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The Fu Foundation School of Engineering and Applied Science

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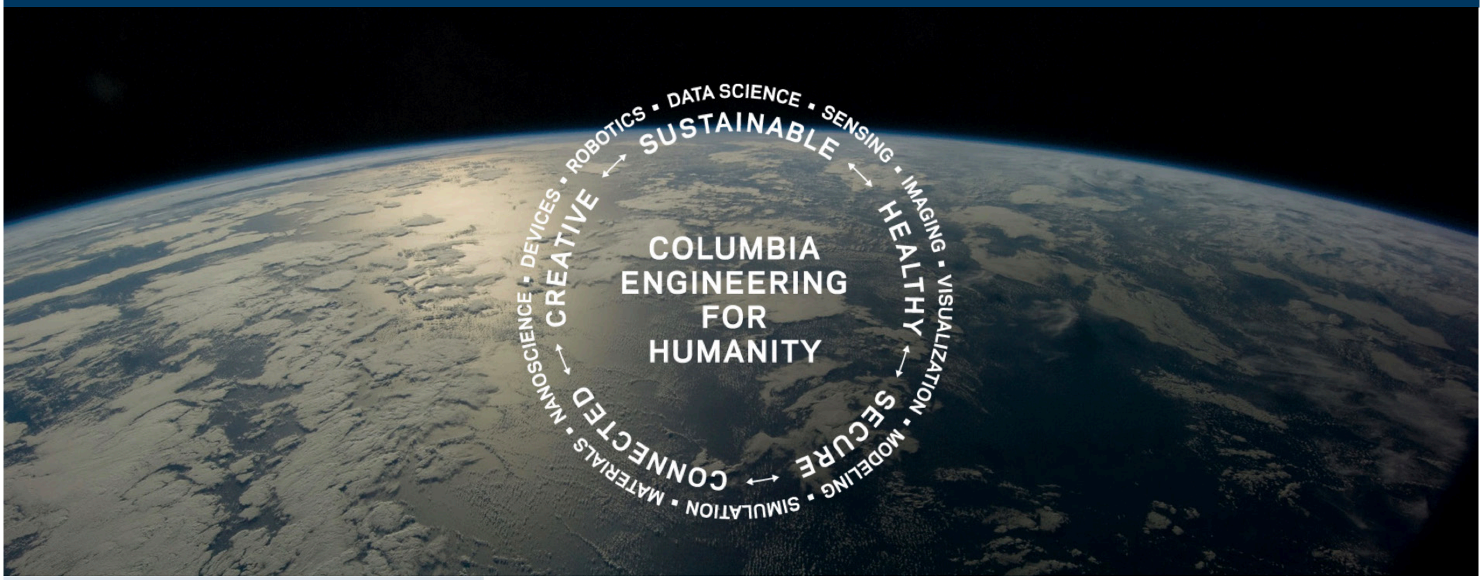
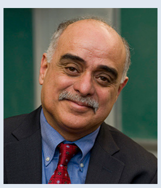
APAM NEWS

Applied Physics & Applied Mathematics Department,
with Materials Science & Engineering
Columbia University in the City of New York





Dear APAM Family,

2017 is almost over. Despite turbulent times, APAM has maintained its progress and is in excellent shape.

As you will see from the various reports in this newsletter, we are able to look back at a year of solid accomplishments. Our climate program is getting world-wide recognition. Our new faculty members are garnering grants and honors, and we are particularly proud of the awards our graduates are receiving on their thesis work.

I am also pleased to report that this will be the last year-end letter I will write; I am stepping down as Chair at the end of June 2018 after six years of service to our beloved APAM.

I wish all of you and yours Season's Greetings and a happy, healthy, prosperous New Year.

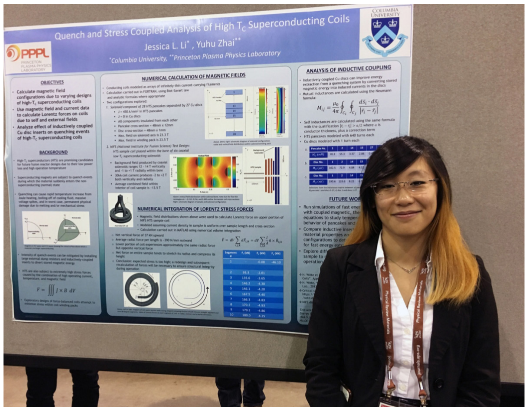
Best regards,

I. Cevdet Noyan
Chair, APAM

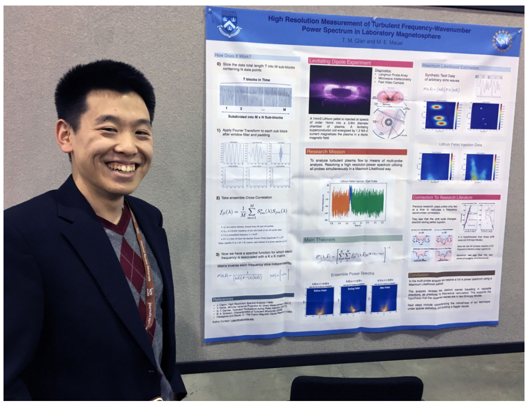
Image: Columbia Engineering for Humanity, the new strategic vision for our School, "articulates our long history and current efforts to further innovative research that has a positive impact and helps to create a sustainable, healthy, secure, connected, and creative humanity. It is exemplified by the diverse and pioneering work that our faculty, students, and alumni are pursuing across departments and disciplines and in partnership with sister schools, institutes, government, and industry."

- Columbia Engineering

Columbia Students & Researchers Participate in the 59th APS Division of Plasma Physics Meeting



Jessica Li (above) and Tony Qian (below) presented their research at the APS Division of Plasma Physics Meeting



Several Columbia University students and physicists participated in the 59th Annual Meeting of the APS Division of Plasma Physics. The meeting, which is the world's largest and most prestigious meeting of plasma physicists, took place from October 23-27, 2017 in Milwaukee, Wisconsin.

Jessica Li (SEAS '18) presented her research conducted during the summer at the Princeton Plasma Physics Laboratory as part of the Science Undergraduate Laboratory Internship (SULI) program. Her research explored the application of high-temperature superconductors (HTS) for next step fusion reactors. Because HTS coils are much more vulnerable to damage during quench events, Jessica used analytic models in FORTRAN and MATLAB to calculate the magnetic fields and resultant forces for various solenoid-like configurations of both high- and low-temperature superconducting coils. Using simulations, she helped to identify optimal designs for both stability and quench protection.

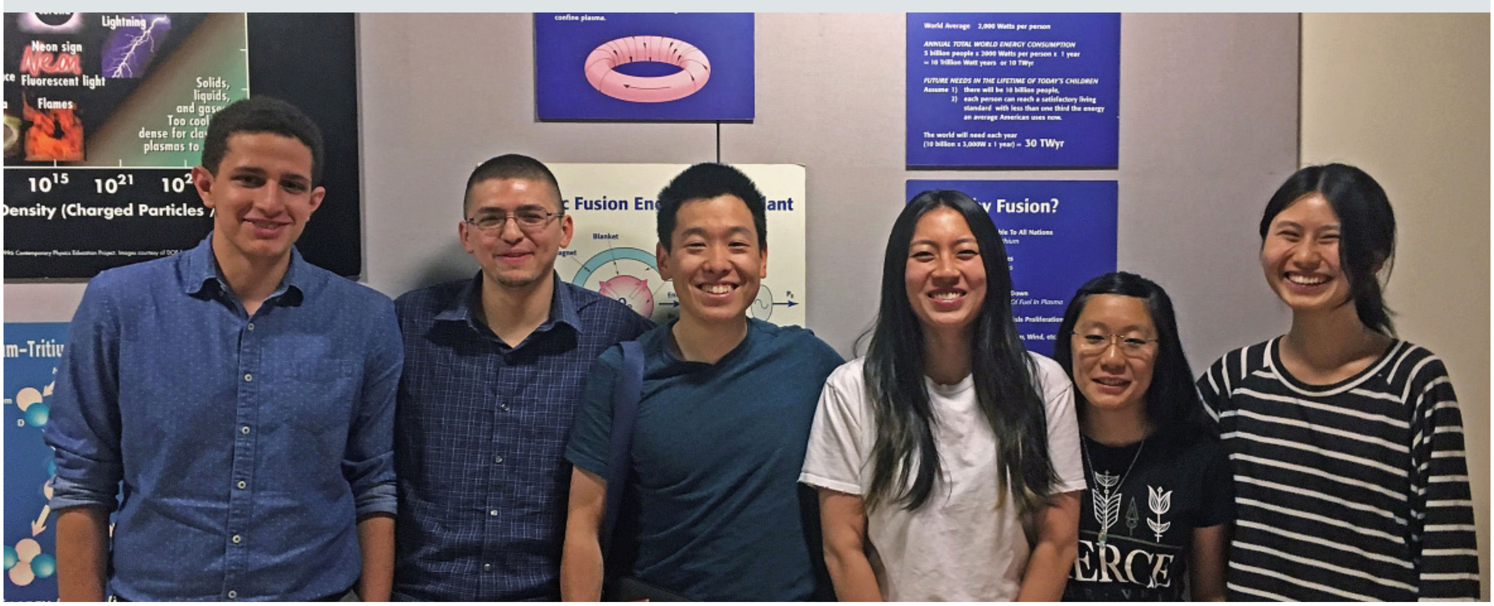
Tony Qian (CC '18), presented his research measuring the frequency-wavenumber power spectrum of plasma turbulence by applying the method of Jack Capon (Ph.D. Electrical Engineering, SEAS 1959) to simultaneous multi-point measurement of plasma entropy modes using an antenna array. Unlike previously reported measurements, in which ensemble correlation between two probes detected only the dominant wavenumber, Capon's "maximum likelihood method" uses all available probes to produce a frequency-wavenumber spectrum, showing the existence of modes propagating in both electron and ion magnetic drift directions.

In addition to Jessica Li and Tony Qian, APAM graduate students **Mel Abler**, **John Brooks**, **Joshua Cabrera**, **S. DeSanto**, and **Ian Stewart** presented research on understanding plasma turbulence cascades and the control and dynamics of the tokamak instabilities.

Two APAM Associate Research Scientists also participated in this meeting. **Dr. Francesca Turco**, who works at General Atomics, delivered an invited lecture titled "Understanding the stability of the low torque ITER Baseline Scenario in DIII-D" and **Dr. Jeff Levesque** presented his research titled "Scrape-off-layer currents during MHD activity and disruptions in HBT-EP." Levesque also gave a talk on the same subject at the ITER site in St. Paul lez Durance, France on October 13, 2017.

Columbia Undergraduates Attend PPPL SULI Course in Plasma Physics

Photo (left-right): Columbia undergraduates, including **Marco Andres Miller** (undecided), **Cade Guitron** (Physics), **Tony Qian** (Physics), **Connie Kang** (Applied Physics), **Jessica Li** (Applied Physics), and **Jessie Ruixuan Yan** (undecided), participated in the 2017 Science Undergraduate Laboratory Internship (SULI) Introductory Course in Plasma Physics at the Princeton Plasma Physics Laboratory. **Prof. Michael Mauel** was one of the featured speakers at the event.



Öztürk '15 Wins Sidhu Award

Hande Öztürk (Ph.D. '15, Materials Science and Engineering, **Prof. I.C. Noyan**'s group) received the 2017 Sidhu Award.

John P. Rose, the President of the Pittsburgh Diffraction Society, wrote, "*The award honors significant contributions to the science of crystallography and/or diffraction by a scientist in the early stage of their career . . . Based on the strong nomination and the impressive credentials on your CV, the award decision was made without hesitation. You are to be commended for the scientific impact you have made at this stage of your career with your contributions to the fundamental understanding of diffraction from nanoparticles*."

Dr. Öztürk received a certificate and a $5,000 cash prize, which were presented at the 75th Pittsburgh Diffraction Conference held the Indiana University of Pennsylvania Campus from October 19–21. Dr. Öztürk presented a lecture on her research related to the award which was live streamed on YouTube.

A native of Turkey, Dr. Öztürk graduated from Boğaziçi University in Istanbul with Physics and Mechanical Engineering degrees and then moved to the U.S. for her graduate studies. She obtained her Master's degree from the Mechanical Engineering Department at Boston University and moved to Columbia University for her doctoral work. Upon defending her thesis in 2015, she was awarded her Ph.D. degree. Since 2016, she has been working at the National Synchrotron Light Source II at Brookhaven National Laboratory as a postdoctoral research associate. Her research interests include characterization of nanocrystalline materials by diffractive techniques and phase retrieval methods from diffraction data.

Tian '16 Wins AWM Dissertation Prize & Chinese Government Award

Xiaochuan Tian (Ph.D. '16, Applied Mathematics, **Prof. Qiang Du**'s group) was selected as a winner of the AWM Dissertation Prize awarded by the Association for Women in Mathematics. She will be presented with the prize at the 2018 Joint Mathematics Meeting in San Diego, the largest annual meeting of mathematicians in the world hosted by the American Mathematical Society (AMS) and the Mathematical Association of America (MAA). Dr. Tian said, "I am very honored to be one of the recipients of the 2nd annual AWM Dissertation Prize. The completion of my dissertation could not have happened without the help and inspiration of many professors, colleagues and collaborators, especially my Ph.D. advisor Prof. Qiang Du, who is a role model for me for being a devoted mathematician, a well-rounded person, and a caring mentor." Prof. Du, said, "I am very proud that, as the AWM citation says, her '*dissertation has produced novel mathematical results that have had significant practical impact*.'"

Dr. Tian also received the Outstanding Students Abroad award from the Chinese government. This highly competitive award, given annually by the China Scholarship Council (CSC), honors overseas Chinese students with outstanding academic accomplishments.

Dr. Tian defended her dissertation in November 2016 and has won several awards previously for her Ph.D. research work, including a 2016 SIAM outstanding paper prize and a best poster award at the conference on topics in applied nonlinear analysis. She was invited for a month long visit to Germany where she took part in the Hausdorff Trimester Program on *Multiscale Problems: Algorithms, Numerical Analysis and Computation* at the Hausdorff Institute of Mathematics in Bonn. Dr. Tian is currently the R. H. Bing Instructor in the Department of Mathematics at The University of Texas at Austin.

Alumni Reports

Prof. Siu Wai Chan recently ran into Eliot Dresselhaus (Ph.D. '91 Applied Physics) in Boston. Eliot, who is the son of the late Mildred Dresselhaus (the first female Institute Professor and professor *emerita* of physics and electrical engineering at MIT), fondly remembers chatting about course choices with Prof. Irving Herman. He is currently President of Cavetocellar.com in San Francisco.

Sicen Du (M.S. '17, Materials Science & Engineering) writes, "I will join the University of Michigan to pursue my Ph.D. in their Materials Science and Engineering Department. I've decided that my future career will be in the field of energy storage and conversion, developing new energy-saving technologies to ameliorate and restore polluted land." (Columbia Engineering)

David Gates (Ph.D. '94, Plasma Physics), a principal research physicist and Division Head at Princeton Plasma Physics Lab (PPPL), was named editor-in-chief of *Plasma*, a new online open access journal. (PPPL News)

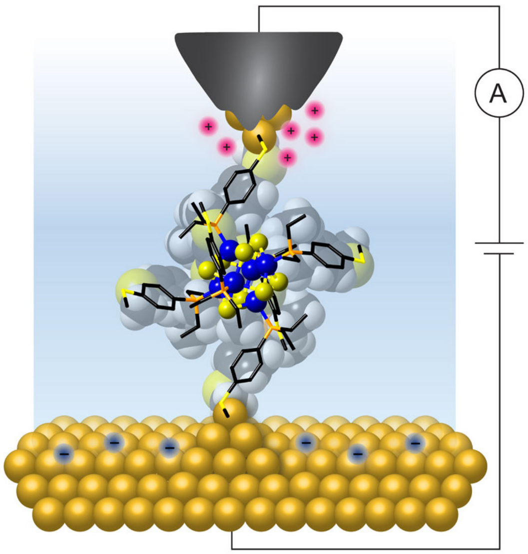
Brian Grierson (Ph.D. '09, Plasma Physics), a Staff Research Physicist at PPPL, received the Kaul Foundation Prize for Excellence in Plasma Physics Research and Technology Development for his ground breaking measurements of the flow of the main atomic nuclei, or ions, in the DIII-D tokamak. (PPPL News)

Phil Efthimion (Ph.D. '77, Plasma Physics) was one of three scientists from PPPL to win an Edison Patent Award from the Research and Development Council of New Jersey "*for their invention of an imaging apparatus that could be used to produce the next generation of integrated circuits*." (PPPL News)

Victoria Chibuogu Nneji (B.S. '14, Applied Mathematics), earned a Master of Engineering Management in 2015 from Duke University and continued in Duke's Robotics Ph.D. program. In 2017, she became the first Ph.D. candidate to model distributed human supervisory control of autonomous vehicle networks in rail, air, and surface transportation systems. She hopes to make a positive difference in mobility and logistics design by considering human factors when artificial intelligence is embedded in operations.

Jay Shah (M.S. '09, Medical Physics) has founded Dynamic Medical Physics Inc., a medical physics consulting company. While planning the company's future endeavors, he continues to practice clinically in Therapeutic Medical Physics, where his chief interest lies in stereotactic radiosurgery, a form of brain surgery for cancer treatment. Instead of using sharp instruments to cut into the brain, this procedure employs highly focused radiation beams to destroy tumors. Jay collaborates with a radiation oncologist and a neurosurgeon to create a custom treatment plan for patients that deposits radiation within a well constrained volume. Recently, Hollywood has come calling for his consultant services, looking for assistance in helping to create more realistic story lines in television and film. He has collaborated with writers from CBS's Madam Secretary as well as Phantom Four Films (responsible for the Batman and Superman franchises). (Columbia Engineering)

Venkataraman: Single Molecules Can Work as Reproducible Transistors—at Room Temperature



Columbia researchers wired a single molecular cluster to gold electrodes to show that it exhibits a quantized and controllable flow of charge at room temperature.
—Photo courtesy of Bonnie Choi / Columbia University

by Holly Evarts, originally published by *Columbia Engineering*

A major goal in the field of molecular electronics, which aims to use single molecules as electronic components, is to make a device where a quantized, controllable flow of charge can be achieved at room temperature. A first step in this field is for researchers to demonstrate that single molecules can function as reproducible circuit elements such as transistors or diodes that can easily operate at room temperature.

A team led by **Latha Venkataraman**, professor of applied physics and chemistry at Columbia Engineering and Xavier Roy, assistant professor of chemistry (Arts & Sciences), published a study (DOI 10.1038/nnano.2017.156) today in *Nature Nanotechnology* that is the first to reproducibly demonstrate current blockade—the ability to switch a device from the insulating to the conducting state where charge is added and removed one electron at a time—using atomically precise molecular clusters at room temperature.

Bonnie Choi, a graduate student in the Roy group and co-lead author of the work, created a single cluster of geometrically ordered atoms with an inorganic core made of just 14 atoms—resulting in a diameter of about 0.5 nanometers—and positioned linkers that wired the core to two gold electrodes, much as a resistor is soldered to two metal electrodes to form a macroscopic electrical circuit (e.g. the filament in a light bulb).

The researchers used a scanning tunneling microscope technique that they have pioneered to make junctions comprising a single cluster connected to the two gold electrodes, which enabled them to characterize its electrical response as they varied the applied bias voltage. The technique allows them to fabricate and measure thousands of junctions with reproducible transport characteristics.

"We found that these clusters can perform very well as room-temperature nanoscale diodes whose electrical response we can tailor by changing their chemical composition," says Venkataraman. "Theoretically, a single atom is the smallest limit, but single-atom devices cannot be fabricated and stabilized at room temperature. With these molecular clusters, we have complete control over their structure with atomic precision and can change the elemental composition and structure in a controllable manner to elicit certain electrical response."

A number of studies have used quantum dots to produce the similar effects but because the dots are much larger and not uniform in size, due to the nature of their synthesis, the results have not been reproducible—not every device made with quantum dots behaved the same way. The Venkataraman-Roy team worked with smaller inorganic molecular clusters that were identical in shape and size, so they knew exactly—down to the atomic scale—what they were measuring.

"Most of the other studies created single-molecule devices that functioned as single-electron transistors at four degrees Kelvin, but for any real-world application, these devices need to work at room temperature. And ours do," says **Giacomo Lovat**, a postdoctoral researcher and co-lead author of the paper. "We've built a molecular-scale transistor with multiple states and functionalities, in which we have control over the precise amount of charge that flows through. It's fascinating to see that simple chemical changes within a molecule, can have a profound influence on the electronic structure of molecules, leading to different electrical properties."

The team evaluated the performance of the diode through the on/off ratio, which is the ratio between the current flowing through the device when it is switched on and the residual current still present in its "off" state. At room temperature, they observed an on/off ratio of about 600 in single-cluster junctions, higher than any other single-molecule devices measured to date. Particularly interesting was the fact that these junctions were characterized by a "sequential" mode of charge flow; each electron transiting through a cluster junction stopped on the cluster for a while. Usually, in small-molecule junctions, electrons "pushed" through the junction by the applied bias make the leap continuously, from one electrode into the other, so that the number of electrons on the molecule at each instant of time is not well-defined.

"We say the cluster becomes 'charged' since, for a short time interval before the transiting electron jumps off into the other metal electrode, it stores one extra charge," says Roy. "Such sequential, or discrete, conduction mode is due to the cluster's peculiar electronic structure that confines electrons in strongly localized orbitals. These orbitals also account for the observed 'current blockade' regime when a low bias voltage is applied to a cluster junction. The current drops to a very small value at low voltage as electrons in the metal contact don't have enough energy to occupy one of the cluster orbitals. As the voltage is increased, the first cluster orbital that becomes energetically accessible opens up a viable route for electrons that can now jump on and off the cluster, resulting in consecutive 'charging' and 'discharging' events. The blockade is lifted, and current starts flowing across the junction."

The researchers tailored the clusters to explore the impact of compositional change on the clusters' electrical response and plan to build upon their initial study. They will design improved cluster systems with better electrical performances (e.g. higher on/off current ratio, different accessible states), and increase the number of atoms in the cluster core while maintaining the atomic precision and uniformity of the compound. This would increase the number of energy levels, each corresponding to a certain electron orbit that they can access with their voltage window. Increasing the energy levels would impact the on/off ratio of the device, perhaps also decreasing the power needed for switching on the device if more energy levels become accessible for transiting electrons at low bias voltages.

"Most single-molecule transport investigations have been performed on simple organic molecules because they are easier to work with," Venkataraman notes. "Our collaborative effort here through the Columbia Nano Initiative bridges chemistry and physics, enabling us to experiment with new compounds, such as these molecular clusters, that may not only be more synthetically challenging, but also more interesting as electrical components."

Faculty Updates

Gang: Nanoparticles that Put Themselves Together

Prof. Oleg Gang was featured in the U.S. DOE's Office of Science news article, "No Assembly Required: Nanoparticles that Put Themselves Together" by Shannon Brescher Shea. "Using DNA, we can instruct particles how to connect to each other," said Gang, a CFN researcher and Columbia University professor. When scientists attach synthetic DNA to nanoparticles, the DNA strands pair up in the same way they do in every living thing, bringing the nanoparticles along." Read the full article at: https://science.energy.gov/news/featured-articles/2017/07-12-17/

Navratil on Nuclear Fusion

Gerald Navratil, the Thomas Alva Edison Professor of Applied Physics, was featured in *The Associated Press* article, "Nuclear Fusion Project Hails Halfway Construction Milestone." Navratil said, "fusion could help solve the problem of how to reliably produce large amounts of electricity without emitting greenhouse gases, noting ITER's current cost is comparable to that of developing a large passenger aircraft. Energy is such an important part of our technological society that expenditure of 20 billion to develop a new energy source is really not out of line."

RAPHEX Exam Editors

Two Medical Physics Program faculty members and one APAM alumn served as editors of the 2017 RAPHEX exam guide. Prof. Cheng-Shie Wuu was the Chief Editor, Prof. Pat Zanzonico was the Diagnostic Editor, and Dr. Sean L. Berry ('04 Ph.D. Medical Physics) was the Therapy Editor.

Sobel Featured in *The Times of India*

Adam Sobel, Professor of Applied Physics and Applied Mathematics and of Earth and Environmental Sciences, and chief scientist of Columbia University's Initiative on Extreme Weather and Climate, recently presented a public lecture at Mumbai's Columbia Global Centre. He was also featured in the *Times of India* article, "Historically, biggest disasters are ones that are rare." In the article, Sobel states, "Estimates of cyclone risk both from our model and from [the MIT model] tell us that in the historical climate, a major cyclone landfall in Mumbai, that is strong enough to generate a significant storm surge, is at least a several-hundred-year-event. That means the probability in a single year is a fraction of a percent. But if you look at Sandy, that was also a couple-of-hundred-years event for New York. The similarity with New York is quite spooky."

Recent Faculty Publications

Professor *Emeritus* Daniel Beshers' article, "Re-entrant spin glass transitions: new insights from acoustic absorption by domain walls" (SREP-17-44979) was published online by *Scientific Reports*. https://www.nature.com/articles/s41598-017-17297-y

Professor Latha Venkataraman group's paper, "A reversible single-molecule switch based on activated antiaromaticity," was published by *Science Advances*. http://advances.sciencemag.org/content/3/10/eaao2615

Du Elected AAAS Fellow

Originally published by *Columbia Engineering*

Qiang Du
Photo by Jeffrey Schifman

Qiang Du, the Fu Foundation Professor of Applied Mathematics, has been elected a 2017 Fellow of the American Association for the Advancement of Science (AAAS) for his "*distinguished contributions to the field of applied and computational mathematics, particularly for theoretical analysis and numerical simulations of mathematical models in various applications*." He joins 391 new fellows awarded this honor from the AAAS, founded in 1848 and now the world's largest multidisciplinary scientific society.

"I am honored to join this esteemed group," says Du, who is also chair of the applied math program and a member of the Data Science Institute. "This is particularly significant to me as an applied mathematician, given the broad representation of AAAS in science and engineering and its social impact. Also, most important, I am happy to share this recognition with my students, postdocs, and collaborators."

Du's research covers many areas of applied mathematics and computational sciences, including modeling, analysis, algorithms, and computation, with selected applications in physical, biological, materials, and information sciences. He has developed approaches to mathematically model and simulate defects and interfaces in nature, such as materials phase boundaries, cracks and fractures, biological membranes, and quantized vortices in superconductors and Bose-Einstein condensates (a state of matter with atoms cooled to temperatures close to absolute zero.) He has also contributed to the design of space tessellation and mesh generation strategies, and developed mathematical models to explore hidden structure and information in images and data. He has been recognized with numerous awards and was selected to be a Fellow of the Society of Industrial and Applied Mathematics in 2013.

"It is fun to work at the interface of mathematical, computational, and data sciences and to collaborate with experts in other domains," Du, who leads the Computational Mathematics and Multiscale Modeling (CM3) group and has a number of ongoing interdisciplinary research projects with several Columbia colleagues, says. "We live in an age where the advent of computing technology is rapidly transforming our society and how mathematics get used in applications. What has intrigued me the most in my research are the challenging questions that have strong practical motivations and demand new mathematical and computational tools for their solutions."

Du joins six colleagues at the Engineering School who have received this honor: **Aron Pinczuk**, professor of applied physics and physics (2001); Jeannette Wing, Avanessians Director of the Data Science Institute and professor of computer science (2007); Shih-Fu Chang, senior executive vice dean and Richard Dicker Professor of Telecommunications and professor of computer science (2010); Peter Schlosser, earth and environmental engineering department chair, Maurice Ewing and J. Lamar Worzel Professor of Geophysics, professor of earth and environmental sciences, and associate director at the Earth Institute (2010); Gordana Vunjak-Novakovic, University Professor and Mikati Foundation Professor of Biomedical Engineering and Professor of Medical Sciences (in Medicine) (2014); and Paul Sajda, professor of biomedical engineering, electrical engineering, and radiology (2016).

Prof. Du and the new AAAS fellows will be presented with an official certificate and a gold and blue (representing science and engineering, respectively) rosette pin on February 17 during the 2018 AAAS Annual Meeting in Austin, TX.

SEAS Faculty Win NSF Grant to Study NYC Storm Surge Infrastructure Resilience

by Holly Evarts, originally published by *Columbia Engineering*

With the recent Hurricanes Harvey, Irma, and now Maria, which ravaged much of Texas, Florida, and Puerto Rico, as well as Hurricane Katrina and Superstorm Sandy, from which NYC infrastructure is still recovering, it has become clear that addressing threats to infrastructure is critical to keeping our communities safe, functional, and healthy. Storm surge has emerged as one of the most destructive forces on infrastructure, especially interconnected structures in cities. To address this issue, Columbia Engineering Professors George Deodatis, **Daniel Bienstock**, and **Kyle Mandli** were recently awarded a two-year $500,000 National Science Foundation (NSF) grant to study storm surge threats to New York City infrastructure.

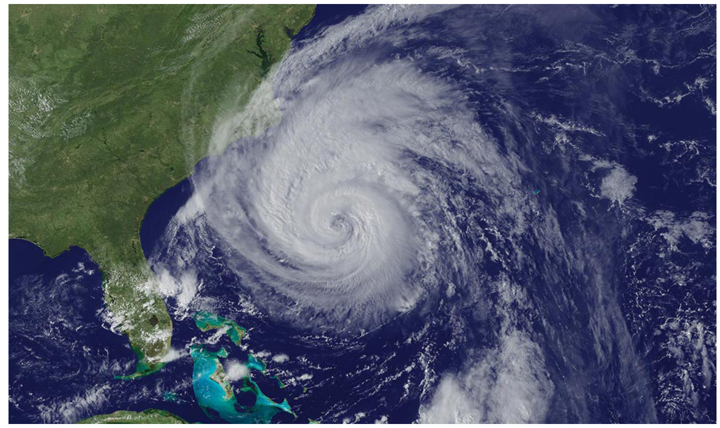
"Events like these powerful hurricanes have underscored the need for comprehensive plans to protect our infrastructure," says Deodatis, Santiago and Robertina Calatrava Family Professor of Civil Engineering, and Chair, Department of Civil Engineering and Engineering Mechanics, who uses probabilistic methods to study the effects of natural hazards, including climate change and extreme weather, to the civil infrastructure. "The two hazards of storm surge and sea level rise carry a high level of uncertainty, and when combined, create a major risk to our coastal infrastructure. We urgently need to develop a multi-pronged approach that takes into account how infrastructure is interconnected and how failures in one type of infrastructure can impact the other."

The team will use the grant to address the threat from storm-induced flooding to interdependent infrastructure –transportation, power systems, and emergency services -- by designing a methodology that can test various adaptation strategies and their ability to protect these important life-lines. They will investigate strategies such as building seawalls or artificial sand dunes, elevating houses and other structures, and other physical, protective options. Beyond assessing the efficacy of protective measures, they will address related questions such as deciding how coastal protection might impact other recreational, cultural, and economic activities, and how to reduce the negative impact while maximizing coastal protection.

"Evaluating resource constraints and how to optimally protect a community given its constrained resources is critical," says Bienstock, Professor of Industrial Engineering and Operations Research and of Applied Physics and Applied Mathematics, who is an expert on power transmission networks, including electrical power grids. "These questions require the combination of advanced computing, mathematics, and social science approaches not only to design tools that address these complex, intersecting problems, but also to provide them to the decision makers who must make these critical decisions."

The researchers will use computational methods to determine flooding levels using an ensemble of storms representing the likely threat together with future rising sea-level scenarios. They will estimate the potential damage to the infrastructure they are considering and then use the data to evaluate the effectiveness of a given strategy, including both cost and social acceptability.

"This is a process that will repeat iteratively until we find a sufficiently optimal strategy," says Mandli, Assistant Professor of Applied Mathematics, who uses computational methods to study geophysical shallow mass flows such as tsunamis, debris-flow, and storm-surge. "Developing this methodology will be challenging as the magnitude of the computational effort needed is significant. We'll use a set of computational models that vary in accuracy and speed with the resulting methodology able to swap between models appropriate for the situation at hand." **(Continued on page 11)**



Mandli & Sobel: New Tech Talks Series Explores Faculty Research

by Jesse Adams, originally published by *Columbia Engineering,* Photo courtesy of NASA

From hurricanes off the coast of Ireland to wildfires raging through Northern California, extreme weather has made some of the biggest headlines of 2017. As global warming continues to transform the climate, the ability to accurately forecast such devastating events could revolutionize infrastructure management and spell the difference between life and death for many around the world.

How Columbia engineers are rising to that challenge was the subject of the School's inaugural Tech Talk on October 24, which featured Professor **Adam Sobel**, an authority on atmospheric and climate dynamics, in conversation with Professor **Kyle Mandli**, an expert on geophysics. Moderated by Dean Mary C. Boyce and organized in collaboration with the engineering student councils, this new series brings together faculty and students for informal, open-ended discussions in Carleton Commons. Through topics that span the five pillars of Engineering for Humanity—the next installment on Nov. 29 is set to explore a healthy humanity through regenerative medicine—students can learn first-hand about the pioneering research underway inside faculty labs.

"These Faculty Tech Talks provide an ideal forum for students to connect with faculty in an intimate setting, where they have the opportunity to ask questions about the current state of the art research as well as hear about the career trajectories of different faculty—what inspired them and what path led them to their research and education field and their interest in an academic career," said Dean Boyce. "It is always interesting to hear about the journey as well as the work."

Plans are currently to host at least three more Tech Talks over the course of the academic year. This first event offered an engaging discussion on the mechanics of modeling extreme weather. The climate is a chaotic system composed of chaotic systems, and devising the technology and methodologies needed to make sense of its convulsions is no mean feat. Take the questions swirling around whether we can make a direct link between the climate change caused by humans and specific events, such hurricanes Harvey, Irma, and Maria. Trying to answer that is "like trying to hear someone talking quietly in a loud room," Sobel said.

That's largely because, even though humans have gotten pretty good at predicting weather over days and weeks, the ability to account for all the variables involved in anticipating complex phenomena like tornadoes and hurricanes over months and years simply doesn't exist yet.

"There's a lot of uncertainty and we really don't know what's going on," said Mandli, who studies and models flood events like storm surges and tsunami. **(Continued on page 10)**

Mandli on Leveraging Open Source Principles for Teaching in STEM

Originally published by the Columbia University's Center for Teaching & Learning (CTL)

Free and open source software (FOSS) has become a linchpin in many of the most advanced technologies to arise in the past two decades. The principles and practices behind the success of open source software has made its way into non-software contexts and education should be no different.

Kyle Mandli, Assistant Professor of Applied Mathematics, facilitated a 2-session workshop on October 24 and 31 titled *Leveraging Open Source Principles and Resources for Teaching and Learning in STEM*. The program, designed for graduate students, postdocs, faculty, and staff in the sciences and engineering, was facilitated by Mandli and Andreas Mueller, a Lecturer in the Data Science Institute.

As a recipient of the Provost's Hybrid Learning Course Redesign and Delivery award, Mandli received support from the Center for Teaching and Learning (CTL) to redesign his introductory course Introduction to Numerical Methods. Below, he shares some of his approaches for engaging students in a large lecture environment using open source technologies and collaborative learning strategies.

What do you teach at Columbia?

I currently teach the first two courses of the computational mathematics sequence for the department. These courses tend to attract a wide variety of students due to the ubiquitous nature and need of computing in the sciences and engineering.

What teaching challenge did you encounter while teaching your course?

One of the challenges I face is teaching to an extremely diverse audience from a technical background perspective. The need causes these courses to be large and often over-subscribed, leading to the need to come up with innovative ways to scale teaching from the usual class sizes commonly found in applied mathematics courses.

How did you approach this teaching challenge?

The technical diversity challenge was partially addressed by adjusting how we taught the course as well as what technology we used in the classroom. Support from the Office of the Provost helped address these challenges through funding for content creators that helped to develop some of the course content. Often times during lecture, I will pause for a few minutes and allow students to reflect on the impact of the mathematical concept just presented or to program an algorithm that was just discussed. This allows students who may not be as mathematically trained to have some time to absorb the concepts. It allows those who are not as experienced as programmers to try to tackle an algorithm before we present the solution. This is all supported by the use of Jupyter notebooks, which form both the lecture notes and assignments, and also allow the mixture of complex mathematical discussions along side coding. Students also need only interact with one type of interface, which is a nice benefit.

Tell us about the open source technologies you leveraged for the course. What was the impact on student learning?

The problem of scaling a course to a large number of students has been partially addressed by the use of open source technologies. Grading is partially done automatically by a system called nbgrader, allowing for coding questions to be easily checked by a grader much more quickly. We also rely on the use of Jupyter notebooks to turn in assignments that mix both what would have been written mathematics with coding questions. Students generally have been eager to learn about and interact with these open source technologies and resources as they become more popular in both academics and industry. The course notes themselves are open source, which allows students to participate in the creation of the notes via the GitHub platform. Students have expressed that they enjoy the feeling of having ownership over their learning as they actively participate in improving the notes. The fact that they are open source has also meant that these notes are used outside of Columbia to help the wider teaching community with teaching these topics.

Sobel on Hurricanes & Extreme Weather

Adam Sobel was featured in several articles and interviews this fall about the recent rash of devastating hurricanes and storms. He wrote articles for *CNN Opinion* and Fortune.com; was interviewed by ABC/KRSO Santa Rosa radio and WNYC; and was quoted in *The New York Times, USA Today, The Washington Post, Bloomberg, Vox, Live Science, Mashable, GantNews,* and *Newsweek,* among others. Sobel is a Professor of Applied Physics and Applied Mathematics and of Earth and Environmental Sciences at Columbia University. He also directs Columbia's Initiative on Extreme Weather and Climate. His research area is meteorology with a focus on atmospheric and climate dynamics, tropical meteorology, and extreme weather. He is the author of *Storm Surge: Hurricane Sandy, Our Changing Climate, and Extreme Weather of the Past and Future*. For more information, see: **http://apam.columbia.edu/sobel-recent-hurricanes-and-extreme-weather**

Prof. Sobel, along with Katinka Bellomo and Suzana Camargo from the Lamont-Doherty Earth Observatory (LDEO), and Marla Schwartz and Peter Zimmerli from Swiss Re, organized the "Workshop on Atlantic Climate Variability – Dynamics, Prediction and Hurricane Risk". The workshop, hosted by Columbia's Initiative on Extreme Weather and Climate, with support from the Swiss Re Institute, took place at Columbia University on September 8. The workshop addressed "the causes and predictability of Atlantic climate variations and associated hurricane risk" and featured talks by Martha Buckley, COLA/George Mason; Mark Cane and Mingfang, LDEO; Timothy DelSole, George Mason University; Kerry Emanuel, MIT; James Kossin, NOAA's Center for Weather and Climate; Christina Patricola, Lawrence Berkley National Laboratory; Gabriel Vecchi, Princeton University; and Rong Zhang, NOAA/GFDL. For details, see: http://extremeweather.columbia.edu/events/past-events/2017-atlantic-climate-variability-dynamics-prediction-and-hurricane-risk-workshop/program-workshop-on-atlantic-climate-variability/

Yang: A Low-Cost Method for Solar-Thermal Conversion That's Simpler & Greener

A "dip-and-dry" approach for selective solar absorbers that exhibit high-performance & durability

Figure: The selective solar absorber (SSA) developed by the researchers appears black, and thus absorptive, under sunlight (as shown on the photograph on the left). However, for thermal radiation, it behaves like a non-emissive metal mirror (reflecting the dark blue sky, as shown on the thermograph on the right), and prevents the absorbed solar energy from being radiated away and lost. Figure courtesy of Jyotirmoy Mandal and Yuan Yang / Columbia Engineering

by Holly Evarts, originally published by *Columbia Engineering*

Researchers led by **Yuan Yang**, assistant professor of materials science and engineering at Columbia Engineering, along with colleagues at the Department of Chemistry at Columbia University, and Stanford University have developed a new, scalable, and low-cost "dip and dry" method for fabricating a highly efficient selective solar absorber (SSA) that can harness and convert sunlight to heat for use in a wide range of energy-related applications, from heating water and generating steam to residential heating. The team's method is outlined in the paper, "Scalable, 'Dip-and-dry' Fabrication of a Wide-Angle Plasmonic Selective Absorber for High-efficiency Solar-thermal Energy Conversion," published in *Advanced Materials* on August 28.

The authors determined that the plasmonic-nanoparticle-coated foils created by their method perform as well or better than existing SSAs and maintain high efficiency throughout the day, regardless of the angle of the sun, due to the wide-angle design. They propose that the simple, inexpensive, and environmentally friendly process provides an appealing alternative to current SSA fabrication methods.

"We saw an unmet need for a facile, inexpensive, and sustainable method for fabricating high-performance SSAs," said Yang. "We were pleased that our relatively simple process produced SSAs that performed on par with commercial SSAs and designs reported in other research. To our knowledge, this is the first time a plasmonic SSA has been made using such a process, and the scalability and cost of this approach brings us closer to making solar energy a practical reality for more people."

Harvesting sunlight for renewable energy remains a primary objective for scientists. Solar-thermal converters, which can absorb light across the entire solar spectrum and convert it to heat at remarkably high efficiencies, offer a highly promising pathway for solar-energy harvesting. However, attaining high-efficiency solar-thermal conversion at low cost remains a challenge.

As a surface component of solar-thermal converters, SSAs are ideal because they have contrasting optical properties for solar and thermal radiation. They are very black across all colors of sunlight (from UV to visible to near infrared light) and can therefore absorb almost all the light and become very hot. However, unlike common black surfaces, they are metallic, i.e. non-emissive, when it comes to thermal radiation (mid- to far-infrared light). Heat is therefore not lost as radiation and can be used, for example, to heat water or generate steam. Most SSAs are made using more sophisticated, energy-expensive, or hazardous manufacturing processes such as vacuum deposition or electroplating. This increases both the environmental footprint and cost while limiting their accessibility. As a basis for manufacturing SSAs, the dip-and-dry process is an attractive option, as it yields SSAs that are highly efficient, while bypassing the costs and environmental hazards associated with other approaches.

Working with instruments and facilities in Columbia Engineering laboratory space and the Columbia Nano Initiative (CNI), the researchers were able to fabricate metal-based plasmonic SSAs using an inexpensive process that can tune the SSAs to suit different operating conditions, and is compatible with industrial manufacturing methods. By dipping strips coated with a reactive metal (zinc) into a solution containing ions of a less reactive metal (copper), solar-absorbing nanoparticles of copper can be easily formed on the zinc strips by a galvanic displacement reaction.

"The beauty of the process is that it can be done very simply," said **Jyotirmoy Mandal**, lead author of the study and a doctoral student in Yang's group. "We only needed strips of metals, scissors – to cut the strips to size – a salt solution in a beaker, and a stopwatch to time the dipping process."

With its wide angle, the SSA addressed another long-standing problem faced by solar-absorbing surfaces: the ability to absorb sunlight throughout the day from sunrise to sunset. In tests, the resulting SSAs showed a significantly higher solar absorption at all angles (~97% absorption when the sun is above, ~80% when near the horizon) than existing designs.

Ronggui Yang, a professor and S.P. Chip and Lori Johnson Faculty Fellow in the Department of Mechanical Engineering at the University of Colorado at Boulder, who was not involved in the study, noted that significant challenges exist in obtaining wide-angle high solar absorptance materials with low thermal emittance. "A low-cost and scalable approach is much sought after by various researchers," he said. "I am excited that Yang's research team demonstrated a scalable and environment-friendly process based on the 'dip-and-dry' technique. Their durable and high performance plasmonic solar absorber will find immediate applications in solar-thermal systems."

The team plans to test other combinations of metals besides zinc-copper and zinc-silver and explore ways to further increase efficiencies. They are especially excited about the potential for the simple and affordable process to be utilized for solar conversion in developing countries.

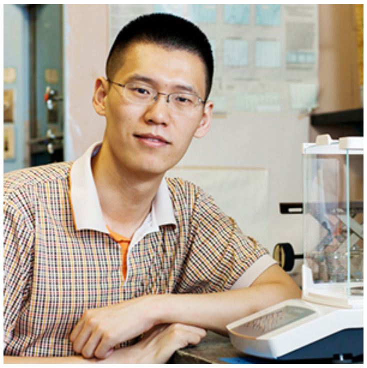
"It is crucial for scientists to find practical ways to address energy- and environment-related problems in communities where they are most acute, like in South Asia," said Mandal.

"This is a promising instance of how novel optical surfaces for energy-related applications can be developed relatively simply, cheaply, and sustainably," said Yuan Yang. "Easy-to-manufacture solar absorbers could play an important role in bringing about a renewable energy future."

The research was conducted by researchers from Columbia Engineering, the Department of Chemistry at Columbia University, and Stanford University. This work was supported by startup funding from Columbia University, NSF IGERT, AFORSR MURI, and AFOSR DURIP. The authors thank Cheng-Chia Tsai from the APAM Department for his help on this study and Sagar Mandal from the Department of Computer Engineering at Georgia Institute of Technology for guidance on figure design.

Yang & Yu: Columbia Engineering for Humanity

APAM Professors Yuan Yang and Nanfang Yu were featured in the article, "Columbia Engineering for Humanity," by Allison Elliott, originally published by *Columbia Engineering*



Imagine a world where renewable energy could fuel everything and be stored in abundance.

As humanity seeks more sustainable forms of energy, scientists are looking for ways to store energy and harness the potential of solar and wind power. As an assistant professor in materials science and engineering, **Yuan Yang** is making progress in the area of advanced batteries with the aim of developing materials to improve their performance and safety.

Lithium batteries hold promise for the ability to power cell phones longer, increase mileage for electric vehicles, and stabilize the output of greener—but less reliable—energy sources like solar and wind power. However, in recent years, the flammability of these batteries has become a notable concern, a problem that is directly related to the liquid electrolyte inside.

Yang, who is also a core faculty member at the Lenfest Center for Sustainable Energy, recently developed a novel ice-templating method for creating all-solid-state batteries that could potentially solve the safety issue hampering this ubiquitous power source. Using the principles of rational design, his team determined an optimized substitute for the liquid and chose a configuration and ratio of ceramic and polymer particles that performed three to four times better than structures in which the particles were randomly dispersed.

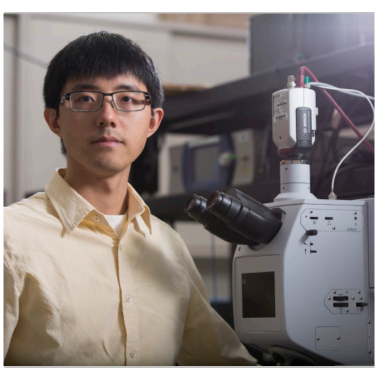
"Ceramic has higher ionic activity, but it's brittle. Polymer is soft and plastic. It's strong, but ions move slowly inside," said Yang. "We optimized the geometry of the two in order to get the benefits of both."

Yang and his team are now using these findings to build better batteries—ones that will be nonflammable and nontoxic, with a longer working life.

Yang Wins 2017 RISE Grant

Yuan Yang and Wei Min, Professor in the Department of Chemistry, were one of six teams selected to receive a 2017 Research Initiatives in Science and Engineering (RISE) grant. The grant will fund their research project: Visualizing Ion Transport in Battery Electrolyte by Stimulated Raman Scattering Microscopy.

"High-performance rechargeable batteries are indispensable to a broad range of applications, including electric vehicles and grid-level energy storage. Transport of ions in battery electrolyte and their insertion into solid electrodes are critical to battery performance. For example, inhomogeneity of ion flux in the electrolyte can deplete ions locally, which not only reduces energy/power density, but also deteriorates cycling life. Therefore, visualizing and quantifying ion transport in the electrolyte and at the solid-liquid interface will not only provide better understanding of battery processes, but also help design better electrolytes and electrodes to enhance battery performance and safety. Here we propose to use the emerging Stimulated Raman Scattering (SRS) microscopy to realize such 3D imaging of ion transport in the battery electrolyte. SRS microscopy is label-free, and its dual-beam configuration employs the stimulated emission amplification, gaining 100 million times higher sensitivity than the common spontaneous Raman microscopy, which enables fast imaging at second level to resolve the transport dynamics of battery electrolyte. Such studies will deepen our understanding of battery reactions and guide further development of batteries with high performance."



Imagine a world where natural phenomena could be replicated in the built environment to protect and enhance human life.

Assistant Professor of Applied Physics, **Nanfang Yu**, brings a physics mindset to biomimicry. While studying physics in college, he maintained a keen interest in biology and what scientists can learn from nature. His interest in the optical properties of living systems led to a connection with biologist Rüdiger Wehner from ETH Zürich, who had been conducting field study of desert ants for decades.

Rüdiger brought to Yu's attention one particular ant species, the Saharan silver ants, remarkable for their ability to withstand the blazing desert sun that kills many other insects. Intrigued, Yu sought to reveal the cause of their amazing self-cooling ability. His studies found that the silvery hairs covering their body were highly reflective in the solar spectrum, preventing significant absorption of sunlight, and also highly emissive in the thermal radiation spectrum, enabling the ants to dissipate heat via blackbody radiation.

Applying this insight to his interest in devising methods for optimizing energy use, Yu set up a pilot project last fall at the Fort Lee Senior Center to test a cool-roof coating his research team had developed to mimic the optical and thermodynamic properties of the silver ants.

Sensors implanted in the 4,000-square-foot roof indicated a reduction of roof temperature by up to 30oC on the coated roof compared with the uncovered portion. The coating also showed less degradation and loss of solar reflectivity compared with commercial cool-roof coatings. Yu is working with Columbia Technology Ventures to develop and potentially commercialize the product.

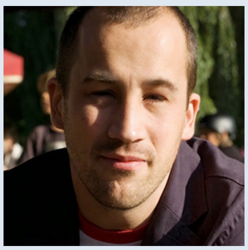
"The challenge is to understand the physical mechanism and develop a technically feasible approach to imitate the mechanism," said Yu. "There are tons of mysteries in life and it is interesting that clever designs could occasionally emerge while one is pondering these mysteries."

New Applied Mathematics Faculty Members: Donsub Rim & Drew Youngren

Donsub Rim is the new Chu Assistant Professor of Applied Mathematics.

Rim received his B.Sc. in mathematics and B.B.A. in business administration from Yonsei University in 2011, then received his M.Sc. in applied mathematics also from Yonsei in 2012. He completed his Ph.D. in applied mathematics at the University of Washington, studying uncertainty quantification (UQ) problems arising in tsunami modeling and reduced order models (ROMs) for hyperbolic partial differential equations (PDEs), under the supervision of Prof. Randall J. LeVeque and Prof. Gunther Uhlmann.

His current research interests are motivated by UQ problems that involve hyperbolic PDEs, such as the probabilistic tsunami hazard assessment (PTHA) problem which aims to estimate the risk of inundation caused by tsunamis at coastal communities. This motivation has led him to explore novel numerical techniques that extract traveling information in the data. He is also interested in inverse problems arising in medical imaging and scattering.



Drew C. Youngren is a new Lecturer in Discipline in Applied Mathematics and he focuses chiefly on undergraduate mathematics education.

Youngren received a B.S. in applied mathematics from Columbia University (2000), an M.A. in mathematics from Stony Brook University (2002), a Ph.D. in mathematics from Northwestern University (2006), and an M.A. in mathematics education from New York University (2007). He has taught for over ten years a range of courses from general interest statistics through non-Euclidean geometry for mathematics majors. He has focused on developing the calculus sequence, co-authoring interactive modules for NYU's "flipped" version of first-semester calculus, and transition courses where students first develop the ideas and techniques of mathematical proof. In addition, he has spearheaded his department's use of data in assessing learning outcomes for accreditation agencies.

Of particular interest to Youngren is the role of technology, and more specifically computation, in the learning of mathematics. He has participated in grant work to introduce computational work in discrete mathematics and on a larger scale in linear algebra. At Columbia, he will be developing the multivariable calculus curriculum tailored to the needs of engineers and applied scientists where he hopes similarly to infuse technological elements into a classical curriculum.

Celebrating Faculty Excellence

APAM professors were honored by Dean Boyce at the 2017 SEAS Faculty Excellence celebration this fall.

APAM's newest faculty members, including **Renata Wentzcovitch**, a Professor of Materials Science and Applied Physics, and also of Earth and Environmental Science; **Donsub Rim**, the Chu Assistant Professor of Applied Mathematics; and **Drew Youngren**, a Lecturer in Discipline in Applied Mathematics, were warmly welcomed.

Other faculty members were recognized for their recent honors and achievements in the past academic year. **Nanfang Yu**, Assistant Professor of Applied Physics, won a DARPA Director's Fellowship; **Yuan Yang**, Assistant Professor of Materials Science and Engineering, was named a Scialog Fellow on Advanced Engergy Storage; and **Katayun Barmak**, the Philips Electronics Professor of Applied Physics and Applied Mathematics, received the Kim Award for Faculty Involvement.

APAM faculty members were also recognized for scholarly leadership. **Adam Sobel**, Professor of Applied Physics and Applied Mathematics and of Earth and Environmental Sciences, was named to the American Meteorological Society Council's Principal Governing Body and **Renata Wentzcovitch** was elected to a 4-year term as Vice Chair of the Division of Computational Physics of the American Physical Society.

Photos of the event are available online at: **http://engineering.columbia.edu/news/faculty-excellence-2017**

Mandli & Sobel: New Tech Talks Series

(continued from page 6)

The climate is definitely changing, but "[w]e don't really understand how fast ice will melt in the Arctic and Greenland, or exactly how the ocean will expand as it gets warmer."

But more powerful computers and ever-richer data sets with higher resolution and more extensive coverage are enabling better models to account for more and more variables. For instance, Sobel was able to calculate that about eight inches of Hurricane Sandy's nine-foot storm surge can be attributed to global warming.

"A good chunk of the improvement in the models is better computing," said Sobel, author of Storm Surge: Hurricane Sandy, Our Changing Climate, and Extreme Weather of the Past and Future. "Every few years we can do something we wouldn't have thought of before."

Following their introductory conversation with Dean Boyce, the professors turned to their attention to audience—in a departure from the format of many talks, faculty presentations only account for about 20 minutes of a Tech Talk, with the lion's share of the time reserved for student questions. Attendees took advantage of the extended Q&A to probe issues ranging from how to dispel disinformation in the media to career paths in climate science. On that last point, at least one picture emerged clearly.

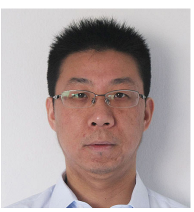
"The weather is probably just going to get worse," Sobel noted wryly. "It's good for job security."

Sabbagh Leads Study to Predict & Avoid Disruptions on KSTAR Tokamak

Preventing disruptions that halt fusion reactions is a top priority of the U.S. magnetic fusion program. In pursuit of that goal, **Steven Sabbagh**, a senior research scientist and adjunct professor at Columbia University on long-term assignment to PPPL, heads a multi-institutional project to study ways to predict and avoid disruptions on the Korean Superconducting Tokamak Advanced Research (KSTAR) facility in South Korea. The long-pulse KSTAR produces plasmas that can last from 30 seconds to a design value of more than five minutes.

"Long-pulse is where tokamaks are going," said Sabbagh. "Future tokamaks must operate for weeks and months at a time." The overall effort seeks to model the step-by-step development of conditions that lead to disruptions, and to outline ways to control such conditions. The work will build on research that Sabbagh and the Columbia group have conducted on the National Spherical Torus Experiment (NSTX) at PPPL and will continue on the National Spherical Torus Experiment-Upgrade (NSTX-U). Joining Columbia in the 3-year project are PPPL and MIT. Steven Scott, a principal research physicist at PPPL, leads the PPPL efforts. Earl Marmar, a senior research scientist at MIT, administrates the university's contribution.

Wang Receives AMS Editors Award



Dr. Shuguang Wang, an Associate Research Scientist in Applied Mathematics, has been selected to receive an Editors Award from the American Meteorological Society. In particular, Dr. Wang's award is from the *Journal of the Atmospheric Sciences* and the citation reads: "*for consistently excellent, careful, and constructive reviews on a wide variety of topics that have helped authors improve their manuscripts*". The award will be presented at the AMS' Annual Meeting in January 2018 in Austin, TX.

An Introduction to Quantum Physics

Wiley-VCH, Berlin recently published "An Introduction to Quantum Physics: A First Course for Physicists, Chemists, Materials Scientists, and Engineers." The book, which was written by Stefanos Trachanas, was translated and edited by **Manolis Antonoyiannakis** and Leonidas Tsetseris. Dr. Antonoyiannakis is an Adjunct Associate Research Scientist in the APAM Department, an Associate Editor at *Physical Review B* (PRB), and a Bibliostatistics Analyst at the American Physics.

SEAS Faculty Win NSF Grant to Study

(continued from page 6)

The Columbia Engineering team notes that the success of their methodology depends on stakeholder engagement, and so they are working with scientists from the National Center for Atmospheric Research to set up interviews with key stakeholders such as the MTA, the Port Authority, and the city and state offices of emergency management. The interviews will help the researchers to identify critical components of infrastructure and the interdependencies among them that could be adversely impacted by coastal flooding. The researchers will also engage communities potentially impacted by the research addressing how these communities might respond to the proposed strategies.

NASA-MIT Study Evaluates Efficiency of Oceans as Heat Sink, Atmospheric Gases Sponge

by Ellen Gray, originally published as a NASA/GSFC feature

The world's oceans are like brakes slowing down the full effects of greenhouse gas warming of the atmosphere. Over the last ten years, one-fourth of human-emissions of carbon dioxide as well as 90 percent of additional warming due to the greenhouse effect have been absorbed by the oceans. Acting like a massive sponge, the oceans pull from the atmosphere heat, carbon dioxide and other gases, such as chlorofluorocarbons, oxygen and nitrogen and store them in their depths for decades to centuries and millennia.

New NASA research is one of the first studies to estimate how much and how quickly the ocean absorbs atmospheric gases and contrast it with the efficiency of heat absorption. Using two computer models that simulate the ocean, NASA and MIT scientists found that gases are more easily absorbed over time than heat energy. In addition, they found that in scenarios where the ocean current slows down due to the addition of heat, the ocean absorbs less of both atmospheric gases and heat, though its ability to absorb heat is more greatly reduced. The results were published in *Geophysical Research Letters*, a journal of the *American Geophysical Union*.

"As the ocean slows down, it will keep uptaking gases like carbon dioxide more efficiently, much more than it will keep uptaking heat. It will have a different behavior for chemistry than it has for temperature," said **Anastasia Romanou**, lead author and climate scientist at NASA's Goddard Institute for Space Studies and APAM Research Scientist.

She and colleagues at the Massachusetts Institute of Technology in Cambridge, Massachusetts used the NASA GISS ocean model and the MIT General Circulation Model to simulate one of the Atlantic's major current systems that delivers absorbed heat and gases to the depths.

In the Atlantic Ocean, the Gulf Stream is part of what's called the Atlantic Meridional Overturning Circulation, a conveyor belt of ocean water that carries warm water from Florida to Greenland where it cools and sinks to 1000 meters or more before traveling back down the coast to the tropics. On its northward journey, the water at the surface absorbs gases like carbon dioxide and chlorofluorocarbons (CFCs) – the latter are, to a large, extent, the gases responsible for the ozone hole over Antarctica – as well as excess heat from the atmosphere. When it sinks near Greenland, those dissolved gases and heat energy are effectively buried in the ocean for years to decades and longer. Removed from the atmosphere by the ocean, the impact of their warming on the climate has been dramatically reduced.

Read the full article online at: **https://www.giss.nasa.gov/research/news/20170612/**

Shifts in Atmospheric Circulation Alter Global Clouds & Affect Climate Sensitivity

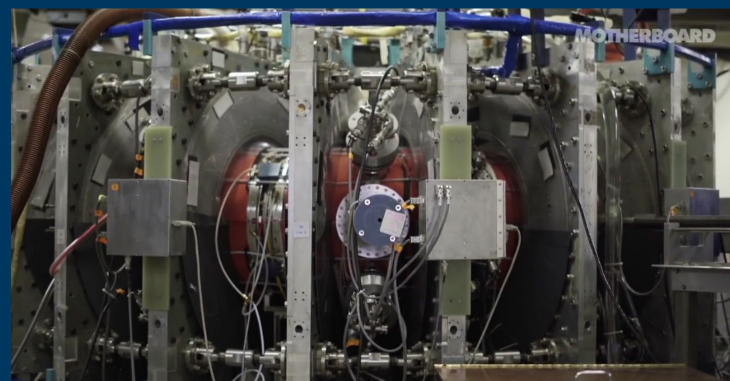
by George Tselioudis, originally published by NASA/GISS

The interaction between atmospheric circulation in the tropics and sub-tropics and cloud structure is highly correlated. Interestingly, changes in the circulation and the consequent shifts of cloud cover lead to differing warming/cooling effects in the northern and southern hemispheres. How well climate models simulate the southern hemisphere effects has implications for the models' climate sensitivity. Read the full article online at: **https://www.giss.nasa.gov/research/briefs/tselioudis_02/**

Nuclear Fusion Energy:
The Race to Create a Star on Earth

Gerald Navratil, the Thomas Alva Edison Professor of Applied Physics, and HBT-EP, the Tokamak at Columbia, appear in the: Nuclear Fusion Energy Video: *The Race to Create a Star on Earth*.

"If the processes powering the fusion reactor at the Sun's core could be recreated on Earth, it would be one of the most important events in the history of our species. Nuclear fusion power plants could end our dependency on fossil fuels and provide a virtually limitless, highly efficient source of clean energy. We went to two of the world's leading nuclear fusion research centers—Sandia National Labs in New Mexico and General Fusion outside Vancouver—to see how close we are to bringing the power of the stars down to Earth." http://apam.columbia.edu/navratil-featured-nuclear-fusion-energy-video-race-create-star-earth



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