Materials Science; Director, Joint Center for Artificial Photosynthesis

Sunita Darbe is a graduate student who found her way to the stage at the most recent Caltech presidential inauguration, where she sat next to Nobel Prize winners.

Darbe's research focus is on designing color-splitting optics. "Sunlight is broadband white light," she says, and a solar cell with a single absorber material is most efficient at extracting power from a narrow color range of sunlight. So her devices separate the incoming colors, sending them to different solar cells with different absorber materials.

Darbe has been working on the project in Professor Harry Atwater's laboratory since soon after her arrival at Caltech in 2011 with a BS from MIT and a master's degree from France's École Polytechnique. Seven Atwater students cooperated in writing the initial proposal for her research focus the summer after her first year. The team has stayed together as the project has moved all the way from fundamental physics to fundraising and financing. It has been a great learning experience for her.

In the meantime, Darbe has become involved with the greater Caltech community. For the Graduate Student Council and other groups such as Women Mentoring Women, she frequently finds herself behind podiums, where her experience with the Atwater group has come in handy: "One thing that Harry emphasizes quite a bit is oral presentation skills."

One notable occasion was when she represented Caltech graduate students at the inauguration of President Thomas Rosenbaum in the summer of 2014. "Speaking in front of a thousand people from a script is a very different thing than giving a conference talk in front of even 50 or 100 people," she says. Despite a moment when she lost her place in the script, she treasures the memory. "It was a very fun event to participate in. I got to sit up on the stage next to Nobel laureates from Caltech and the past president," including David Baltimore and Thomas Everhart.

In addition to presentations she is organizing, Darbe has started an Applied Physics and Materials Science student group with the department's executive officer, Professor Kerry Vahala. Beyond Caltech, she is interested in being part of the technology pipeline between more fundamental research and technologies that are impacting the world. "I want to spend my career on that trajectory, to be part of the whole process," she says. "I think, moving forward, it's going to be smaller pieces at a time, but I'm excited about a career bringing new technologies into the world. Right after graduation, I will start working in Japan with a company called Spiber Inc. that is commercializing spider silk. Specifically, I will be working on developing spider-fiber composites."

What languages do you speak?
English, French, some Telugu, and I've just started learning Japanese for my new job!

What is your favorite online activity?
I'm a big fan of streaming podcasts. I just started listening to *More Perfect*, about significant Supreme Court cases.

What is your favorite story?
A new one!

What is your favorite destination?
My hometown, Edmond, Oklahoma.

EAS STUDENT FEATURE

Carlos A. Pérez-Arancibia

Graduate Student: Applied & Computational Mathematics

Advisor: Oscar Bruno, Professor of Applied and Computational Mathematics

Carlos Pérez-Arancibia came to Caltech from Chile because he knew exactly how and what he wanted to study. He had also identified the best place and person to learn from. "I came to work with Oscar," he says. "I have Oscar telling me, with all his characteristic passion, 'We're going to solve this problem! It's really hard, but we're going to do it.' That combination of intellectual ambition and determination to achieve something outstanding in terms of research is really hard to find anywhere else, I think. It is one of the best things Caltech has offered me."

Pérez-Arancibia's work is highly mathematical and abstract, and the resulting algorithms can be used to tackle a wide range of problems in different areas of science and engineering, such as electrical engineering, physics, and astronomy. It focuses on new, fast, high-order integral equation methods for solving PDEs (partial differential equations). "PDEs come from physical models most of the time," he explains. "That's why I got involved with this particular branch of mathematics—because I love physics."

The current state of the art of integral equation methods involves pushing beyond the general understanding of simple shapes to model intricate, real-world objects. "PDEs allow you to extract very detailed information about the physical world, as long as you take some of the complexity of the physical world into account in your model," he says. "To extract reliable information from a PDE, you have to develop efficient algorithms and implement them in the computer to then produce approximate solutions that you need to analyze, to make sure you're computing the right thing. This whole process is what excites me about applied math."

He offers the example of visualizing interior structures: "Let's say you have layers of various kinds of dielectric materials, and you're interested in solving the scattering problem they create when you illuminate them with an electromagnetic or acoustic wave. If you can solve this problem accurately and efficiently, you can extract very useful information. For instance, you can determine if there is an object buried underground, and, even more, you can theoretically determine the shape of that object and the materials it is made of by solving an inverse problem."

At Caltech, Pérez-Arancibia is relishing the experience of diversity in people and cultures. Chile, he notes, is a very "homogenous country. It has been wonderful to get to know people from all parts of the world. I have friends from Syria, India, Poland, Argentina, and Mexico. In fact, very few of them are born Americans. I think that's an experience that very few places can give you."

There is something, though, he's been missing: "I like philosophy, and I have not yet met anyone at Caltech who is interested in philosophy." But he will soon be moving on. "I accepted an offer from MIT. I'll be a postdoc in the math department starting this fall. I'm very excited about that," he says—and perhaps he will find philosophers in Massachusetts.

What languages do you speak?
Spanish and English

What is your favorite online activity?
Get to know new bands, especially progressive rock and jazz

What is your favorite story?
"El Aleph" by Jorge Luis Borges

What is your favorite destination?
New York City

What languages do you speak?
I speak English and some Spanish.

What is your favorite online activity?
My favorite online activity is going on food and travel websites.

What is your favorite story?
My favorite books are *One Hundred Years of Solitude*, the *Harry Potter* series, and *The Caine Mutiny*.

What is your favorite destination?
My favorite destination would be anywhere exotic, with new food to try and sights to explore.

Nikita A. Sirohi

Undergraduate Student: Computing and Mathematical Sciences

Undergraduate student Nikita Sirohi enjoys finding unexpected connections, both engineering and human. Speaking of her computer science courses, she says, "I like classes where I can see different ideas coming together, where you approach a problem from very different angles, where you get similar insights from really different approaches."

She is applying that strategy to work on two very different problems: the behavior of subatomic structures, as in the search for dark matter, and the behavior of large groups of human beings in social media and financial markets.

She began working on dark matter with a Caltech team of 40 faculty and students associated with the research being conducted at the Large Hadron Collider (LHC) in Switzerland. While still a freshman, Sirohi helped to model particle collisions, seeing if the particle models predictably matched what was being found in the LHC.

Her other internship involved very different models, analyzing trade in commodity futures. "I was working with a Caltech alum and his partner at Crabel Capital, a quantitative hedge fund based in Century City, on creating an algorithmic trading system by analysis of a 20-year universe of daily and monthly data for 24 commodities futures markets," she explains.

She helped to develop two momentum-based strategies now close to implementation, a process that involved generating long and short signals signing certain moving averages. "I never really explored the world of finance before then," she says. "And it was amazing to understand how complicated it is and how the things I'm learning at Caltech are so applicable."

The Caltech environment has, according to Sirohi, allowed her to move out of the restrictive "girl science-math student" she felt like during high school in the suburbs of Seattle. "There weren't many others who were as interested in the things I am interested in," she says—but Caltech has allowed her to broaden her identity. "I define myself through different things because I now know so many people that are interested in the same things I am. It's allowed me to explore other parts of myself."

For example, she is now involved in student government and is a mentor. "This type of work never really occurred to me as something I would enjoy," she says. "But it's been very rewarding. It's taught me skills like how to manage my time and how to communicate effectively. I am now thinking much more about how I can do things for other people."

As for career plans, Sirohi says, "I think in the immediate future, I want to go into finance or the computer science industry. I'm not sure exactly what combination of finance and programming I would want to do. I'm hoping to figure that out and learn more about both fields this summer." ENG

What languages do you speak?
Spanish and English

What is your favorite online activity?
Reading or watching reviews and news about technology and cars; following sports like NBA, swimming, soccer; watching Netflix

What is your favorite story?
Science fiction

What is your favorite destination?
Places near water, like seas, lakes, rivers

Manuel Alejandro Monge Osorio

Graduate Student: Electrical Engineering
Advisor: Azita Emami, Professor of Electrical Engineering; EAS Division Deputy Chair

Manuel Monge Osorio is originally from Lima, Peru. He graduated first in his undergraduate university class in electrical engineering and won a Caltech Atwood Fellowship and US State Department Opportunity Grant that brought him to Pasadena.

At Caltech, he works with Professor Emami on advancing ultra-low power systems for novel implantable, wearable, and point-of-care medical devices. One of them is a fully intraocular epiretinal prosthesis that helps patients suffering from severe vision loss due to degenerative retinal diseases.

As he works toward his PhD, Monge Osorio is appreciating the compact academic and scientific power he finds characteristic of Caltech, as well as its focus on collaboration. "I do not take many classes as a graduate student, but there are still many opportunities to learn more about my area, and I get exposed to so many other fields," he says. He adds that his faculty mentors "really appreciate a student's interest to get to know other areas, because it makes their vision grow. Originally, coming here, I just wanted to learn more and deeply about electrical engineering. But now, I focus on how I can incorporate other ideas and approaches. You think about your research in the context of the greater goal rather than just yourself. You start looking into, 'How can I solve this particular problem in a better way?'"

Monge Osorio's approach is broadening. "I'm excited about biology, chemical engineering, applied physics, materials science, medicine," he says. "And when I see a class that relates to what I want to do in the future, I try to go and sit in on it."

One of his favorite Caltech traditions involves the Summer Undergraduate Research Fellowship (SURF) program, in which graduate students can serve as mentors to undergraduate students. He's been a mentor four times. "I'm very happy with the results," he says. "My first SURF student won one of the poster competitions. Now she's a very talented graduate student and my friend. I have also served as a SURF judge a few times."

He also enthusiastically participates in international-student orientation events. "It is great to share my own experiences and meet new students. I try to answer questions and provide some perspective about being new to this country, the academic life, and, in general, interacting with others," he says.

As for his next steps, he offers: "I would love to continue in academia. One of my goals is to become a professor, because I love doing research and mentoring students. Those are two things I want to keep doing throughout my career, no matter where it takes me." ENG

Aashrita Mangu

Undergraduate Student: Electrical Engineering

Aashrita Mangu came to Caltech from next door: her home is in South Pasadena, only a few miles from campus. She jokes, "My parents threatened to send me to Pasadena City College, but they chose Caltech because it was closer."

Mangu has found much to like at Caltech. "I chose Caltech because I feel there's a lot more opportunity to take classes across disciplines, which I do a lot. And then, on top of that, research opportunities at Caltech are a lot easier to get."

She also likes the Caltech approach: "I have so many friends in other schools, and they're caught up in rote-learning material rather than figuring out how to learn things quickly and how to apply them. That's one of the best things I learned at Caltech, and probably one of the most important life skills."

She has used this skill during her summers of research, first in applied physics at the Joint Center for Artificial Photosynthesis and then in high-energy physics at Fermilab. Next, she spent time at Princeton, where she did cosmic microwave background radiation research, building a user interface for a Fourier transform spectrometer. This year, she was at JPL doing avionics. "It's kind of interesting to work on flight hardware, because it is so different from the typical hardware I'm making at school."

Mangu is also a student leader and is the outgoing Institute of Electrical and Electronics Engineers (IEEE) student chapter president. She also served on the liaison committee between faculty and students, the Academic and Research Committee. "I loved going to meetings and hearing about what's going on around Caltech," she says. "You get to talk to some amazing people. You talk about what work they're doing, the sort of things they're interested in. It gets you inspired to do other things." Furthermore, she was on the Student-Faculty Committee for the electrical engineering department, where she led meetings and wrote a report on changes to the curriculum. "The faculty ended up implementing a few of them!" she reports.

As for what's next, Mangu says, "I'm going to take a year off before I go to graduate school. I hope to do a PhD in experimental physics. I'm definitely going to be doing research during that year, and I have a few options."

Wherever she goes, she'll carry with her the unusual, remarkable culture of the school a few miles from her home. "I think Caltech, precisely because outsiders label students as dorks or nerds, ends up being a tighter community. There are stereotypes with every school, but I really think that Caltech has some of the sweetest people you'll ever find and also some of the most humble." ENG

What languages do you speak?
I speak Hindi and English. I can also understand some Telugu, I took Chinese (Mandarin) in high school for three years, and I took a year of German this past year.

What is your favorite online activity?
I'm not really sure I have a favorite online activity—usually I'm online to waste time, so it never really feels too good afterward.

What is your favorite story?
I have so many favorite stories, and most of them come from Indian history! I'll choose the *Mahabharata* because it's so intricate—there are stories within stories within stories.

What is your favorite destination?
My favorite destination is India, where I get to visit family every few years and reconnect with my culture more personally. It's always incredibly fun and filled with adventure.

EAS STUDENT FEATURE

Natalie Higgins

Graduate Student: Mechanical Engineering
Advisor: Nadia Lapusta, Professor of Mechanical Engineering and Geophysics

How do earthquakes initiate, and can one notice this process before the destructive shaking comes? Natalie Higgins is trying to deepen our understanding of foreshocks, small seismic events that sometimes occur close in time and space to the large earthquake.

She performs numerical simulations to study earthquake nucleation and foreshocks, and along with her advisor, Professor Nadia Lapusta, she is zeroing in on critical moments when earth structures move "from still to motion, the moment between when a fault is not doing anything to when an earthquake is happening."

Higgins underlines a crucial distinction: "The ultimate goal of my research," she says, "is to contribute to earthquake forecasting. But equally critical is to improve early warning, a process that only works once the earthquake has already begun. It can warn people by indicating that in a few seconds the waves will be in their area and they will feel the shaking and therefore they should get ready."

Moving beyond early warning to actual earthquake forecasting—that is, the ability to translate monitoring data about the fault's current behavior into information about when and where the upcoming quake will happen—is far, far more difficult, Higgins says, but she is looking for ways. "We do not have the mechanical understanding of the Earth in order to do real earthquake forecasting. And that's why we do the research we do."

Higgins came to Caltech from a small all-undergraduate college in Oregon; she had previously worked on a Fulbright grant study of wave-based damage detection in overhead power lines. On her visit to Caltech as a prospective student, she met with Professor Lapusta to discuss research, and a bell rang: "It's completely new, but it's still vibrations." Higgins has fully embraced Caltech's interdisciplinary identity. "I like that the boundaries between departments and divisions are blurry, so it is easier to do what you want and fill in there," she says. Her classroom experiences have been rewarding, as well: "All the professors are here because they're at the top of their field. Attending their classes is exciting in a celebrity sort of way."

Higgins has become increasingly interested in organizational structures as well as geological ones. She has served as the vice chair of the Graduate Student Council. She was also one of the leaders of the Society of Professional Students and has been instrumental in redesigning the Big Sib mentoring program for mechanical and civil engineering students. "I spearheaded the revamping of the program, from the basic matching of contact info to a more careful structure where the incoming students fill out a survey about what they want in a mentor, and then we do the matching based on that," she explains.

"I'm learning a lot about how the administration works and how universities are run," Higgins adds. "Because I have enjoyed it, I'm wondering if there is a way to add this aspect to my career as an academic. It is great to be at a place like Caltech, where I can explore all that academia has to offer." ENG

What languages do you speak?
English is my native language, and I also speak German.

What is your favorite online activity?
Netflix!

What is your favorite story?
I love a good underdog story. For example, the story of Erin Brockovich.

What is your favorite destination?
Sauvie Island U-pick farms.

Edward D. Fouad

Undergraduate Student:
Mechanical and Civil Engineering

Edward Fouad has compiled an impressive set of both theoretical and hands-on talents on his way to a BS in mechanical engineering. And not just with his human hands: at JPL, he joined up with the Extreme Environment Robotics Group to construct a robotic gripper that could pick up a large boulder from the surface of an asteroid and bring it back.

In constructing the first full-scale prototype of the gripper, it became clear to the group that the existing design presented critical fabrication and assembly challenges. So Fouad developed an entirely new approach by using a flexure-based mechanism, which addressed the manufacturing concerns and showed improved grasping ability on the various surfaces tested. "The best part of that experience was the relationship I had with my mentor, Aaron Parness," Fouad says. "He has incredible experience with these types of systems, but he didn't hold my hand throughout the process. He gave me the freedom to pursue my own designs."

Fouad has also been working with students as an undergraduate teaching assistant (TA) in the introductory mechanical engineering design course (ME 14) and the robotics competition course (ME 72). "Being an undergrad TA was one of my favorite parts of the Caltech experience," he says. In both courses, the instructor, Michael Mello, gave Fouad and the other TAs tremendous responsibility in making modifications and improvements. "It fills me with pride to know that the current curriculum is even better now than what it was when I first came in," Fouad says. "I know that Caltech's progressive teaching approach will allow it to continue improving in the years to come."

Beyond the classroom, Fouad served as project manager and mechanical lead on the Caltech Robotics Team, an undergraduate group that has constructed three autonomous underwater vehicles for the International RoboSub Competition. He also was co–editor-in-chief of the *Caltech Undergraduate Research Journal*, a Hixon Writing Center peer tutor, a Caltech Y Rise tutor, and an active violinist in the Caltech orchestra.

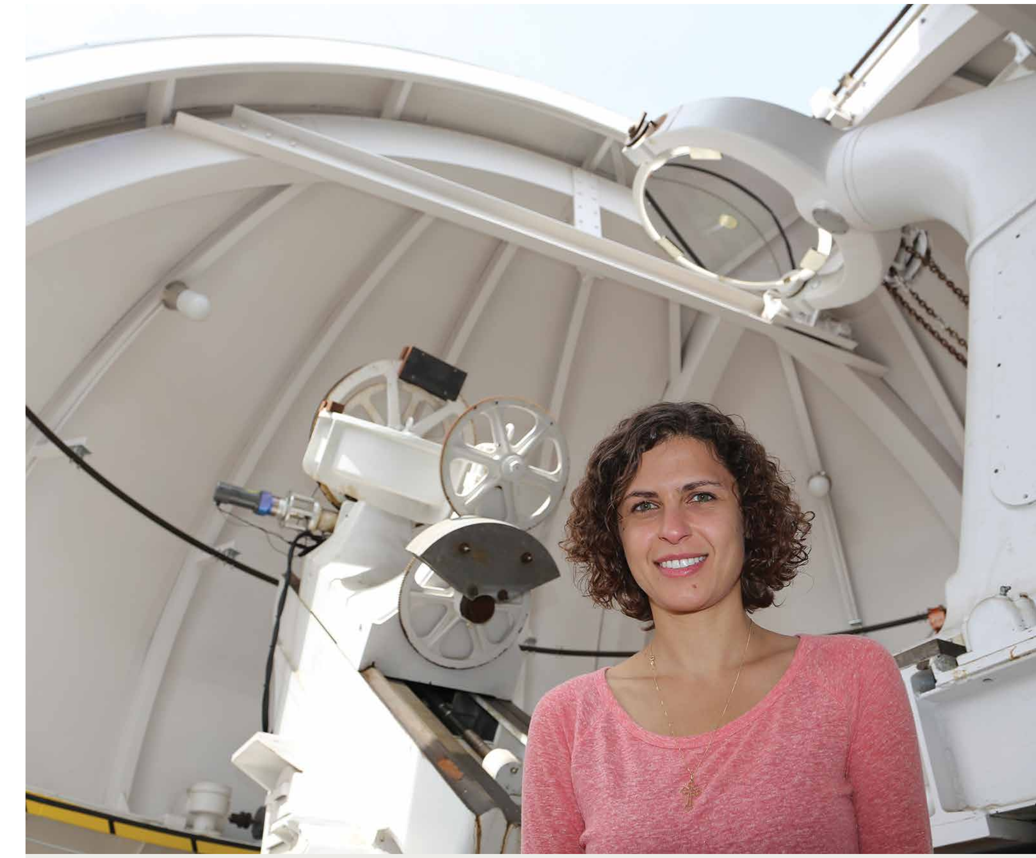
Fouad is now at SpaceX, where he will be working on mechanism design for the Dragon 2 spacecraft. "I interned in the same group last summer and was blown away by the talent, intensity, and commitment of everyone I worked with," he says. "I couldn't be more excited to join the team and be contributing to SpaceX's ultimate mission of bringing about the first human colony on Mars." ENG

What languages do you speak?
English, French

What is your favorite online activity?
Watching *How It's Made* videos

What is your favorite story?
Pocahontas

What is your favorite destination?
Mars



Katherine M. Saad

Graduate Student: Environmental Science and Engineering
Advisor: Paul Wennberg, R. Stanton Avery Professor of Atmospheric Chemistry and Environmental Science and Engineering; Director, Ronald and Maxine Linde Center for Global Environmental Science

Katherine Saad had been in graduate school in Boston for two years before transferring to the Caltech Environmental Science and Engineering (ESE) program because the research of Professor Paul Wennberg captured her imagination and fit her scientific vision.

She has now found that besides research power, Caltech's academic culture has provided an excellent pathway for her efforts to solve a pressing world problem that she is passionate about, as well as to understand and enhance the role of science in doing so.

Saad is investigating subtle changes and feedbacks that occur in the gas composition of the lower atmosphere. "We can measure abundances of different molecules because we know how each one of them absorbs and emits light," she explains. Using data from a network of instruments, including a sophisticated spectrometer that measures minute changes in the solar spectrum, she creates continuous and accurate assays of the chemical composition of the atmosphere the sun's rays transit.

The molecule she is focusing on now is methane, a greenhouse gas that is a product of a vast set of different human processes and the subject of many ongoing policy debates. "But because we don't know which of the myriad sources have been changing in the last 10 years, we don't know how effective these policies and regulations are going to be," she says.

Saad is attacking the methane problem on an instrumentation and analytical level—but also on a person-to-person level at Caltech, with the aim of understanding (and someday perhaps influencing) science policy. She founded the student organization Science & Engineering Policy At Caltech to discuss key questions related to this work: Do we have any say in the way that science is used in this country? If so, what are the ways we can engage? And if not, how do we change that? She explains, "It was really important to me to create this organization not just as an outlet for my own interests but also as a resource that serves the needs of the community in such a way that people would always want to invest in it."

A Southern Californian, Saad visited Caltech years before enrolling. At her visit, she says, "It wasn't clear how vibrant of a community there is at Caltech. There's so much here, not just in terms of interaction and communication but [in terms of] interest in other people's work and research. Even if it's not directly relevant to your work, you're still interested in it because you're interested in science. And that doesn't exist everywhere." ENG

What languages do you speak?
I speak Arabic and French, but neither well enough to claim fluency.

What is your favorite online activity?
Looking up new recipes and baking techniques.

What is your favorite story?
If you mean any story, I would say the biography of St. Katherine, whom I was named after. If you mean a story found in a book, probably *The Alchemist*.

What is your favorite destination?
My favorite destination is the beach, but I also love going out into the desert.

What languages do you speak?
English and some Spanish

What is your favorite online activity?
Listening to podcasts or TED Talks

What is your favorite story?
Gone with the Wind

What is your favorite destination?
Mo'orea (I studied abroad there for three months)

Chanel A. Valiente

Graduate Student: Environmental Science and Engineering
Advisor: Jared Leadbetter, Professor of Environmental Microbiology

Chanel Valiente came to Caltech three years after she obtained a BS in ecology at UC Berkeley. Her initial motivation for graduate school was to continue her career in microbial ecology, but once at Caltech she was struck by how much besides ecology was on her educational plate. "Environmental science and engineering requires you to have a fundamental knowledge of most fields, so I was learning oceanography, atmospheric science, geological sciences. It was amazing to learn all of this, and it's given me a good foundation for understanding most fields. So I can go to a seminar now, and although I might not know the fine details, I can understand the basic goal, the higher purpose of the work."

Her research focus is single-celled eukaryotes, microorganisms with genetic affinities to larger, multicellular plants and animals, that exist in astonishing, still-little-understood abundance and variety.

This abundance and obscurity motivates her research: "Because there's so many of them and they're so abundant and basically ubiquitous in the environment, they have to be doing something important." Working with Professor Leadbetter, she is finding out what part they may be playing in climate change and the global carbon budget.

Caltech is near Valiente's family home in the San Fernando Valley, so it is relatively easy for her to reach out to others who share her roots. She reflects on how Latino students who live nearby often know little about Caltech: "When I tell my friends or old coworkers that I go to Caltech, I have to explain that it is a top-ten university, leading the way in many research areas. Then I say, 'Those people who talk about the earthquakes on TV, that's Caltech.' Or 'You know JPL? That's Caltech.'" She is reaching out and spreading the word, "mostly with my old high school, but I also speak to my nephews. I focus a lot on them because most of my family members do not have a college degree, and my nephews are asking questions that I can answer!"

She has been involved with outreach on campus, as well. "Last term, I was involved with Club Latino, which is for graduate students," she says. "There's another undergrad club that is dedicated to undergrads and in some ways is more active. But as graduate students, we are so focused on our research that it is sometimes hard to get together and socialize. We are trying to change that by organizing more events." But her spare time is scarce: "I'm mostly focusing on my research, because that's why I'm here! I also make sure my fiancée doesn't feel neglected. I have another at least three or four years here. So I'm just buckling in." ENG

Colin A. Cook

Graduate Student: Medical Engineering
Advisor: Yu-Chong Tai, Anna L. Rosen Professor of Electrical Engineering and Mechanical Engineering; Executive Officer for Medical Engineering

Colin Cook, an aspiring entrepreneur, is working with Professor Yu-Chong Tai on new ways of delivering oxygen to hypoxic cells for applications including cancer therapy, pancreatic islet transplantation, and ophthalmology.

Some eye diseases arise from lack of oxygen. Cook explains: "In diabetic retinopathy, the blood vessels that supply the retina start to die, and patients experience progressive vision loss but also subsequently get the pathological ingrowth of new blood vessels, which causes blindness by obstructing vision."

Cook and others on Professor Tai's team are working on solutions. "We have an implant that sits just below the surface of the eye, exposed to the atmosphere, where oxygen is 21%. This implant has a hollow conduit to shuttle this oxygen back to the retina, where it can nourish the retinal cells," Cook says.

Beyond the technical, design in medical engineering requires clinical, regulatory, and commercial considerations. It's the need for multidisciplinary and creative solutions that keeps Cook engaged in the work, he says. Ultimately, he'd like to "create some kind of IP-driven company that's developing new technologies and translating them as efficiently as possible."

He's glad to be at Caltech. "I had been looking at all the top medical and biomedical engineering schools in the country," he says, "and I saw Caltech pop up as introducing this new medical engineering program. So I visited, and the passion and the energy here and also the nimbleness of the Institute attracted me to it."

The closer was his meeting with Professor Tai. "I spent about two hours with him, interviewing and talking about research interests, going around the lab," Cook recalls. It was Professor Tai's commitment to building working medical devices that really caught Cook's attention. "He let me sit in on a patent call that he was making, and we kind of looked at each other afterward and he said, 'Do you want to come to Caltech?' And I said, 'Yeah, I think I do.' And soon I was here," part of the inaugural class of the new Department of Medical Engineering.

Soon after arriving, Cook started engaging his classmates and organizing events. "Because we were the inaugural students, we worked to set up something of a social committee or a government body to create events to help the medical engineers network with each other and create the cohesion that you would like in a new class," he explains. He found examples in other departments: "I had an opportunity to go to Northrop Grumman with the aerospace students, and I thought: if we could start doing that with the medical engineering department as we grow, that would be really important."

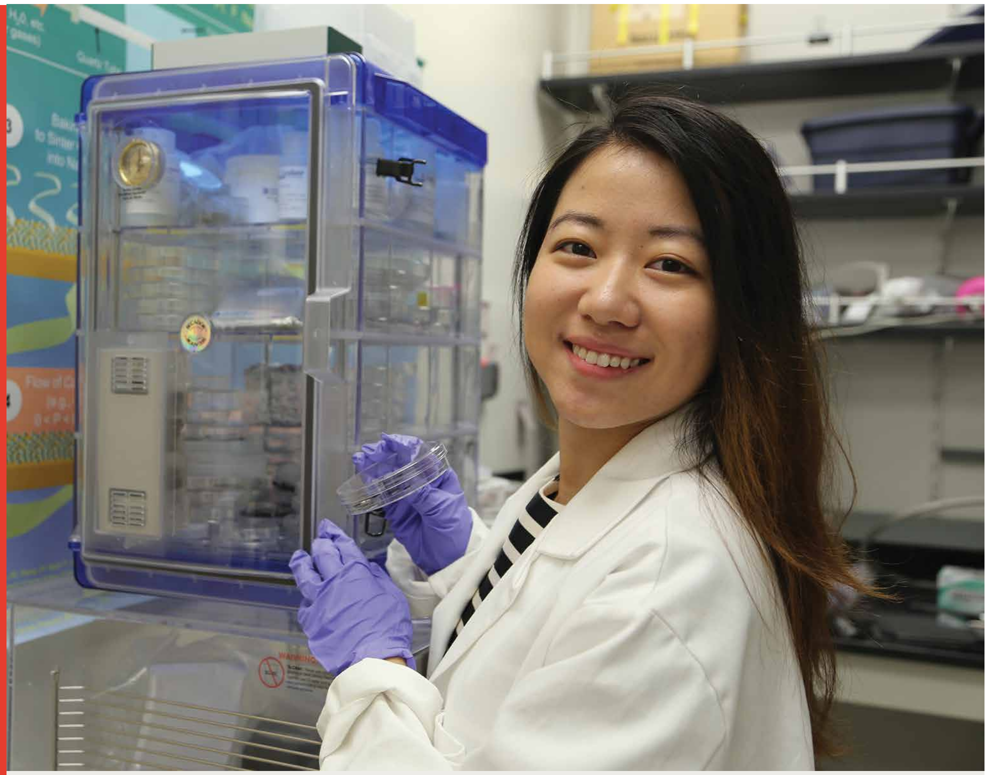
One of his first mentors was his grandfather, Dr. Wilfred Goodman, who was a professor of otolaryngology and developed open rhinoplasty. But, Cook says, "I saw that it took him close to 20 years before it became widely adopted. So rather than going to the clinical side, I decided I would go to the engineering side, where we can develop these technologies and then disseminate them globally, to have the maximum impact possible." ENG

What languages do you speak?
English and a little German and French

What is your favorite online activity?
Reading academic journals (I'd rather be outside than online)

What is your favorite story?
A story my grandfather told me about his father and a little pig named Funny Face

What is your favorite destination?
Vanaheim, a cherished family farm in beautiful Ontario, Canada



Jinglin (Alice) Huang

Graduate Student: Medical Engineering
Advisor: Morteza Gharib, Hans W. Liepmann Professor of Aeronautics and Bioinspired Engineering; Director, Graduate Aerospace Laboratories

Jinglin Huang works at the borders of disciplines, interests, and nationalities. She is mentored and advised by Professor Morteza Gharib, whom she admires for his innovative and entrepreneurial approach. "I want to have my own company and make my own products," says Huang. "I am learning from him to be creative and spontaneous."

Two projects she is working on in Gharib's lab illustrate the range of both the laboratory and her interests.

As a Resnick Institute Graduate Fellow, she is investigating the potential applications of carbon nanotubes in seawater desalination. "Drinkable water could be an urgent problem in the near future. So I'm glad that what I am working on right now has the potential to be of benefit to many people," she says.

She is also involved in microneedle research efforts to create an extremely small, painless drug administration system. She explains: "There are lots of things we can do to make minimally invasive surgery possible. Microneedles are just the beginning."

Huang identifies potential needs in the medical field by shadowing a physician. He gave her some key advice: "He said, 'It is important for the engineer to go from benchside to bedside.' I find this to be a broader way of getting into the engineering theory, because you include the needs of the physician."

Huang relishes the entrepreneurial possibilities of her work—but only in ways that will benefit others as well as herself. "I really want my own patent, a working patent. I want to collaborate with great people, build devices, and sell them. I also think it's important to come up with a product that works well and is reasonably priced so that more people can benefit from it in the developing world."

One of the keys to her success is her network of learning, family, and social relationships. She's part of the Caltech Chinese Students Association, Smith College Club of Los Angeles, and the Junior League of Los Angeles. "Through my network, I was able to get connected with people with similar interests and mindsets," she says. "It keeps me up to date on front-end technologies, allows me to listen to voices from different perspectives, and gives me a chance to embrace various opportunities in the field."

Huang did her undergraduate work at Smith College, which shares, she says, the intimate cross connections of Caltech. There, she studied engineering science and music. Continuing her passion for music, she is a pianist with Caltech Chamber Music. E N G

What languages do you speak?
I speak Chinese and a bit of French.

What is your favorite online activity?
I like watching documentaries on the BBC.

What is your favorite story?
Alice's Adventures in Wonderland by Lewis Carroll. Alice is adventurous, curious, logical, and rational. She has to re-establish her identity in a whole new world, but she's not scared. She always tries to maintain her good manners, even at moments when she's facing fears and loneliness. She stands up for herself and her beliefs but still tries to understand and assimilate into the nonsense world. I think she has a lot of good qualities for me to learn from.

What is your favorite destination?
London!

Caltech Graduating Class of 2016

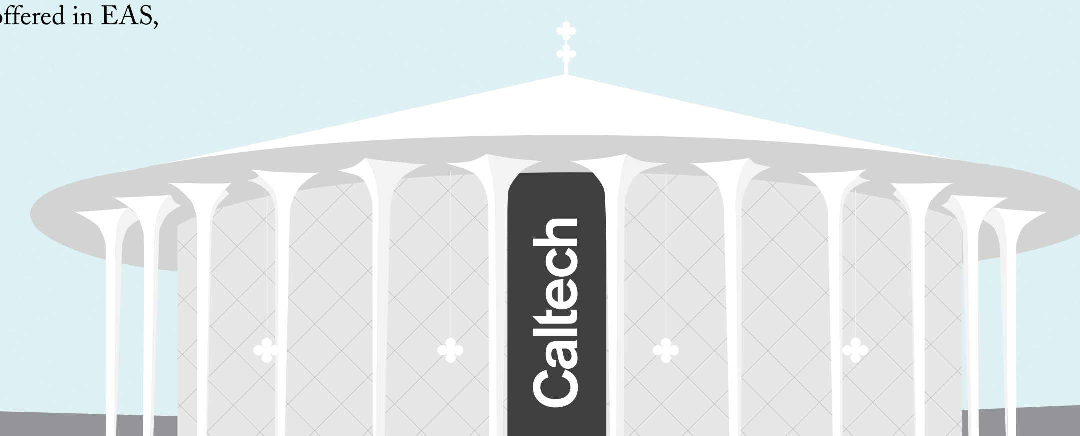
54% of Caltech graduates are from the Division of Engineering & Applied Science (EAS)

53% of BS degrees earned are in EAS

69% of MS degrees earned are in EAS

44% of PhD degrees earned are in EAS

To learn more about degrees offered in EAS, visit eas.caltech.edu/dept.



Photons, Electrons, Silicon:
Caltech's Electric Light Orchestra

Caltech has long brought together masters from many fields to create the unimaginable. In the field of silicon photonics, in particular, the open and collaborative culture of the Division of Engineering and Applied Science has allowed for the assembly of an incredible orchestra of scientific expertise. Silicon (Si) wafers have for decades provided the instruments for this orchestra, but recently, a flood of integrated-systems research has led to applications that have completely transformed these instruments—and this, in turn, has impacted the life of almost every human on the planet.

There are many conductors of this orchestra, but *ENGenious* sat down with four of them: Professors Azita Emami, Ali Hajimiri, Kerry Vahala, and Amnon Yariv. They shared the history of the field, their current work in it, and some incredible potential applications, ranging from 3-D cameras on T-shirts to biosensors under the skin to planetary imagers.

The key innovation behind these efforts is the possibility of manipulating photons and electrons together in a single device. As the sophistication of building devices into the fabric of silicon has increased, researchers have learned to use devices based on or embedded in silicon to generate and process light quanta and photons, for data processing, storage, and more.

Photonics offers the possibility of immense bandwidth for the transmission of data, as demonstrated by the capacity of the optical cables that carry the information weight of the Internet around the planet. Electronics, on the other hand, can store and manipulate exabytes or zettabytes of data as well as perform trillions of operations in an instant. The two sister technologies, electronics and photonics, started with immense potential but also some seemingly irreconcilable differences.

Amnon Yariv, Caltech's Martin and Eileen Summerfield Professor of Applied Physics and Professor of Electrical Engineering, provides some historical perspective on the critical work that allowed for the integration of photonics and electronics on silicon. "Up until the 1960s, these two technologies were considered and treated as two separate fields

PROGRESS REPORT

"Up until the 1960s, these two technologies were considered and treated as two separate fields. The main reason was that the two basic enabling 'mother materials' for these disciplines were very different."

Amnon Yariv, *Martin and Eileen Summerfield Professor of Applied Physics and Professor of Electrical Engineering*

Silicon photonics group:
Professors Amnon Yariv, Azita Emami,
Kerry Vahala, and Ali Hajimiri

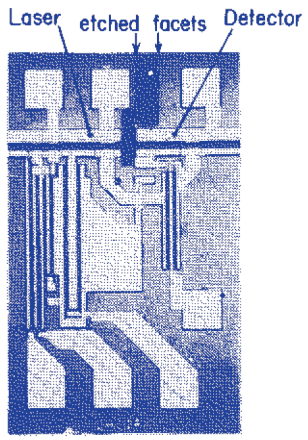


Figure 1: An integrated optoelectronic circuit, consisting of a laser, detector, and control circuits

and pursued separately," he explains. "The main reason was that the two basic enabling 'mother materials' for these disciplines were very different. Electronics was mostly based on silicon, which cannot, for fundamental reasons, be made to also make lasers."

But, he continues, "starting in the mid 1970s, it became clear that major advantages could follow if these two foundational technologies could come together, with both optical and electronic functions carried out in physical proximity, ideally on single optoelectronic chips. The first steps in this direction were taken at Caltech starting around 1970, when we proposed and demonstrated the new field of optoelectronic integrated circuits (OEICs). A canonical example was the demonstration of transistors [electronics] driving lasers [optics] on a single gallium arsenide (GaAs) crystal—that is, having the key devices of optics and electronics [see Figure 1]. A more recent example from my group involves a hybrid Si/III–V platform that is a demonstration of a new type of laser in which light is generated in the III–V material but is stored in the essentially transparent Si that is bonded to it. The result is a reduction of a thousand times in the quantum phase noise of the laser output field and a corresponding increase in its coherence."

Ali Hajimiri, Thomas G. Myers Professor of Electrical Engineering and Medical Engineering, explains further. "Now, the beauty is, electronics and optics have their own strengths. For example, if you think about electronics, the strength of the electronics is that gain, amplification, is easy to generate in electronics. We have also learned to perform other complex tasks, such as mixing and oscillation, as well as signal processing in both analog and digital domina, thanks to the practically unlimited number of transistors. These are the strengths of electronics. Now optics, on the other hand, gives you extremely high-quality delays and extremely large bandwidths. The trick is the combination. It is a match made in ether!"

Products of Hajimiri's laboratory illustrate these powerful congruencies and combinations. One recent example is a 3-D camera chip called a nanophotonic coherent imager (NCI) that translates laser illumination of a target object into high-resolution three-dimensional images. The prototype uses only 16 pixels but can scan a larger area by imaging four squares at a time to create a mosaic (see Figure 2). He imagines one possible application of this technology to be a 3-D camera on the surface of a T-shirt.

"I think silicon photonics is in the same place as electronics was, in terms of the number of elements and the growth of the number of elements, in the '60s and '70s."

Ali Hajimiri, *Thomas G. Myers Professor of Electrical Engineering and Medical Engineering; Executive Officer for Electrical Engineering; Director, Information Science and Technology*

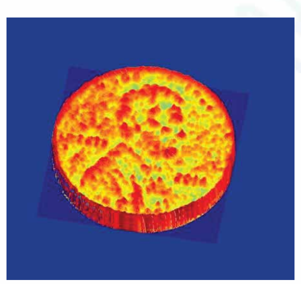


Figure 2: A silicon nanophotonic coherent imager (NCI) that uses interferometry and the chirp radar principle to capture a 3-D profile of objects from a distance. A lens is used to form an image on the NCI pixel array. Using this setup, the surface profile of a penny has been imaged from a distance of 0.5 m with an average depth resolution of 15 μm.

"Caltech is a place where you can, at every dimension, find your research passion and explore new directions."

Azita Emami, *Professor of Electrical Engineering; EAS Division Deputy Chair*

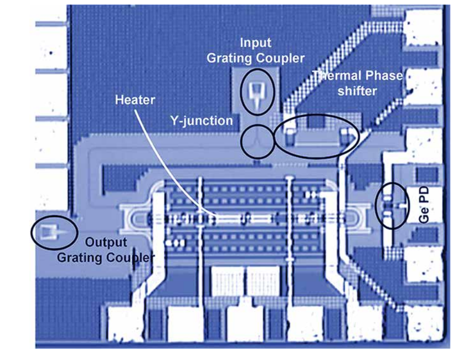


Figure 3: Compact, low-power, and high-speed electro-optic modulators (EOM) are one of the key components of optical interconnects. Resonant structures such as micro-ring modulators (above) are promising candidates due to their compact size and low power consumption. This differential ring modulator maintains a constant energy in the ring to avoid pattern-dependent power droop.

These kinds of advances are part of a pattern, says Hajimiri. "I come from an electronics background. I think silicon photonics is in the same place as electronics was, in terms of the number of elements and the growth of the number of elements, in the '60s and '70s. The beauty of it is that now you can integrate the electronics and the photonics to create something that is more than the sum of the parts."

Yariv adds: "The early OEICs did not employ silicon and thus could not benefit from the existing base of fabrication technology, representing a cumulative investment of trillions of dollars. We are now in a position to benefit in optoelectronics from this investment."

Azita Emami, Professor of Electrical Engineering, is also working on the co-design of electronics and photonics to take advantage of this investment. Her lab is designing devices that can dramatically reduce the energy consumption of data communication systems in data centers and high-performance computers. Examples of such devices are the silicon photonic differential micro-ring modulator (MRM) (see Figure 3) and the 3-D–integrated CMOS-silicon photonic optical receiver (see Figure 4). Such devices reflect a holistic approach to the design of electronics and photonics.

"The years that we have put into the silicon industry to develop all the infrastructure for electronic systems can now be repurposed and used for development of silicon photonics," Emami says. "This can lead to lower cost, a better platform for integration of electronics and photonics, and use of computer-aided design tools."

It is a particularly interesting time for scientists to be working in this field, she continues, "because now we can use the same kind of approach for building sophisticated systems in both electronics and photonics. My focus is on what enables high-performance computing, data centers, and efficient communication systems. Silicon photonics is well suited for these applications, because it provides a low-cost platform for very low-power and high-speed data communications in the optical domain."

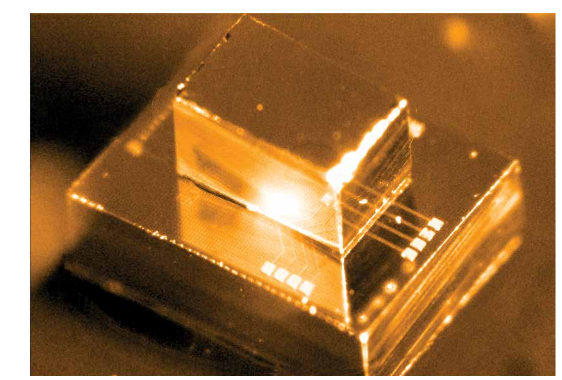


Figure 4: Integration of electronics and photonics leads to better performance in optical links but necessitates a holistic approach for co-design of the two. This figure features a 3-D–integrated CMOS-silicon photonic receiver, which employs a novel low-bandwidth trans-impedance amplifier (TIA) front-end, doublesampling, and equalization through dynamic offset modulation.

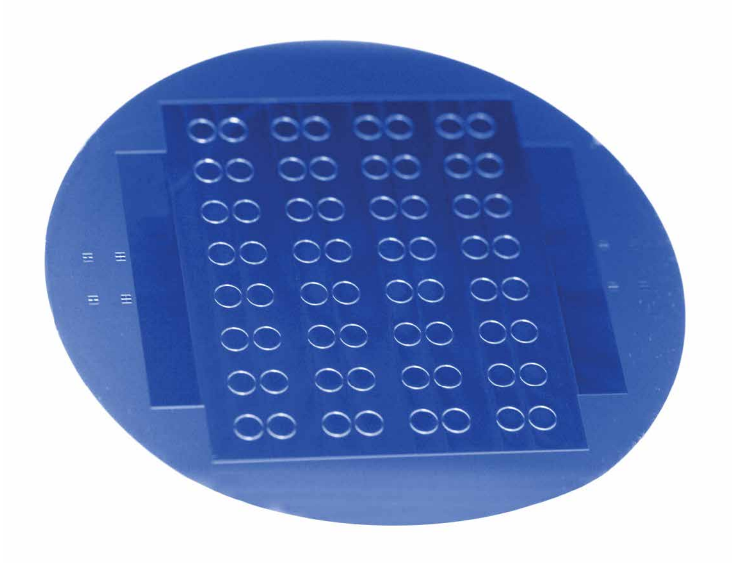


Figure 5: A silicon wafer of nonlinear optical ring resonators fabricated by the Vahala group. The devices on this wafer produce soliton waves when power is applied using a microscopic optical wire (not visible in the photo). These particular ring resonators will be used in a larger system called an optical synthesizer that is being built under support from DARPA (Defense Advanced Research Projects Agency) at the National Institute of Standards and Technology (NIST) in Boulder, Colorado.

Kerry Vahala, Ted and Ginger Jenkins Professor of Information Science and Technology and Applied Physics, has pioneered silicon photonic devices that dramatically lower the power required for nonlinear optical processes. Optical devices that traditionally require hundreds of watts of optical power are possible using 100,000 times less power, in the milliwatt range. This new class of extreme-nonlinear optical device is the underlying breakthrough in a number of integrated devices that can challenge the dominance of electronics in areas like microwave oscillators.

Vahala says that while photons and electrons continue to have clearly defined roles, certain traditional electronic functions will shift to photonics because of the inherent performance advantages of these new silicon-photonic devices. Other areas will also benefit from the same class of device. For example, his group is studying special optical waves called solitons to create precisely spaced "combs" of optical lines that are useful in spectroscopy, accurate time keeping, and even astronomy. One version of this device is going into a silicon photonic system to create a device called an optical synthesizer (see Figure 5) that generates tunable optical frequencies with extremely high stability. Vahala says: "An added benefit of placing components on silicon is that sophisticated electronics can be called upon to monitor and control these new all-optical functions."

The professors who are leading Caltech's electronic light orchestra agree that the Institute is an ideal place to research and develop silicon photonics. As Hajimiri puts it, "Caltech obviously is very strong in fundamentals. But because of how open it is to new ideas, people here have the ability to jump from one field to another."

He continues, "If I have a question, I go knock on Kerry's door. I know that he will be helpful. It's so easy to access the top-class talent in everything."

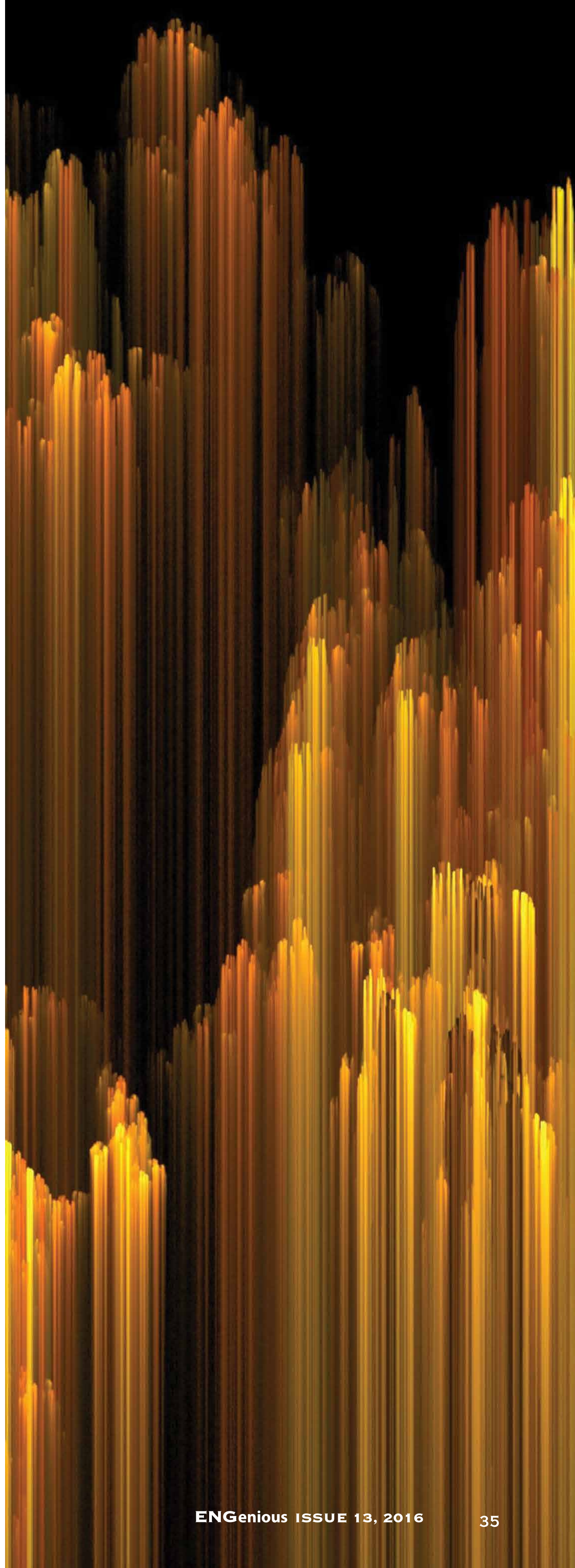
Emami adds, "Caltech is a place where you can, at every dimension, find your research passion and explore new directions. Faculty take risks all the time. We do different things in any given stage of our careers. It's amazing that we can do that."

Hajimiri agrees: "I think combining top-tier, high-quality scientific expertise together with risk taking at a place like Caltech has allowed it to be a center of gravity for the silicon photonics effort. Now we can take it to the next level, applying the concepts over a broad range of applications." ENG

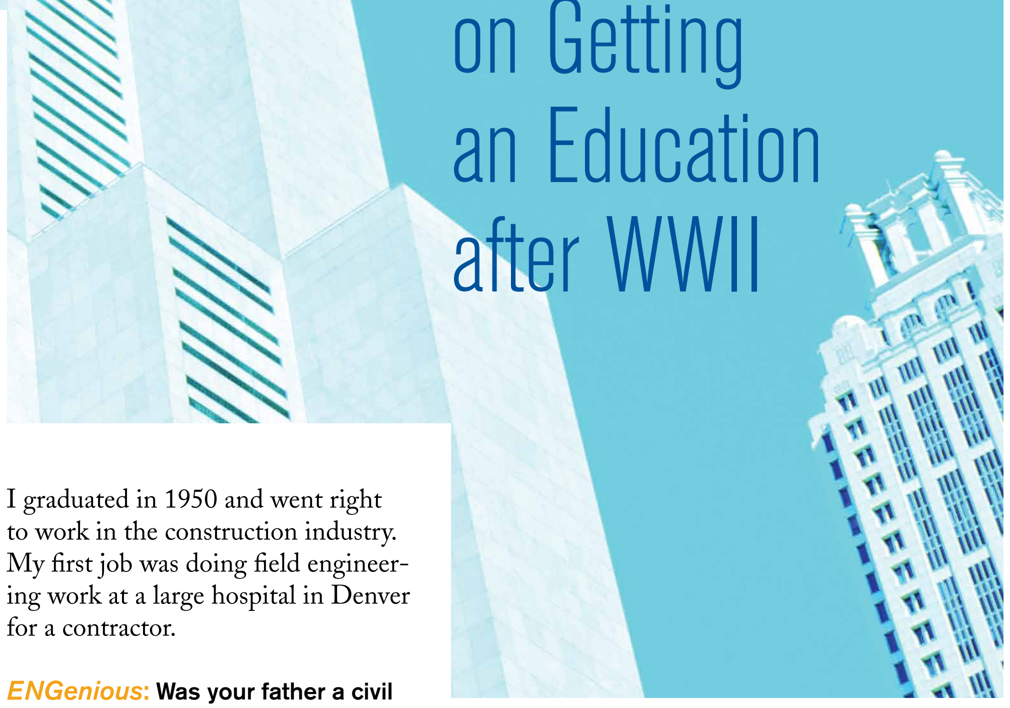
"While photons and electrons continue to have clearly defined roles, certain traditional electronic functions will shift to photonics because of the inherent performance advantages . . ."

Kerry J. Vahala, *Ted and Ginger Jenkins Professor of Information Science and Technology and Applied Physics; Executive Officer for Applied Physics and Materials Science*

Azita Emami is Professor of Electrical Engineering and EAS Division Deputy Chair. To learn more about her research, visit eas.caltech.edu/people/3341/profile*. Ali Hajimiri is the Thomas G. Myers Professor of Electrical Engineering and Medical Engineering, Executive Officer for Electrical Engineering, and Director, Information Science and Technology. To learn more about his research, visit* eas.caltech.edu/people/3038/profile*. Kerry J. Vahala is the Ted and Ginger Jenkins Professor of Information Science and Technology and Applied Physics and Executive Officer for Applied Physics and Materials Science. To learn more about his research, visit* eas.caltech.edu/people/3238/profile*. Amnon Yariv is the Martin and Eileen Summerfield Professor of Applied Physics and Professor of Electrical Engineering. To learn more about his research, visit* eas.caltech.edu/people/3262/profile.



Cecil Drinkward: Focused on Getting an Education after WWII



Cecil Drinkward (BS ’50, civil engineering) joined Hoffman Construction Company in 1967, later serving as president and now retired. Hoffman Construction has built many major structures in downtown Portland, Oregon, including the Convention Center and more than half of the modern office buildings. The company also built sewage and water-treatment plants and industrial facilities in the northwestern United States. *ENGenious* sat down with Drinkward to learn about his experience as a Caltech student during the World War II years and how it has influenced his career.

***ENGenious*: How did you experience Caltech as a student?**

Drinkward: I went there a year and a half out of high school at age 17, during World War II. I did my freshman and half of my sophomore years, and then I went into the navy for two years. I flew to Caltech after I was discharged and I still had my uniform on—I didn’t even have civilian clothes when I came back! I started classes sometime in March and the quarter had already started, so I had about eight weeks to finish a 10-week quarter. Eight weeks of school was really tough when you get back after serving in the navy. I managed to skate through by the skin of my teeth. I graduated in 1950 and went right to work in the construction industry. My first job was doing field engineering work at a large hospital in Denver for a contractor.

***ENGenious*: Was your father a civil engineer?**

Drinkward: No, he was a construction superintendent. Both my parents were immigrants. He came from Holland and she came from Germany. They didn’t come here looking for any freebies, I know that. They came here to get a better life after World War I, when things were horrible in Europe. They had the intent of going back, which of course never happened.

***ENGenious*: How did you decide to study at Caltech?**

Drinkward: I had grown up in San Gabriel and South Pasadena, and all I knew was Caltech was supposed to be the best place. Interestingly enough, I never applied to another school. I don’t even know what it’s like to get an application now for a school. At the time we got admitted, it was on the basis of an all-day test.

***ENGenious*: Was it similar to what we now call the SAT?**

Drinkward: Yes. I thought the test was awful tough. I couldn’t answer some of the questions. There were several wise guys who said, “Oh, I knew all that stuff. I answered them all. This isn’t hard.” It made me think I would never get in. The other guys were too dumb to know what they didn’t know. And I never saw them in my freshman class.

> “I flew to Caltech after I was discharged and I still had my uniform on—I didn’t even have civilian clothes when I came back!”

***ENGenious*: What was your Caltech graduating class like?**

Drinkward: My class was probably two-thirds veterans, including myself. It was an excellent learning environment because you had senior people that set a really good example. We were a very focused group. Just as an aside, I managed to meet Linus Pauling 30 years later to speak to him. I said I graduated in 1950, and he said the classes of 1950 and ’51 were the best students he ever had because they were all focused on getting an education.

***ENGenious*: How has your civil engineering degree helped you in your career?**

Drinkward: I never did civil engineering as such. What I did was construction. The best thing civil engineering did for me was that the structural engineers I worked with wondered how I fit in, and when I would say I graduated from Caltech, they were impressed. If we were in a meeting and an issue came up, I would give an opinion, and it would be looked at as an engineering opinion, in addition to the construction feasibility. That was a big plus.

***ENGenious*: Is there a project that you’re most proud of or that you found the most challenging?**

Drinkward: It was probably the Trojan Nuclear Plant, which has since been decommissioned and torn down. That was at the start of the nuclear program at Portland General Electric (PGE). It was just so different technologically. At that time, there was no precedent for building these plants, so in a way it was a pioneering nuclear plant. There was nothing to compare with, which made it interesting to me.

***ENGenious*: What’s next for the field of civil engineering?**

Drinkward: I think the biggest challenge is the aging infrastructure of the United States. There’s got to be better and more cost-effective ways to do it than we did it in the past, with more longevity built in. We can’t just build a road like we did 50 years ago. People don’t have the money to do it over. This includes roads, bridges, airports, other civil structures and projects, including wastewater and water-treatment facilities. We need cheaper and better ways.

***ENGenious*: There is a tendency to think that most of the problems of civil engineering have already been solved. How much more can you innovate? Cement is still cement.**

Drinkward: Well, cement is one that I think can be improved. It still shrinks. It cracks. It has a series of problems that you have to accommodate. Maybe it can be made better so you don’t get all that shrinkage. I always felt that reinforced concrete was the best way to build for the right structures, but the whole engineering of reinforced concrete has a lot of advances that could be made.

***ENGenious*: What are some of the ingredients needed to create a forward-looking civil engineering program?**

Drinkward: There needs to be an investment in teaching the latest in materials research and structure research. We also need to be able to—and willing to—think out of the box when training the next generation of civil engineers. It is not just about using computers and following what’s been done before. It has to be done better. So far, we’ve done so much that makes things more expensive, but not better. ENG

Nurturing Nanoscience

The Kavli Nanoscience Institute at Caltech

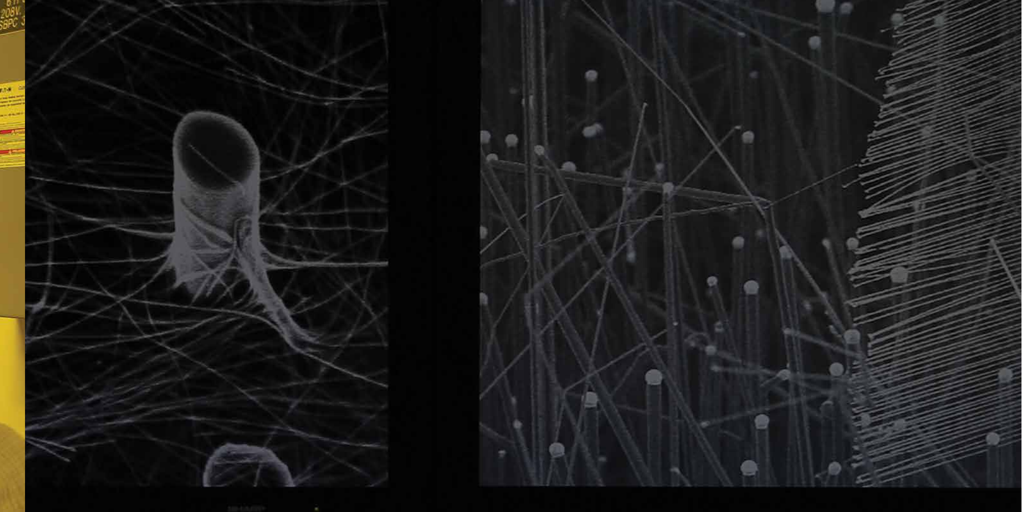
For over a decade, the Kavli Nanoscience Institute (KNI) at Caltech has been an intellectual hub and facilitator of cross-disciplinary research in the areas of nanoscience and nanotechnology. It houses an advanced nanofabrication facility that supports the research endeavors of many Caltech and Jet Propulsion Laboratory (JPL) researchers and has been critical to realizing exciting breakthroughs in nanoscale photonics, materials science, and biotechnology. *ENGenious* sat down with the KNI's two Fletcher Jones Foundation Co-Directors, Professors Oskar J. Painter and Nai-Chang Yeh, as well as the KNI's Associate Director of Business Operations, Mary Sikora, to discuss the past, present, and future contributions of this intellectual hub.

***ENGenious:* How has the purpose of the KNI evolved since its creation?**

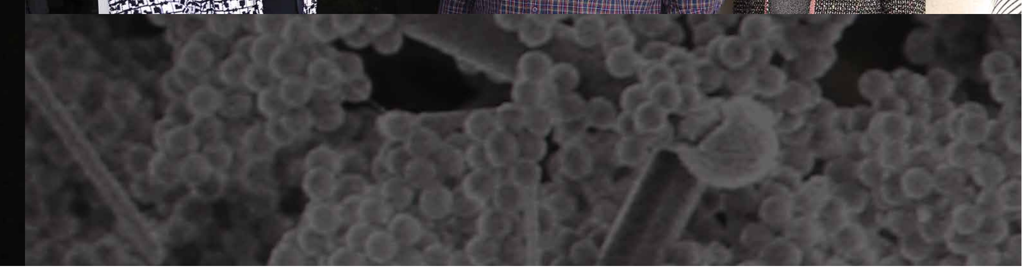
Yeh: Nanoscience and technology was starting to become an important interdisciplinary research area at the time the KNI was created, and a lot of the research required very expensive facilities. Thus there was a sense that it would be much more productive if we could create a centralized facility that housed a variety of instruments for nanoscience and technology research. As we brought multi-disciplinary researchers together, they would come up with new ideas, and the KNI evolved into an intellectual hub. Initially, the KNI members' research focused on nanophotonics and nano-biotech, and then, as time passed, the opportunities for nanoscience and technology became broader and broader. Now we are facilitating work on the frontiers of nanoscience and technology research, particularly in areas of quantum science and technology, bio- and medical engineering, renewable energy and sustainability, and space exploration and astronomy.

Sikora: When I came on board in late 2005, we were still building and planning the facility. We were also trying to grow the community, but the main focus was the renovation of the sub-basement of Steele Lab.

Painter: From the beginning, it was clear that the creation of the KNI was going to be an exciting opportunity for many of us to conduct nanoscience research. Michael Roukes, the first director of the KNI, and Axel Scherer, who later became a co-director, were instrumental in the genesis of the KNI. They started by acquiring an industrial electron beam lithography system. Previously, most university facilities were limited to small scanning electron microscope tools that were retrofitted to do lithography, greatly limiting the fidelity and throughput of the features being made. This new tool, which Michael and Axel made available to a community of users (not the norm at the time at Caltech), enabled one to do nanoscale fabrication on the scale of a six-inch wafer, integrating many devices together over multiple steps of lithography. This was prior to the establishment of the KNI, and it was a pivotal moment at Caltech both in the sense of the new technology available to do science and also in the culture.



Mary Sikora, Oskar Painter, and Nai-Chang Yeh



***ENGenious:* How do you know that the KNI has been successful?**

Yeh: The facilities have enabled lots of research activities by groups around the campus, from JPL, and also from industry and local universities. To get a more concrete sense of this, we did an estimate of how much Caltech research funds have supported people using the facility since it opened.

Painter: It has been roughly $150 million over 10 years. That's an impressively big number for a place the size of Caltech. It's a little bit scary, actually, because as a co-director you quickly realize how important it is to make sure this facility is running optimally, since it is so critical to everyone's research now. Before the creation of the KNI, everyone had their own clean room to do their own nanofabrication or microfabrication. The KNI has been a total remodel for Caltech in many ways, and the estimate of research funds used shows the vitality and the importance of the facility and the approach.

Yeh: Every year, we have on the order of 100 users from five different divisions at Caltech, as well as 20 to 30 research groups that professorial faculty members are affiliated with. We also host international workshops, symposia, and tours.

Sikora: We hosted the first TEDx event on the Caltech campus. The KNI organized it because of the connection of nanoscience to Richard Feynman. The event was sold out! Five of the talks made it to the TED channels. There was so much energy in the air that day and everyone was so excited about what was happening on campus. That event lead to a new way to describe science. Through post-event surveys, we discovered that for approximately 25% of the audience members, it was their first time on the Caltech campus. The event was livestreamed and had more than 21,000 unique views. We had a second TEDxCaltech event in 2013, and in total, the talks from both events have had more than three million hits just on YouTube. This translates into an amazing amount of outreach!

Yeh: We're not just running facilities. We are creating an environment that nurtures nanoscience and technology.

***ENGenious:* What are you doing to ensure the continued success of the KNI?**

Painter: The KNI is an enabling resource. We're trying to think beyond just the facility. What is the meaning of the KNI? What are the real horizons in nanoscience, and where do we see that going in the future? Because it's such a broad field, it's sometimes hard to articulate, but we're working on trying not just to have the facility but to have this community, this environment, that can help nurture these various aspects of nanoscience as well.

Yeh: Since we acquired our industrial electron beam lithography tool, a lot of universities have caught up to us, and we're thinking about how to reinvent ourselves in such a way that we will continue to lead the pack in the future. We recently put in a proposal to the National Science Foundation to get a special focused ion beam system that uses very light atoms, helium and neon, to do extremely fine three-dimensional cutting and patterning of materials. It directly sculpts your three-dimensional mask. It's like an Etch A Sketch, but at the atomic scale. There's only one other university in California that has such a tool. I see that as being another moment where we're really going to advance the capability here at Caltech. This new tool enables researchers to do things they never could have done before.

ENGenious: How are your roles different? Is there a secret behind your team's success?

Yeh: Oskar and I always consult with each other, work on things together, and, if necessary, take the blame together. Mary has been marvelous; she helps with all kinds of things, and Guy DeRose, the KNI Associate Director of Technical Operations, takes good care of the staff members and the day-to-day operation of the facilities.

Painter: The constants throughout the years have been Mary and Guy; they've worked with all the co-directors since the inception of the KNI. We really rely on the expertise of Mary and Guy, as well as the rest of the excellent technical and administrative staff of the KNI. We have a relatively lean staff that does a huge amount of work, if you compare it to other institutes of similar size.

Sikora: The staff is really great. They're quite dedicated, and they will answer pleas from people who can't get equipment to work at all hours and on the weekends. We have good team spirit! Also, I like that my job is different every single day.

Painter: The other thing that's very special about the KNI, and I think Caltech in general, is that the students and postdocs play a vital role. Our pseudo-staff are our students and postdocs that help optimize fabrication techniques, improve the running of the equipment, and invent entirely new methods for using our equipment. They also help teach our technical staff these new methods and help in the training of new students. So it's very much a communal atmosphere.

ENGenious: How does the KNI serve nanotechnology startup companies?

Painter: When I graduated from Caltech, I started a company with Kerry Vahala and Amnon Yariv. At the time, we used a good portion of our A-round of fundraising to build our own clean room. Today, with the presence of the KNI, as a faculty member it's much easier to think about starting a company using the KNI as a cost-effective means to create proof-of-principle devices. But there's always a balance between serving industry and serving students and faculty on campus. Right now, I think we are in a sweet spot. We have a good amount of industrial users, and they don't tend to monopolize any of the equipment. I should add that the benefits can also go both ways; there's the potential for the cross-fertilization of ideas between academic innovation and industrial "know-how."

ENGenious: What's next for the KNI?

Yeh: If we continue to build up our endowments, we'd like to give seed funds to people who have brilliant new ideas that cannot immediately get federal grants. We are starting with a smaller program, the KNI-Wheatley Scholarship. We plan to support one junior faculty member every year with $25,000 in discretionary research funds for new and innovative projects. Then we are hoping to expand the program so it isn't limited to junior faculty.

Painter: At a technical institute like our own, the most important thing that comes out of any sort of group like the KNI is the science. The areas of science that connect to nanoscience and the KNI are myriad, ranging from materials and renewable energy research to biology. One area that is currently benefiting greatly from nanoscale research at the KNI is quantum physics, where the science and engineering of new quantum materials, information processing systems, and sensors are rapidly progressing. In general, I am very excited by the scientific opportunities I see on the horizon for the KNI.

ENGenious: How are the KNI and the JPL Microdevices Laboratory complementary?

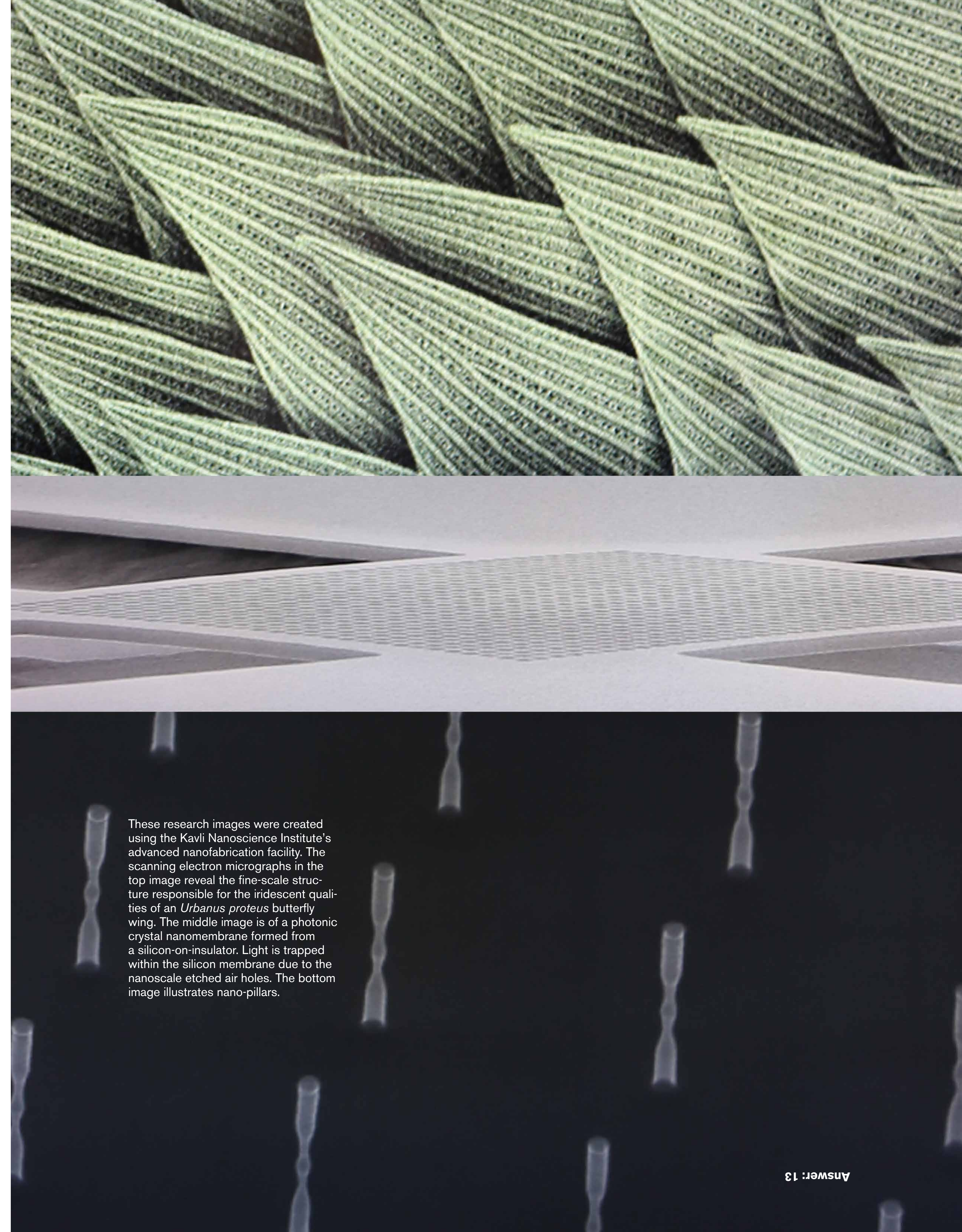
Painter: They have an amazing facility at JPL. At the KNI, we have some tooling and some ways of doing things that are different and complementary. In some ways, our facility is a little freer in terms of what processes you can run and how accessible different tools are. Of course, we don't have the same sort of demand on us in terms of the reliability of our processes. At the KNI, you can fail a little bit more, which means you also get to explore more things.

ENGenious: What do Caltech alumni need to know about the KNI?

Yeh: The KNI has nurtured a new generation of scientists and engineers in nanoscience and technology. And it's incredibly cross-disciplinary; this is an area that can always have a major impact on the world. Caltech alumni are welcome to tour the facilities and learn more about what we have been doing for Caltech, for education, for research, and for frontier endeavors. E N G

Oskar J. Painter is the John G Braun Professor of Applied Physics and Fletcher Jones Foundation Co-Director of the Kavli Nanoscience Institute. Nai-Chang Yeh is Professor of Physics and Fletcher Jones Foundation Co-Director of the Kavli Nanoscience Institute. Mary Sikora is Associate Director of Business Operations for the KNI.

Visit kni.caltech.edu.



These research images were created using the Kavli Nanoscience Institute's advanced nanofabrication facility. The scanning electron micrographs in the top image reveal the fine-scale structure responsible for the iridescent qualities of an *Urbanus proteus* butterfly wing. The middle image is of a photonic crystal nanomembrane formed from a silicon-on-insulator. Light is trapped within the silicon membrane due to the nanoscale etched air holes. The bottom image illustrates nano-pillars.

Answer: 13

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