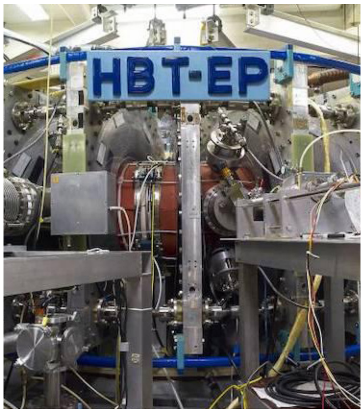
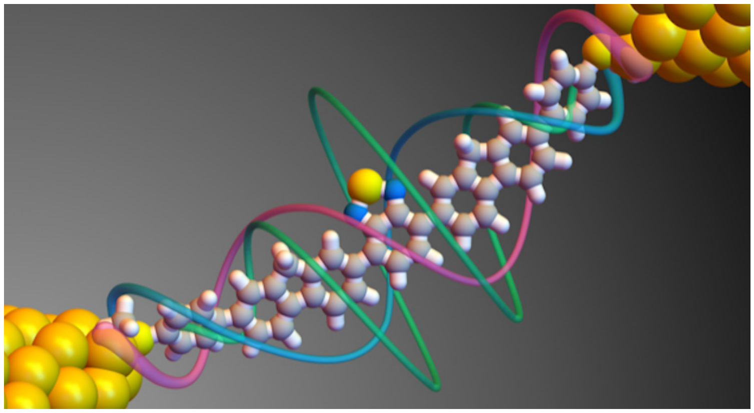
COLUMBIA | ENGINEERING
The Fu Foundation School of Engineering and Applied Science

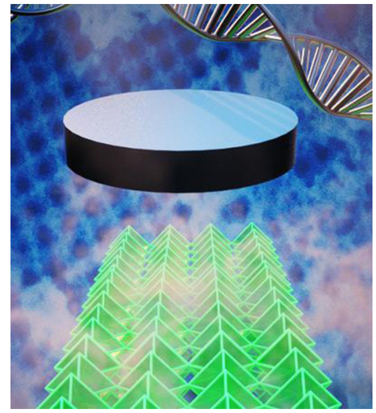
Fall 2020, Vol. 15 Issue 1

APAM NEWS

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







Dear APAM Family,

We have just finished a fall term under the unusual conditions made necessary by the COVID-19 situation. Most teaching has been remote, but some classes have had an in-classroom component. Research has largely returned to the pre-COVID normal level of activity. Our campus life has been very productive, but the campus has still been unusually "quiet." I thank the wonderful efforts of our faculty, staff and students for making this fall term, one that we can be proud of.

APAM has much to be proud of! This term has seen our faculty being awarded new honors (Mike Mauel and Michal Lipson), winning many new grants-including Center grants (on quantum science, chemistry with electric fields, "green" data, and power grid risk), and making breakthroughs in research (on single-molecule devices, in plasma physics, and in modeling coastal regions and the seasonal frequency of major storms, controlling the flow of disinformation, and making 3D nanosuperconductors with DNA). Our alumni and students continue to achieve and to win honors, and we are honored to highlight their remarkable accomplishments in this issue.

We are very proud to welcome our new Chu Assistant Professor of Applied Mathematics, Lu Zhang, and Prof. Carlos Paz-Soldan who is joining APAM (and our plasma physics program) on January 1, 2021.

We enter the Spring 2021 term largely following the same health and safety protocols as in the fall, but we are very hopeful that the situation will approach a healthy normal quite soon.

Stay well,

Irving P. Herman
Chair, APAM

Images: (left) HBT-EP Experiment in the Columbia Plasma Physics Lab, p. 9; (center) Novel type of quantum interference enables single-molecule switch with high on/off ratio, p. 4; (right) An illustration showing how highly nanostructured 3-D superconducting materials can be created based on DNA self-assembly, p. 10

Columbia Scientists Present Latest Results at APS Division of Plasma Physics Meeting

By Michael Mauel

Ian Stewart

Columbia University fusion scientists and students presented their latest results during the 62nd Annual Meeting of the APS Division of Plasma Physics.

The APS-DPP Annual Meeting is the largest in the world, with more than 2,200 participants reporting the latest research in all areas of fundamental and applied plasma physics. To ensure the safety of all participants, this year's Annual Meeting was virtual, with lectures presented and recorded over the internet.

Highlights from this year's meeting were the invited presentations from Columbia University scientists and students. Applied Physics graduate student, **Ian Stewart**, described measurements from the HBT-EP Tokamak Experiment at Columbia University and demonstrated how plasma turbulence can be suppressed by carefully driving a thin layer of plasma flow at the plasma edge. Ian's measured the destruction of turbulent eddies and the reduction of plasma transport and fluctuations that results from plasma flow shear.

Columbia University research scientist, **Dr. Jeremy Hanson** presented new simulations and insights into the control instabilities in the DIII-D Experiment (operated by General Atomics at San Diego, CA). Jeremy showed how improved plasmas modeling leads to more accurate simulations of plasma instability control and presented innovative methods for real-time control that can be applied to upcoming fusion energy experiments using the ITER device.

Dr. Francesca Turco presented her analysis of the physics basis to integrate a very high-temperature, high-power fusion reactor core with the much cooled divertor that handles the escaping plasma heat and particles from the plasma. Francesca showed how to optimize the plasma heating and radiation profiles to maintain steady-state stability, good confinement, and adequate radiative power for steady-state reactor operation.

In addition to the three invited presentations of Stewart, Hanson, and Turco, more than 20 other presentations were made by Columbia University students, scientists and faculty from APAM. Presenting their results were APAM graduate students **Boting Li**, **Alex Saperstein**, **Rian Chandra**, and **Yumou Wei**; scientists **Dr. Jack Berkery**, **Dr. Chris Hansen**, **Dr. Jeff Levesque**, **Dr. Jae Kyung Jang**, **Dr. Young Seok Park**, **Dr. Jayoung Park**, **Dr. Yanzheng Jiang**, **Dr. Steven Sabbagh**; and **Professors Allen Boozer**, **Michael Mauel**, and **Gerald Navratil**.

Further information about the invited lectures by Ian Stewart, Dr. Jeremy Hanson, and Dr. Francesca Turco can be found online at **https://bit.ly/3qF2VQg**

Lee Wins 2020 Korean Honor Scholarship

Hwi Lee, a fourth year PhD student in applied mathematics under the supervision of **Prof. Qiang D**u, was chosen as a recipient of the 2020 Korean Honor Scholarship awarded by the Embassy of the Republic of Korea.

This Scholarship, which was first established in 1981, is awarded to "outstanding students of Korean heritage to encourage high achievement of academic performance and the development of leadership qualities for their future professional careers."

Doctoral Defenses

Congratulations to numerous APAM graduate students who successfully defended their doctoral dissertations this past term, even in the midst of a pandemic which required many to work remotely. We are very proud to celebrate the fantastic achievements of **Oded Stein** (Applied Mathematics, advised by Eitan Grinspun), **E-Dean Fung** (Solid State Physics, advised by Latha Venkataraman), **Zhengqian Cheng** (Solid State Physics, advised by Chris Marianetti), **Long Yang** (Materials Science & Engineering, advised by Simon Billinge), **Rachael Keller** (Applied Mathematics, advised by Qiang Du), and **Jiayang Hu** (Materials Science & Engineering, advised by Irving Herman).

Master of Science Specialization & Concentration

The APAM Department now offers qualified Master of Science (MS) students the option to pursue an MS Research Specialization in Applied Mathematics or an MS Materials Science and Engineering Concentration in Materials Theory and Simulation (MTS).

Students admitted to the inaugural year include Applied Mathematics MS students, **Qi Gao** (supervised by Qiang Du), **Sameh Nadeem Hameedi** (supervised by Amir Sagiv), **Qing Zhu** (supervised by Kui Ren), and Materials Science and Engineering MS student, **Chaoxuan Gu** (supervised by Renata Wentzcovitch). For more details, please see: **https://bit.ly/38heR2j**

Alumni Featured in Career Services Events

By Kristen Henlin

The APAM Department continued to host virtual career events this semester. Thanks to the support of our wonderful alumni, we kicked off the summer with career talks. We hosted four APAM alumni each Tuesday during the month of July. Undergraduate and graduate students had the opportunity to connect with **Colton Smith** (MS '19, Applied Mathematics), a Quantitative Researcher at Imbue Capital and **Yuri Brovman** (PhD '11, Applied Physics), a Machine Learning Engineer at EBay. Later in the month, students learned about career opportunities at The Johns Hopkins Applied Physics Laboratory from Research Engineer, **Michael Berkson** (MS '18, Materials Science). We wrapped up our summer talks with **Kai Pak** (MS '18, Applied Physics), who not only discussed his journey to NASA Jet Propulsion Laboratory, but also offered insight on life as a Data Scientist.

We had the privilege of hosting another batch of APAM alumni in September, including **Preston Bradham** (MS '19, Applied Mathematics), a Consultant at DayBlink and **Eric Issacs** (PhD '16, Applied Physics), a Postdoctoral Fellow at Northwestern University. We concluded the month with an informative session from **Will Martin** (MS '19, Medical Physics), a first year Medical Physics Resident at Montefiore Medical Center.

In October, our students learned how Research Staff Member, **Edward Chen** (MS '12, Applied Physics) applies his research background to applications in quantum information processing, simulations and optimization at IBM Research. Machine Learning Engineer **Jingjing Ling** (MS '13, Applied Physics), who offered advice to students who were interested in pursuing similar roles at Apple. We ended our semester with a talk from **Matthew Worstel**l (PhD '13, Plasma Physics), who discussed his role as a Physicist in the Nuclear Technologies Department within the Defense Threat Reduction Agency at SAIC.

Given the current climate, many students are facing uncertainty regarding employment. If you have full-time, part-time, or summer internships available, please reach out to Kristen Henlin, at kah2247@columbia.edu.

Alumni Reports

Originally published in Columbia Engineering Magazine

Sri Aradhya (PhD ’13, Applied Physics) writes: “After graduating with a PhD from the Venkataraman Lab in 2013, I moved upstate to Cornell as a postdoc. I now work as a technologist at Western Digital Corp., where I work on pushing the boundaries of process technologies to make the next generation of enterprise storage products. Our family has now relocated to the Bay Area with two boys added to our family that are keeping everyone busy.”

Jack B. Freeman (BS ‘55, Materials Science) writes: “I’m still working as a material scientist. Accumet is the fourth successful start-up company I’ve formed. We provide several specialized products, including metal single crystals other than silicon. After many years of study, crystals of gold, aluminum, and tungsten are being used commercially.”

Dan Gant (BS ‘07, Applied Mathematics) married Stephanie Hao in June of 2019. In January, they’ll be celebrating five years since their first date. Dan is working as an engineer at Facebook AI Research on reinforcement learning and natural language processing.”

Charles Henager (BS ‘76) writes: “I will be retiring from my materials scientist position at Pacific Northwest National Laboratory (PNNL) in Richland, WA after 40 years. Although I had many activities at PNNL over the years, my major research was in the field of nuclear materials and computational materials science, where I explored both metals and ceramics for nuclear applications, including SiC/SiC composites and tungsten for fusion energy applications. I helped develop solid-state displacement reactions to produce novel radiation-resistant joints for SiC-based materials that are still being tested in-reactor. I am a member of the Advisory Editorial Board for the Journal of Nuclear Materials and a past recipient of the Roland B. Snow Award from the American Ceramics Society. My most recent activity was as the technical co-chair for the 19th International Conference on Fusion Reactor Materials (ICFRM-19) held in La Jolla, CA in 2019. I will return as Emeritus Scientist at PNNL with some traveling and volunteer work.”

Shawn Kolitch (BS ‘89, Applied Mathematics) writes: “On October 1, 2019, I celebrated the one-year anniversary of my new intellectual property law firm, Kolitch Romano LLP, based in Portland, OR. My partner TJ Romano and I launched the firm after spending many years as partners with another Portland firm. We work with small and large companies around the world to obtain and enforce their IP rights and have a reputation for providing extremely high-quality service while educating our clients about complex issues in a clear and approachable way. Shortly after the firm’s anniversary, I spent 10 days in China, where I was invited to give presentations about US intellectual property law to the Hangzhou IP Bureau, the China Council for the Promotion of International Trade, and an audience of in-house attorneys at Alibaba headquarters. Although it’s been a long time, studying Chinese as a Columbia undergraduate was extremely helpful!”

June Lau (MS’02, PhD’06 Materials Science) writes: “Our invention, the laser-free GHz stroboscopic TEM, won the R&D 100 award in 2019.” The full announcement is available at **https://bit.ly/33XzJu0**

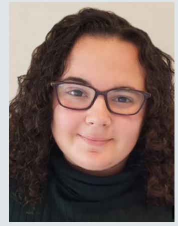
Anna Liveris (BS ‘07, Materials Science) writes: “2019 was a special year. I married my long-time partner, Georgios Mol ‘07 (IEOR), and we welcomed our first child in September, a beautiful baby girl, Stavroula. Professionally, I have taken a position as a trauma surgeon and intensivist in the Bronx, NY.”

Stefano Migliuolo (BS ‘73) writes: “On July 6th, 2019, I completed my Atlantic-to-Pacific journey on a bicycle. Traveling at roughly 10 miles per hour across eleven states gave me an unparalleled opportunity to enjoy this magnificent country, from the lilacs of Massachusetts to the wild sage and oregano of the Western states! Miraculously, I pedaled 3,320 miles in 60 days without a single puncture, ending on the Oregon coast. Every person I met had his/her story, and every conversation gave me a lift. My night camps in Wyoming and Idaho allowed me to see the glory of the Milky Way, unspoiled by city lights. As I enter the waning years of my professional career (which I still enjoy immensely), I appear to have stumbled on a new path to adventures: bicycle touring. Next summer, it will probably be the Black Hills and Badlands of South Dakota.”

Bruce Terris (BS ‘79, Applied Physics) was named an IEEE fellow for “contributions to high density magnetic recording and spintronic materials.” He had previously been named a fellow of the American Physical Society and is currently director of non-volatile memory materials research at Western Digital in San Jose, CA.

Shelly Weinig (MS’53, EngScD’55, Metallurgy) writes: “I taught for two years as an assistant professor, but decided that the bureaucracy of academia was not for me and became an entrepreneur and started Materials Research Corp. (The story of that entrepreneurial adventure is in my book Rule Breaker.) 30 years later, the company went public and global and we were acquired by Sony Corporation. I spent five years with them as vice-chair of engineering and manufacturing and accepted adjunct professorships from Columbia University and SUNY Stonybrook. I taught for 25 years pro bono at both universities until the summer of 2019, when I resigned both professorships at the age of 91 so that I could write another book called Breakfast with Shelly. My contributions to electronic materials resulted in my induction into the National Academy of Engineering in 1984, and the French government awarded me in 1988 the rank of Chevalier of the Ordre National de la Légion d’Honneur.”

Aaron Wininger (BS ‘94, Applied Physics) writes: “After 13 years in China, I’ve returned to the US, where I am now the director of the China intellectual property law practice at Schwegman, Lundberg and Woessner PA in their San Jose office. I help US companies protect their intellectual property (mainly patents and trademarks) in the US and China by drafting and prosecuting their US and China patent applications and coordinating their worldwide trademark strategies.



Baransky ‘16 Named One of Forbes “30 Under 30”

Isabel Baransky (B.S.’16, Applied Physics) was named one of Forbes “30 Under 30” in the finance category. She is currently Vice President, Bank of America in San Francisco.

Forbes states that she is “an engineer building Bank of America’s automated foreign exchange offering, which spans over 80 countries and billions of dollars in transactions annually. She spearheads a multiyear initiative to use machine learning intelligence to improve payments space, and now oversees the firm’s largest revenue generating data initiative. Automated FX payments have risen 10-fold in volume since Baransky took over the project as new products have been launched and Baransky has won early promotions to associate, then vice president. She graduated with a B.S. in Applied Physics and a minor in Music from Columbia University.”

Isabel is the daughter of APAM alum, **Yurij Baransky** (Ph.D. ‘87, Applied Physics, concentration in Applied Mathematics) who donated hundreds of physics and mathematics books from his personal collection to the APAM Department graduate student library.

When sharing the good news about his daughter Dr. Baransky wrote, “She says that what her time at APAM taught her is to not be afraid . . . to use Math and Physics-ish reasoning like any other tool, like pen and paper, or tape measures, or analogies or powerpoints or language. It’s just part of her toolkit, like breathing.”

Harnessing Quantum Properties to Create Single-Molecule Devices

Columbia team discovers 6nm-long single-molecule circuit with enormous on/off ratio due to quantum interference; finding could enable faster, smaller, and more energy-efficient devices

By Holly Evarts, Originally published by Columbia Engineering

Researchers, led by **Latha Venkataraman**, report that they have discovered a new chemical design principle for exploiting destructive quantum interference. They used their approach to create a six-nanometer single-molecule switch where the on-state current is more than 10,000 times greater than the off-state current—the largest change in current achieved for a single-molecule circuit to date.

This new switch relies on a type of quantum interference that has not, up to now, been explored. The researchers used long molecules with a special central unit to enhance destructive quantum interference between different electronic energy levels. They demonstrated that their approach can be used to produce very stable and reproducible single-molecule switches at room temperature that can carry currents exceeding 0.1 microamps in the on-state. The length of the switch is similar to the size of the smallest computer chips currently on the market and its properties approach those of commercial switches. The study was published on December 7, 2020 in *Nature Nanotechnology*.

"We observed transport across a six-nanometer molecular wire, which is remarkable since transport across such long length scales is rarely observed," said Venkataraman, Lawrence Gussman Professor of Applied Physics, professor of chemistry, and Vice Provost for Faculty Affairs. "In fact, this is the longest molecule we have ever measured in our lab."

Over the last 45 years, steady decreases in transistor size have enabled dramatic improvements in computer processing and ever-shrinking device sizes. Today's smartphones contain hundreds of millions of transistors made out of silicon. However, current methods of making transistors are rapidly approaching the size and performance limits of silicon. So, if computer processing is to advance, researchers need to develop switching mechanisms that can be used with new materials.

Venkataraman is at the forefront of molecular electronics. Her lab measures fundamental properties of single-molecule devices, seeking to understand the interplay of physics, chemistry, and engineering at the nanometer scale. She is particularly interested in gaining a deeper understanding of the fundamental physics of electron transport, while laying the groundwork for technological advances.

At the nanometer scale, electrons behave as waves rather than particles and electron transport occurs via tunneling. Like waves on the surface of water, electron waves can constructively interfere or destructively interfere. This results in nonlinear processes. For example, if two waves constructively interfere, the amplitude (or height) of the resulting wave is more than the sum of the two independent waves. Two waves can be completely cancelled out with destructive interference.

"The fact that electrons behave as waves is the essence of quantum mechanics," Venkataraman noted.

At the molecular scale, quantum mechanical effects dominate electron transport. Researchers have long predicted that the nonlinear effects produced by quantum interference should enable single-molecule switches with large on/off ratios. If they could harness the quantum mechanical properties of molecules to make circuit elements, they could enable faster, smaller, and more energy-efficient devices, including switches.

Greenwald, J.E., Cameron, J., Findlay, N.J. et al. "Highly nonlinear transport across single-molecule junctions via destructive quantum interference," *Nature Nanotechnology* (2020). https://doi.org/10.1038/s41565-020-00807-x

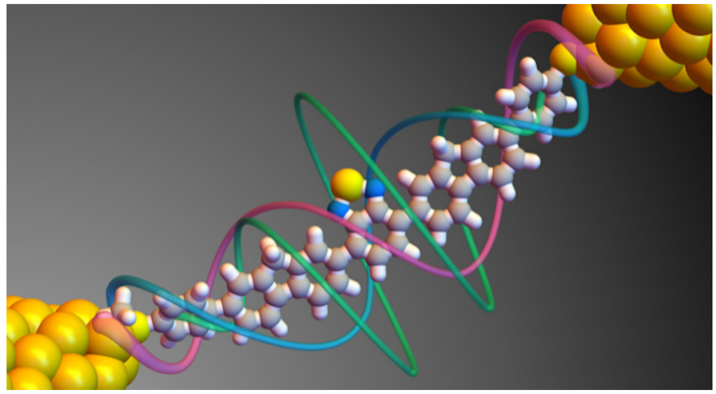


Image: Novel type of quantum interference enables single-molecule switch with high on/off ratio. Credit: Julia Greenwald & Suman Gunasekaran

"Making transistors out of single molecules represents the ultimate limit in terms of miniaturization and has the potential to enable exponentially faster processing while decreasing power consumption," said Venkataraman. "Making single-molecule devices that are stable and able to sustain repeated switching cycles is a non-trivial task. Our results pave the way towards making single-molecule transistors."

A common analogy is to think of transistors like a valve on a pipe. When the valve is open, water flows through the pipe. When it is closed, the water is blocked. In transistors, the water flow is replaced with the flow of electrons, or current. In the on-state, current flows. In the off-state, current is blocked. Ideally, the amount of current flowing in the on- and off-states must be very different; otherwise, the transistor is like a leaky pipe where it is hard to tell whether the valve is open or closed. Since transistors function as switches, a first step in designing molecular transistors is to design systems where you can toggle current flow between an on- and off-state. Most past designs, however, have created leaky transistors by using short molecules where the difference between the on- and the off-state was not significant.

To overcome this, Venkataraman and her team faced a number of hurdles. Their main challenge was to use chemical design principles to create molecular circuits where quantum interference effects could strongly suppress current in the off-state, thus mitigating the leakage issues.

"It is difficult to completely turn off current flow in short molecules due to the greater probability of quantum mechanical tunneling across shorter length scales" explained the study's lead author Julia Greenwald, a PhD student in Venkataraman's lab. "The reverse is true for long molecules, where it is often difficult to achieve high on-state currents because tunneling probability decays with length. The circuits we designed are unique because of their length and their large on/off ratio; we are now able to achieve both a high on-state current and very low off-state current."

Venkataraman's team created their devices using long molecules synthesized by collaborator Peter Skabara, Ramsay Chair of Chemistry, and his group at the University of Glasgow. Long molecules are easy to trap between metal contacts to create single-molecule circuits. The circuits are very stable and can repeatedly sustain high applied voltages (exceeding 1.5 V). The electronic structure of the molecules enhances interference effects, enabling a pronounced nonlinearity in current as a function of applied voltage, which leads to a very large ratio of on-state current to off-state current.

The researchers are continuing to work with the team at the University of Glasgow to see if their design approach can be applied to other molecules, and to develop a system where the switch can be triggered by an external stimulus.

"Our building a switch out of a single molecule is a very exciting step towards bottom-up design of materials using molecular building blocks," Greenwald said. "Building electronic devices with single molecules acting as circuit components would be truly transformative."

Carlos Paz-Soldan Joins APAM as Associate Professor in January 2021


Carlos Paz-Soldan

Associate Professor **Carlos Paz-Soldan** joins the Columbia University's Department of Applied Physics and Applied Mathematics on January 1, 2021. Paz-Soldan's research focuses on understanding and controlling high-temperature ionized gas, known as plasma, to achieve efficient and reliable operation of devices used to produce fusion energy. These devices confine plasma using some of the world's most powerful superconducting magnets. Professor Paz-Soldan is a pioneer in the understanding how three-dimensional magnetic fields influence the interactions between the high-temperature fusion core of the plasma and the cooler edge and how the excitation of plasma instabilities can control relativistic electrons produced by transient events within the plasma.

Paz-Soldan is currently a scientist at the DIII-D National Fusion Facility operated by General Atomics in San Diego, CA, where he is leader of the Edge Localized Mode (ELM) Control Research Area. He graduated from Queen's University at Kingston, Canada with his B.Sc.E. degree in Engineering Physics. He received his Ph.D. in physics from the University of Wisconsin - Madison in 2012 where he was awarded graduate fellowships from the American Nuclear Society and the Canadian National Science and Engineering Research Council. Paz-Soldan was awarded the Marshall N. Rosenbluth Outstanding Doctoral Dissertation Award by the American Physical Society in 2013 for the thesis *Stabilization of the Resistive Wall Mode and Error Field Modification by a Rotating Wall*. He serves as an expert in several International Tokamak Physics Activity research areas and served as national leader of the MHD Plasma Physics topical group of the U.S. Burning Plasma Organization from 2019-2020.

Professor Carlos Paz-Soldan brings expertise in the science and technology of making fusion energy a reality on earth. As a new member of the faculty, Paz-Soldan plans to conduct on-campus research at Columbia University's Plasma Laboratory, continue his activities at the large national fusion research facilities, and grow his research activities with an increased emphasis on training and mentorship of the next generation of fusion scientists.

Columbia Wins $1.8M NSF Grant for CCI Phase 1 Center for Chemistry with Electric Fields

Led by Applied Physics Prof. Latha Venkataraman with Department of Chemistry colleagues, the new ChEF center will focus on developing methods to use electric fields control and facilitate chemical reactions

Originally published by Columbia Engineering

A team led by **Latha Venkataraman** (pictured below) together with Department of Chemistry faculty Timothy Berkelbach, Colin Nuckolls, Tomislav Rovis, and Xavier Roy, has won a three-year $1,800,000 grant from the National Science Foundation to build the NSF Center for Chemistry with Electric Fields (ChEF). Supported by the Centers for Chemical Innovation Program of the NSF's Division of Chemistry, the Phase 1 Center will focus on using directional electric fields to understand, control, and manipulate chemical transition states to alter the outcomes of chemical reactions.

"Chemistry is at the center of the nanoscience revolution," says lead PI Venkataraman, Lawrence Gussman Professor of Applied Physics, professor of chemistry, and Vice Provost for Faculty Affairs. "By bringing together a team of like-minded scientists from a diverse set of backgrounds, we will create a new field of study that will transform reaction chemistry. We expect to create a new paradigm for molecular construction: molecules, pathways, and intermediates that were not possible with traditional catalysis will now be accessible through our new center's research."

The researchers, who have a broad range of expertise in synthesis, measurement, and computation, will use their complementary expertise to gain a molecular-level understanding of electric field-driven catalysis, and to use this insight to drive chemical reactions, control reaction kinetics, and modulate thermodynamics. They will explore a range of reactions that show promise through quantum computations, and utilize scanning probe techniques to apply large and directional electric field during the reaction. The overarching goal of the team is to demonstrate that an oriented electric field can completely alter the reaction trajectories and pathways, achieving transformations not possible under traditional conditions.

The ChEF will also collaborate with Merck and Columbia Technology Ventures to get effective new techniques from the lab to the marketplace. There will also be broad outreach to students, including undergraduates, together with a partnership with the Harlem Children's Zone School in New York City to expand the excitement of chemistry to K-12 underrepresented groups.

"Our new center will explore the concept and scope of how to use electric fields to control chemical reactions and provide sustainable and green pathways to synthesis," notes Venkataraman, whose experimental group is expert in measuring electronic, mechanical, optical, and thermoelectric properties of single-molecule circuits."

Berkelbach, who runs a computational group at Columbia and the Flatiron Institute, adds, "As a computational research group, we're thrilled to integrate with such a diverse group of experimental scientists who will drive our theoretical developments and test our predictions."

"The Center will enable us to explore orthogonal modes of activation and bond construction," states Rovis, whose group works on transition metal and photoredox catalysis strategies for organic synthesis. "In addition to the plethora of tools we have already, we will add directional electric fields. The possibilities are endless."

New Applied Mathematics Faculty Member: Lu Zhang

Lu Zhang

The APAM Department is proud to announce the appointment of **Dr. Lu Zhang** as the Ju Tang Chu and Wu Ping Chu Assistant Professor of Applied Mathematics.

Her research interests are in the area of numerical and theoretic analysis of Partial Differential Equations (PDEs) and applied mathematics in general. In particular, she focuses on developing high order discontinuous Galerkin methods in studying various PDEs with physical and biological backgrounds, such as advective wave equations, semi-linear wave equations, chemotaxis models, population dynamics models, etc. PDEs serve as the basic languages that describe the spatial-temporal dynamics of the phenomena within the physical and biological sciences. The challenges brought by the structural complexity and computational intensity within these dynamics call for the applications and development of high-order, computationally efficient and energy stable numerical methods. Theoretical analysis of these systems also yields insights into and contributes to the understanding of the continuum systems. Zhang obtained a Master's in Computational and Applied Mathematics in 2017 and a PhD in Computational and Applied Mathematics in 2020 from Southern Methodist University.

Kyle Mandli

Holding Back The Tide

Originally published in Columbia Engineering Magazine, by Lisa W. Foderaro

For leaders of coastal cities, addressing climate change means confronting an existential threat, as rising seas and stronger storms inundate critical infrastructure with increasing frequency. But even while the cost of doing nothing is too high, city officials around the world struggle to identify not just which protections are most useful to pursue, but also which among them are affordable.

A team of Columbia engineers is trying to help answer those questions, using New York City as a model. Armed with reams of data, recent experience of Hurricane Sandy, and insight from local government agencies, the researchers are creating a framework to take much of the guesswork out of creating smart defenses. "The goal is to have a tool that, in principle, optimizes coastal protection given a specific budget," said **Kyle Mandli**, associate professor of applied mathematics. "One reason we picked New York was that the city is great about sharing data. In a lot of other countries, I wouldn't be able to find a map of every building and what it's made of."

Since the fall of 2018, Mandli, along with George Deodatis, Santiago and Robertina Calatrava Family Professor of Civil Engineering, and **Daniel Bienstock**, Liu Family Professor of Industrial Engineering and Operations Research and Professor of Applied Mathematics, have pored over those records and maps while deploying their students to interview stakeholders about Sandy's toll on the city's infrastructure, including the transportation network, power grid, and emergency services.

In collaboration with the National Center for Atmospheric Research, the team is constructing a set of computational models that urban planners will eventually be able to access for free. The models will recommend various protections, from restored wetlands and dunes to seawalls and even selective retreats, based on a given budget and topography.

The devastation wreaked by Hurricane Sandy offers an instructive example, says Deodatis. In their New York City models, the team calculated a rise of 2 to 4 feet between 2050 and 2100 and 4 to 6 feet after 2100. Such an increase could turn even moderate hurricanes into highly destructive events. During Sandy, he said, the storm surged to 2.8 meters. If New York experiences sea level rise of a meter by the end of the century, a surge of only 1.8 meters would equal that of Sandy.

"Six feet of sea level rise will flood lower Manhattan if we do nothing," Deodatis says. "The critical part is the coastline. If you can prevent water encroaching along the coastline by raising highways or building barriers, then lower areas inside the city won't be affected."

With this in mind, the researchers are examining impacts caused by the interdependence of infrastructure and services. For instance, loss of road access due to flooding can make it impossible for emergency personnel to reach victims or damaged buildings. Loss of power, meanwhile, can undermine a subway system and hospital services.

Deodatis called New York's post Sandy-efforts to seal subway entrances and ventilation openings a prudent step against future hurricanes. And he notes a proposed series of raised parks around lower Manhattan coupled with a stormsurge barrier across the mouth of Lower New York Bay could make economic sense for preserving its Financial District. Whether these strategies are making use of limited funds in an optimal way, he notes, is precisely the sort of issue the group's research is designed to tackle.

Sometimes, however, a city may need to consider more even complex measures like strategic retreat. How to factor in the social and psychological cost of relocating entire communities is something they've begun exploring with the aid of psychologists, anthropologists, and other such experts.

The team hopes the tool will prove invaluable for urban planners from Miami to Mumbai, who could plug their inputs into the model as a key first step for generating solutions grounded in a local context.

"Having our methodology in place would save time for somebody doing the same analysis in another city," says Bienstock.

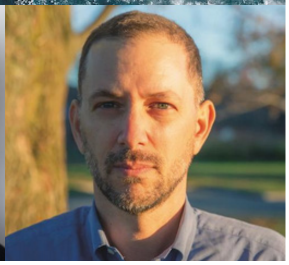
Indeed, it's smaller cities that might benefit the most, since they also have smaller budgets for both protection measures and the analysis required to choose between them.

"The computational costs to this kind of analysis are extremely high," Mandli explains. "We want to create a tool that's just as accessible to every small town in New Jersey as it is to New York City."

A Less Hazy Forecast

Climate modelers use machine learning & novel statistical methods to paint a clearer picture

Originally published in Columbia Engineering Magazine, by Mindy Farabee



Images: A climatology comparison (above), Michael Tippett (left) & Adam Sobel (right)

Michael Tippett, associate professor of applied math, seeks to forecast seasonal frequency for severe thunderstorms. **Adam Sobel**, professor of applied physics and applied math, works to do the same for hurricanes. The two often collaborate, as with their current project unearthing correlations between larger climate patterns and localized extreme weather. Once correlations are established, they apply an innovative methodology combining physics and statistics to generate synthetic storms in order to extrapolate not just the likelihood of increasing frequency and strength, but also whether shifting patterns will translate into new kinds of risks and areas of vulnerability.

"Weather models can be stripped for useful parts," says Tippett. "There are statistical relationships between what models can do and what you'd like to know."

One thing physics-based models do is roughly predict when ingredients for severe weather—wind direction, rising air, rainfall—could materialize over wide areas, one around the size of, say, Albany. By mapping this against observational weather data, Tippett can assess whether ingredients exist for more tornado outbreaks, more frequent lightning, or more damaging hail. Ultimately, "I'm looking for statistical relationships for climate change that can hold up for monthly timescales," he says.

It's not just a matter of when patterns will shift, but also to where. Under the auspices of President Bollinger's Global Innovation Fund, Sobel, also director of the Columbia Initiative on Extreme Weather and Climate, and **Kyle Mandli**, associate professor of applied math, teamed up with the Columbia Global Center|Mumbai to examine what would happen if that city took a direct hit from a synthetic storm. Their thought experiment has useful applications for coastal populations that have never experienced a hurricane—but may soon.

This approach can't forecast when one might hit, but it can quickly and cheaply deliver actionable data about how to build in resilience against when one does. As a consequence, this work has caught the attention of the insurance industry, which has come to understand global warming as a significant threat to business as usual.

"This is exploring what uncertainty means and making rational decisions in the face of it," says Sobel. "Our job is to explain the nuance of that."

Columbia Researchers Team with Global Firm to Enhance Hurricane Risk Scenarios

Adam Sobel and Michael Tippett, together with Chia-Ying Lee and Suzana Camargo from Lamont Doherty Earth Observatory, "will work with the firm Aon to integrate climate change information into the company's hurricane risk models. They will combine peer-reviewed climate change data into Aon's Impact Forecasting tropical cyclone catastrophe model suite." (State of the Planet, Earth Institute) https://bit.ly/2Kb1LLY

From The Top Down

Originally published in Columbia Engineering Magazine, by Mindy Farabee

"High Top" models are a special subset of climate models capable of capturing the inner workings of the stratosphere, the atmospheric layer sitting just above the jet stream.

The stratosphere is a curious place—winds there can race around at 120 mph, but storms are rare, and sudden warmings in this region often induce dramatic cold snaps down on Earth. The polar vortex resides in the stratosphere, as does the all-important ozone layer, which absorbs UV radiation, thereby protecting us from the sun's harmful rays.

Much of **Lorenzo Polvani'**s work focuses on the peculiar chemistry of the stratosphere and the significant role it plays in climate change. An expert on ozone-depleting substances (ODS) regulated by the Montreal Protocol, his research has expanded our understanding not just of how these greenhouse gases affect that unique environment, but also of the broader impact of ODS on the entire climate system.

Since 1987, the Montreal Protocol has been hugely successful in healing the hole in the ozone layer by tightly regulating chlorofluorocarbons (CFCs) and other ODS substances that eat away at it. The role ODS play in climate change has been less widely appreciated. In early 2020, Polvani's team published new insights into how ODS, whose impact can be 23,000-fold more potent than carbon dioxide, contributed specifically to warming in the Arctic and generally to global warming.

They determined that had ODS not been present over the past 50 years, only half the warming at the North Pole and a third of overall warming would have occurred. Their study provides a rare bit of good news; as ODS are phased out and drop from the atmosphere, their impacts will likewise fade.

"The profound link between global warming and ozone-depleting substances is only now beginning to be appreciated," says Polvani, a senior scientist at of the Lamont Doherty Earth Observatory and the Maurice Ewing and J. Lamar Worzel Professor of Geophysics at Columbia Engineering. "Although most research has focused on carbon dioxide, it is now becoming clear that other greenhouse gases are also important. ODS are a good example. Not only did they create the ozone hole, but they have also been warming the planet. There's so much more we need to learn."

Drowning in Disinformation

Wiggins collaborates on a white paper issued by CRA's Computing Community Consortium addressing how we can stop the deluge of disinformation flooding the internet and social media

Originally published by Columbia Engineering

The use and spread of disinformation—false or misleading information intended to deceive people—is being amplified and accelerated at an alarming rate on the internet via social media.

Within the U.S., this has quickly eroded trust in institutions that serve as the bedrocks of our society, including science, the media, and government, to the point that we can't even agree on basic facts.

In a white paper for the Computing Research Association's (CRA) Computing Community Consortium (CCC), researchers from Columbia University, the Santa Fe Institute, the University of Colorado, and Arizona State University outline steps to begin dealing with the disinformation problem.

"Disinformation has become a major problem not just across this country but around the world," says co-author **Chris Wiggins**, an associate professor of applied mathematics at Columbia Engineering and the Chief Data Scientist at The New York Times. "We think an interdisciplinary approach is critical to restoring a trustworthy information ecosystem."

Disinformation damages society by creating confusion and eroding trust in traditionally trusted institutions. One obvious example of disinformation today is the way COVID-19 has been called a "hoax," which has resulted in reduced adoptions of precautions necessary to contain its spread.

"Within the past few months, we've seen other large-scale disinformation about elections and the democratic process in terms of the validity, legality and security of mail-in ballots, fraudulent voting, rigged elections, dead people voting, supercomputers changing votes, etc.," says co-author Joshua Garland, an Applied Complexity Fellow at the Santa Fe Institute. "And there are many other examples surrounding migrants, vaccines, and climate change."

Disinformation is an existential threat to democracy and society, points out Elizabeth Bradley, a professor of computer science at the University of Colorado.

"We technologists created many of the tools being used by disinformation creators and circulators—the internet, social media, etc.—and it's incumbent upon us to think about solutions," Bradley says.

One of CRA's goals is to explore how computing research can help address national priorities. "Disinformation and the poisoned information environment we're all swimming in needs to be a national priority," says Nadya Bliss, executive director of the Global Security Initiative at Arizona State University.

To address disinformation, the researchers emphasize that both supply and demand must be addressed. "On the supply side, we need to develop better methods for detecting and isolating or at least mitigating disinformation before it spreads," explains Bliss. "On the demand side, we need improved efforts to educate the citizenry so people are less susceptible to believing and spreading disinformation."

Purveyors of disinformation are excellent at manipulating human emotions—they create content that is meant to seem believable while triggering an emotional response. As an individual, the best thing you can do to stop the spread of disinformation is to be sure you aren't part of the problem. If you're online and see a post that outrages you, Bliss cautions to take a moment to think before sharing it.

The researchers say the challenge of combating disinformation requires a comprehensive response that goes far beyond computing research, and includes education, psychology, journalism, and other disciplines.

"There's a tremendous need to understand how data empowered algorithms are impacting our reality and the offline world," says Wiggins. "Just like for any other complex system, addressing this will require interacting with the system—here the information ecosystem—in a way that respects ethical concerns for rights, harms, and justice."

"Our white paper outlines a clear agenda for research on the topic that could help inform a national response driven by the public and private sectors together," says Bliss.

Wiggins on Disrupting Disinformation

6 ways to understand & combat online disinformation

Originally published by Columbia Engineering

As an applied mathematician, **Chris Wiggins** built his career applying machine learning to the basic sciences, designing computational tools that help illuminate biological processes like gene regulation and personalized medicine for cancer.

But these days he's using that expertise to elucidate a very different social ill—the rapid proliferation of disinformation. And that means first answering broader questions about how to factor human experience into the equation.

Due to its digitized nature, the new disinformation ecosystem is vulnerable to detection and correction by the same computational tools that make it possible. But it isn't enough to focus on technical tools, Wiggins argues; to create a truly healthy information environment, researchers need to design new rules of engagement.

How would you sum up the big idea animating your research?

I've long been interested in how we can adapt machine learning methods, designed largely for engineering and industrial applications, in ways that answer questions from the basic sciences and from health and medicine. A couple years ago, I was looking for new ways to bring understanding of these tools to more students, so I partnered with History Professor Matt Jones to co-design a course on the history of data.

We thought it would be a great way for students in the humanities to gain an understanding of how we make sense of the world through data while also encouraging technologists to understand the impact of these methods. Interestingly, the students pushed us to go further—they wanted not just to cover the history of data but also to explore the ethics of these methods and their human impact. One thing we really focused on is how massive data collection, paired with unprecedented computational power, has allowed social media platforms to conduct massive, online social experiments without any ethical oversight. Discussions in class pushed me to rethink the role technologists and researchers should play in our information ecosystem and was a main impetus for a paper I recently co-authored trying to sharpen what's possible in disinformation research. In it, we have six specific recommendations for better detection at scale and measuring impact, new data infrastructure and ethical guidelines, and educational initiatives and workforce training.

Much of the conversation around disinformation focuses on what tech companies can and should do to counter false narratives. Your work makes the case that we aren't focusing enough on the "demand side" of the disinformation ecosystem. What have we been missing about the social side of this socio-technical problem?

(continued on page 14)

Mauel Receives Fusion Power Associates 2020 Leadership Award

Michael E. Mauel, Professor of Applied Physics, received the 2020 Leadership Award from the Fusion Power Associates (FPA) for his outstanding leadership qualities. The FPA Board recognized the leadership he has provided over several decades to both the scientific community and to national fusion program strategic evaluation and planning efforts. In particular, the Board made note of Prof. Mauel's significant role as co-chair of the National Academies 2018 study, *A Strategic Plan for U.S. Burning Plasma Research*, that proposed "the United States should start a national program of accompanying research and technology leading to the construction of a compact pilot plant that produces electricity from fusion at the lowest possible capital cost."

Is Nuclear Fusion Finally Within Reach?

Originally published in Columbia Engineering Magazine, by Ryan Mandelbaum

Fuse two hydrogen atoms, and the result is a massive release of energy akin to the energy that powers the sun and stars. Even better: The process emits only inert helium gas, not greenhouse gases. The challenge: fusion devices must heat their hydrogen plasmas to well over 100 million degrees Celsius—roughly ten times hotter than the temperature of the sun—and keep that plasma controlled and confined.

Dramatic advancements in fusion technology have brought the first tests of sustained fusion energy production within sight, thanks in no small part to the work of applied scientists at Columbia Engineering. Around 2030, an international team of scientists and engineers is scheduled to complete ITER, the world's largest fusion experiment. When fully operational, the scientific and technical achievements embodied in ITER will provide a critical step toward delivering abundant electricity from fusion energy.

Applied scientists at Columbia are currently developing novel techniques to control the hot plasma that will be confined by ITER's strong magnets and in similar but smaller devices such as the High Beta Tokamak–Extended Pulse (HBT-EP) experiment in the Columbia Plasma Physics Laboratory.

A tokamak is a device that confines plasma in a torus surrounded by magnetic field-generating coils, while another current-generating coil runs through its middle. **Gerald Navratil**, Thomas Alva Edison Professor of Applied Physics, and **Michael Mauel**, professor of applied physics, use the HBT-EP to investigate causes of instability in plasmas at high pressures, and then apply magnetic control feedback using advanced algorithms and optical sensors to suppress those instabilities. Their advances at HBT-EP and the DIII-D National Fusion Facility in San Diego have already raised the pressure limit at which tokamaks can stably operate and increased their power production capabilities—work that will be incorporated into ITER once it begins to run at higher pressures.

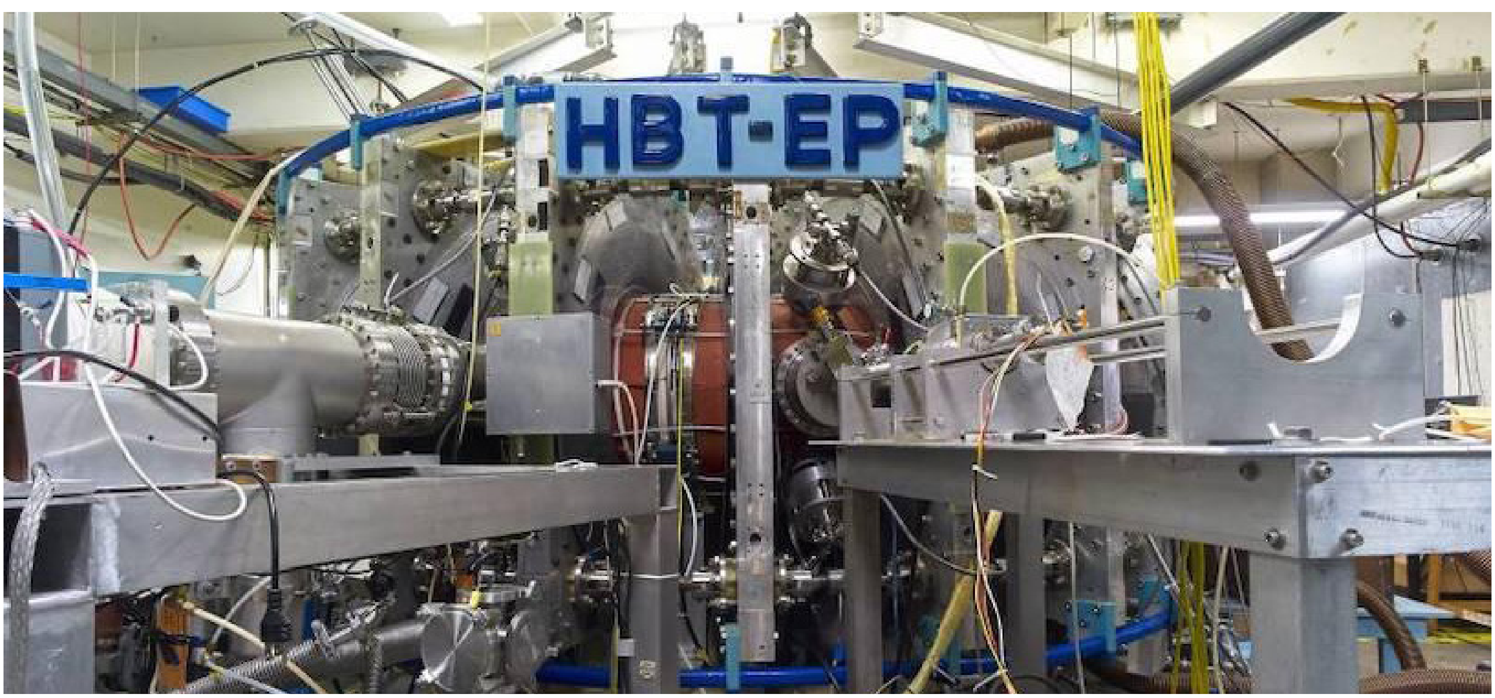
"Imagine a society where we don't have to worry about the supply of energy or the cost of sustainability."

- Prof. Michael Mauel

Scientists create magnetic bottles in other configurations as well. One alternative design, the stellarator, relies on twisted magnetic-field-generating coils surrounding the torus to confine the plasma. Early stellarator experiments lost energy quickly and struggled to reach sufficient temperatures. But in the 1970s and 1980s, **Allen Boozer**, professor of applied physics, developed core mathematics governing magnetic fields and particle behavior in the stellarator, which allowed designers to overcome these problems. Today, Boozer is refining designs to the modern version's magnetic field-generating coils and waste product-removing diverters. The largest stellarator, the Wendelstein 7-X in Germany, is based in part on his research.

Such experiments could ultimately transform the way we create energy in the United States.

"Imagine a society where we don't have to worry about the supply of energy or the cost of sustainability," says Mauel. "We have a lot to do to get there. But the benefit of abundant, clean fusion energy makes the pursuit worthwhile."



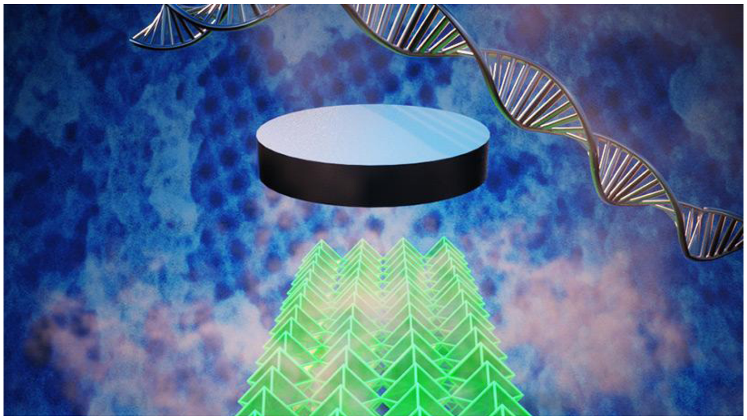


Image: An illustration showing how highly nanostructured 3-D superconducting materials can be created based on DNA self-assembly. Illustration Credit: Brookhaven National Laboratory

Gang Makes 3-D Nanosuperconductors with DNA

Complex 3-D nanoscale architectures based on DNA self-assembly can conduct electricity without resistance and may provide a platform for fabricating quantum computing and sensing devices

By Ariana Manglaviti, jointly issued by the U.S. Department of Energy's Brookhaven National Laboratory and Columbia Engineering

Three-dimensional (3-D) nanostructured materials—those with complex shapes at a size scale of billionths of a meter—that can conduct electricity without resistance could be used in a range of quantum devices. For example, such 3-D superconducting nanostructures could find application in signal amplifiers to enhance the speed and accuracy of quantum computers and ultrasensitive magnetic field sensors for medical imaging and subsurface geology mapping. However, traditional fabrication tools such as lithography have been limited to 1-D and 2-D nanostructures like superconducting wires and thin films.

Now, scientists from Columbia, the U.S. Department of Energy's (DOE) Brookhaven National Laboratory, and Bar-Ilan University in Israel have developed a platform for making 3-D superconducting nano-architectures with a prescribed organization. As reported in the Nov. 10 issue of *Nature Communications*, this platform is based on the self-assembly of DNA into desired 3-D shapes at the nanoscale. In DNA self-assembly, a single long strand of DNA is folded by shorter complementary "staple" strands at specific locations—similar to origami, the Japanese art of paper folding.

"Because of its structural programmability, DNA can provide an assembly platform for building designed nanostructures," said co-corresponding author **Oleg Gang**, professor of chemical engineering and of applied physics and materials, and science leader of the Soft and Bio Nanomaterials Group at Brookhaven Lab's Center for Functional Nanomaterials (CFN). "However, the fragility of DNA makes it seem unsuitable for functional device fabrication and nanomanufacturing that requires inorganic materials. In this study, we showed how DNA can serve as a scaffold for building 3-D nanoscale architectures that can be fully "converted" into inorganic materials like superconductors."

To make the scaffold, the Brookhaven and Columbia Engineering scientists first designed octahedral-shaped DNA origami "frames." **Aaron Michelson**, Gang's graduate student, applied a DNA-programmable strategy so that these frames would assemble into desired lattices. Then, he used a chemistry technique to coat the DNA lattices with silicon dioxide (silica), solidifying the originally soft constructions, which required a liquid environment to preserve their structure. The team tailored the fabrication process so the structures were true to their design, as confirmed by imaging at the CFN Electron Microscopy Facility and small-angle x-ray scattering at the Complex Materials Scattering beamline of Brookhaven's National Synchrotron Light Source II (NSLS-II). These experiments demonstrated that the structural integrity was preserved after they coated the DNA lattices.

"In its original form, DNA is completely unusable for processing with conventional nanotechnology methods," said Gang. "But once we coat the DNA with silica, we have a mechanically robust 3-D architecture that we can deposit inorganic materials on using these methods. This is analogous to traditional nanomanufacturing, in which valuable materials are deposited onto flat substrates, typically silicon, to add functionality."

The team shipped the silica-coated DNA lattices from the CFN to Bar-Ilan's Institute of Superconductivity, which is headed by Yosi Yeshurun. Gang and Yeshurun became acquainted a couple years ago, when Gang delivered a seminar on his DNA assembly research. Yeshurun—who over the past decade has been studying the properties of superconductivity at the nanoscale—thought that Gang's DNA-based approach could provide a solution to a problem he was trying to solve: How can we fabricate superconducting nanoscale structures in three dimensions?

"Previously, making 3-D nanosuperconductors involved a very elaborate and difficult process using conventional fabrication techniques," said Yeshurun, co-corresponding author. "Here, we found a relatively simple way using Oleg's DNA structures."

At the Institute of Superconductivity, Yeshurun's graduate student Lior Shani evaporated a low-temperature superconductor (niobium) onto a silicon chip containing a small sample of the lattices. The evaporation rate and silicon substrate temperature had to be carefully controlled so that niobium coated the sample but did not penetrate all the way through. If that happened, a short could occur between the electrodes used for the electronic transport measurements.

"We cut a special channel in the substrate to ensure that the current would only go through the sample itself," explained Yeshurun.

The measurements revealed a 3-D array of Josephson junctions, or thin nonsuperconducting barriers through which superconducting current tunnels. Arrays of Josephson junctions are key to leveraging quantum phenomena in practical technologies, such as superconducting quantum interference devices for magnetic field sensing. In 3-D, more junctions can be packed into a small volume, increasing device power.

"DNA origami has been producing beautiful and ornate 3-D nanoscale structures for almost 15 years, but DNA itself is not necessarily a useful functional material," said Evan Runnerstrom, program manager for materials design at the U.S. Army Combat Capabilities Development Command Army Research Laboratory of the U.S. Army Research Office, which funded the work in part. "What Prof. Gang has shown here is that you can leverage DNA origami as a template to create useful 3-D nanostructures of functional materials, like superconducting niobium. This ability to arbitrarily design and fabricate complex 3-D-structured functional materials from the bottom-up will accelerate the Army's modernization efforts in areas like sensing, optics, and quantum computing."

"We demonstrated a pathway for how complex DNA organizations can be used to create highly nanostructured 3-D superconducting materials," said Gang. "This material conversion pathway gives us an ability to make a variety of systems with interesting properties—not only superconductivity but also other electronic, mechanical, optical, and catalytic properties. We can envision it as a 'molecular lithography' where the power of DNA programmability is transferred to 3-D inorganic nanofabrication."

Lipson Named 2021 John Tyndall Award Recipient by the Optical Society

Lipson, the first woman to win this award, is honored for her pioneering work in photonics

By Holly Evarts, Originally published by Columbia Engineering

Michal Lipson, Eugene Higgins Professor of Electrical Engineering and professor of applied physics, has been named the 2021 John Tyndall Award recipient by the Optical Society (OSA) and the IEEE Photonics Society. The first woman to receive the award since its establishment in 1987, Lipson was cited for her "fundamental and technological advances in integrated photonic devices."

The award, one of the highest honors in the fiber optics community, recognizes an individual who has made groundbreaking contributions in any area of fiber optic technology. It is named for John Tyndall, a 19th century scientist who made distinguished contributions to physics, particularly his demonstration of total internal reflection in a continuous stream of water.

"I am so honored and grateful to receive this significant award," said Lipson, who will receive the Tyndall Award at OFC 2021 (Optical Fiber Communication Conference and Exhibition), the world's leading conference and exhibition for optical communications and networking professionals, June 6 to 10, 2021, in San Francisco. "This distinction truly recognizes the transformational impact that silicon photonics has had on communications technology."

Lipson has been a pioneer in advancing the field of silicon photonics, a fundamental technology that uses optical rays to transfer data among computer chips and is now considered to be one of the most promising directions for solving major bottlenecks in microelectronics. She investigates the physics and applications of nanoscale photonic structures and is particularly interested in light-confining structures that can slow down, trap, enhance, and manipulate light.

Lipson's research is centered on areas where nanophotonics has a big impact, both fundamentally and technologically. Her main focuses include novel photonic materials and fabrication, silicon photonics and non-reciprocity, nanomagnetism and thermal control, nanophotonics for neuroscience, optomechanics, nonlinear and quantum optics, and sensing and optofluidics. Among her many discoveries is the first silicon photonics GHz modulator for transmitting electronic signals over large distances with low power. Her research interests are constantly evolving to keep up with important trends, and her Lipson Nanophotonics Group now includes expertise in areas ranging from imaging of the brain to energy recycling.

Lipson, who joined Columbia Engineering in 2015, has received extensive honors, including election to the American Academy of Arts and Sciences and the National Academy of Science; the Erna Hamburger Award; the IEEE Photonics Award; the NAS Comstock Prize in Physics; an honorary degree from Trinity College, University of Dublin; the Optical Society's (OSA) R. W. Wood award; MacArthur Fellowship; Blavatnik Award; IBM Faculty Award; and the NSF Early Career Award. In 2020, she was elected OSA 2021 Vice President and will serve as the Society President in 2023.

Lipson Elected 2021 Vice President of The Optical Society

The Optical Society (OSA) has elected Prof. Michal Lipson to serve as the society's 2021 Vice President.

The Optical Society stated, "Lipson's four-year commitment to OSA's Board of Directors consists of serving one year as vice president in 2021, followed by one year as president-elect in 2022, president in 2023 and past president in 2024."

"In the field of silicon photonics, Lipson is a pioneer whose work in tailoring the electro-optic properties of silicon and advancing research and development is world-renowned," said OSA CEO Elizabeth Rogan. "Her contributions to OSA and the optics and photonics community have been extraordinary and the society will continue to benefit from her serving in this key leadership role." (www.osa.org)

https://bit.ly/2JFiW8j

Lipson Wins 2020 Hamburger Prize

Lipson was named the Erna Hamburger Prize Winner 2020 by the Women In Science & Humanities (WISH) Foundation from the École polytechnique fédérale de Lausanne (EPFL).

https://bit.ly/2K3w5Yu

Crunching the Numbers

Research from Electrical Engineering Professors Keren Bergman and Michal Lipson was featured in the *Columbia Engineering Magazine* article, "Crunching the Numbers: Frictionless optical components increase computer performance while lowering energy consumption."

https://bit.ly/37MxJWF

Lipson on All Things Photonics

Lipson was interviewed on the All Thing Photonics Podcast in the episode, "Silicon Photonics in the Fast Lane, Light on a Chip, and 20-Plus Years of Innovation" on September 22, 2020.

https://bit.ly/2Lo7fmT

Lipson Named 2020 Highly Cited Researcher

Lipson was named a 2020 Highly Cited Researcher by Web of Science.

https://bit.ly/3m3NNrY

Top Most Cited *Optics Express* Article

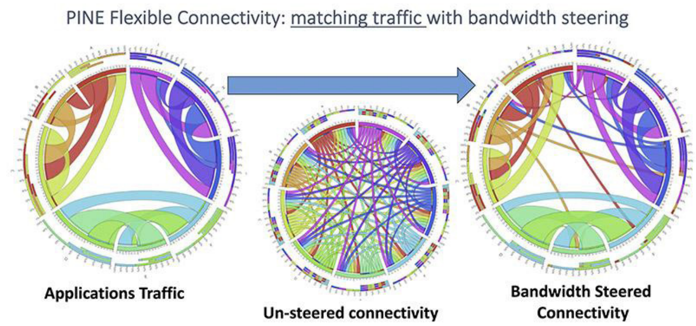
A paper from the Lipson Group, "Nanophotonic lithium niobate electro-optic modulators," is one of the top 15 most cited *Optics Express* articles.

https://bit.ly/37Savyr

New ARPA-E $6M Grant Supports Research on "Green" Data Centers

Profs Keren Bergman, Alexander Gaeta, and Michal Lipson win funding for phase 2 of their project, Photonic Integrated Networked Energy-efficient Datacenters

By Holly Evarts, Originally published by Columbia Engineering



The Photonic Integrated Networked Energy-efficient (PINE) datacenters will steer bandwidth to where it is needed.

With the explosive growth of data analytics applications, high-performance computing (HPC) systems and datacenters are today's critical information infrastructure. Increasing compute performance is essential to meeting future needs, but the scaling systems are highly energy-inefficient. The performance of these systems' parallel architectures is determined by how data is moved among the numerous compute and memory resources, and is dramatically affected by the growing energy consumption associated with the necessary massive data movement.

Professors Keren Bergman**, Alex Gaeta**, and **Michal Lipson** are working to fundamentally address these data movement challenges with new optical computing architectures. Their team, which includes collaborators from MIT, Lawrence Berkeley National Laboratory, SUNY-Polytechnic Institute's College of Nanoscale Science and Engineering, Quintessent Inc., Nvidia, and Cisco Systems, recently won an ARPA-E (Advanced Research Projects Agency–Energy, U.S. Department of Energy) $6 million two-year grant to support phase 2 of their project, "Photonic Integrated Networked Energy-efficient datacenters" (PINE). PINE's goal is to leverage the unique properties of photonics to steer bandwidth to where it is needed rather than over-provisioning, which currently dominates energy consumption.

"Our PINE architecture unleashes the truly revolutionary impact of photonics to create a new paradigm for future ultra-energy-efficient datacenters and HPC high-performance computing systems," said project PI Bergman, Charles Batchelor Professor of Electrical Engineering. "In essence, we are using optical interconnection networks to reduce the system-wide energy consumption of datacenters and HPC systems and make them 'green.'"

The PINE architecture is designed to support diverse emerging data-intensive workloads while optimizing energy efficiency. It maximizes the benefits provided by seamlessly integrating low-power silicon photonic links and large numbers of embedded photonic switches to link together photonic multi-chip modules. PINE's low costs and deep integration capabilities will allow all links to be optical, making possible the availability of each server's resources to all other servers.

Bergman explained, "The sharing of resources presents an abstract concept of the datacenter as a single, unified machine that enables fine-grained allocation of resources and prevents applications from being bottlenecked on a particular resource type. This 'deeply disaggregated' approach gives us much more flexibility."

Phase 2 will build upon the successes of phase 1, which was a two-year $4.4M project that demonstrated the first energy optimized high-bandwidth density silicon photonic links. In phase 2, the team will perform system-level integration consisting of photonic interconnected multi-chip modules with switching flexibility to demonstrate the PINE architecture under realistic workloads. On their Columbia testbed in Bergman's Lightwave Research Lab, the team plans to demonstrate speed-up of machine learning and data analytics applications, executing with substantially reduced energy consumption.

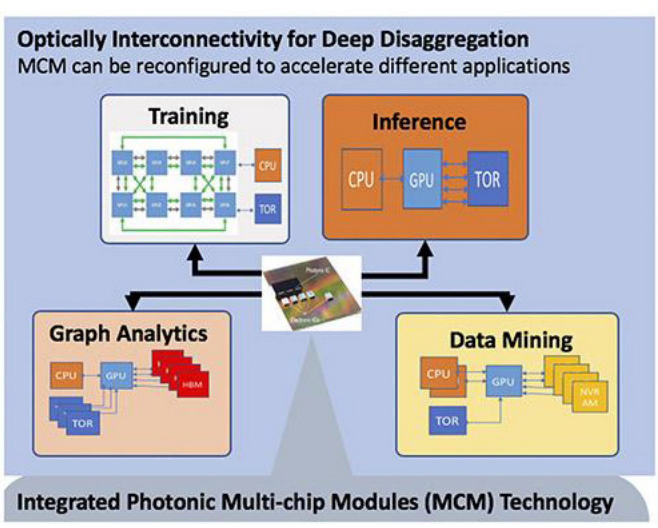


Figure: Representation of the integrated photonic multi-chip modules.

PINE's flexible interconnectivity enables it to assign datacenter/HPC resources to workloads with precise temporal and size accuracies so that only the required amounts of computation power, memory capacity, and interconnectivity bandwidth are made available over the needed time period. This efficient usage of resources reduces the vast amounts of wasted energy consumption of current datacenters, and simultaneously accelerates time to completion of HPC applications.

Working with industry leading partners, including NVIDIA, the leader in GPUs and GPU-accelerated datacenter analytics, Cisco Systems, main developers and suppliers of datacenter networking equipment, together with startup Quintessent, the PINE team is also focused on accelerating technology transfer to practical datacenter and HPC system deployments.

"Our team encompasses the complete stack of leading expertise necessary to drive a full solution with transformational impact on the market deployment of ultra-energy efficient scalable datacenters," Bergman said. "We're very excited to move this forward."

Alexander Gaeta is the David M. Rickey Professor of Applied Physics and Materials Science and Professor of Electrical Engineering

Michael Lipson is the Eugene Higgins Professor of Electrical Engineering and Professor of Applied Physics

Columbia Partners in National Effort to Spur Advancements in Quantum Science

Three University researchers have joined a $115 million DOE-funded center that will pioneer quantum technologies that could benefit national security, pharmaceutical development, and more.

By Carla Cantor, Originally published by Columbia News

Columbia University will team up with scientists from other leading institutions, research laboratories, and industry in an initiative to accelerate quantum research and realize the full potential of quantum-based applications to help tackle real-world challenges.

The University was named a partner in the Co-design Center for Quantum Advantage (C2QA), funded by the U.S. Department of Energy. The new center will receive up to $115 million over five years to develop materials, devices, software, and applications that will serve as a platform for the next-generation of quantum computing capabilities.

C2QA, led by the Long Island-based Brookhaven National Laboratory, is one of five multi-institution research centers created by the DOE Office of Science following the National Quantum Initiative Act of 2018, which launched a $965 million federal program to facilitate and foster quantum innovation. The program aims to enhance national security and economic competitiveness, and retain the nation's global leadership in scientific research and development

"We are excited about working with the talented, interdisciplinary C2QA team on building the tools necessary for the United States to create quantum computers that offer a large computational advantage," said Dmitri Basov, professor of physics and one of three Columbia lead investigators in the C2QA initiative.

Other lead C2QA investigators from Columbia include **Alexander Gaeta** and **Michal Lipson**, professors of applied physics and applied mathematics and of electrical engineering in the School of Engineering.

In all, two dozen institutions and more than 70 lead investigators will participate in C2QA, which will bring together scientists and engineers from a variety of backgrounds. This multidisciplinary expertise and a network of world-class research facilities will enable the team to co-design the solutions needed to build quantum systems that outperform today's computers.

Gaeta said the Columbia team will focus on developing cutting-edge photonics technology to interface with microwave devices in quantum computers and on deploying a revolutionary nano-imaging system to investigate the fundamental physics of materials and circuits employed in these quantum systems.

"We hope our efforts will contribute toward the development quantum systems that will lead to breakthroughs in how we collect, communicate, and process information," Gaeta said. "Ultimately, such systems offer advantages that could revolutionize the design of new chemical compounds, including drugs, and create ultra-sensitive sensors that could not be realized with traditional computers and devices."

Other partnering institutions in C2QA in addition to Columbia include Ames Laboratory, Caltech, City College of New York, Harvard University, Howard University, IBM, Johns Hopkins University, MIT, Montana State University, National Aeronautics and Space Administration's Ames Research Center, Northwestern University, Pacific Northwest National Laboratory, Princeton University, State University of New York Polytechnic Institute, Stony Brook University, Thomas Jefferson National Accelerator Facility, University of California-Santa Barbara, University of Massachusetts-Amherst, University of Pittsburgh, University of Washington, Virginia Tech, and Yale University.

Gaeta & Yu Receive NSF Grant for Quantum Computing

APAM Professors Alexander Gaeta and Nanfang Yu are part of a Columbia team who recently received an NSF funded grant to work on quantum computing - SF Convergence Accelerator Track C: Cloud-Accessible Integrated Quantum Simulator Based on Programmable Atom Arrays.
https://bit.ly/2VZbOWM

NSF Expands Funding for I-CORPS Award

The NSF made an expansion to its award for the tri-university I-CORPS award, of which Professor Chris Wiggins is the Columbia University Principal Investigator.

Since 2013, "NYCRIN" (New York City Regional Innovation Node, nycrin.org) has been an early NSF node in their entrepreneurial I-CORPS program. The NSF program seeks to help science and engineering researchers explore whether their research might be ready to lead to development outside the university, for example, as a patent, or a new technology startup corporation.

Wiggins explains: "This expansion by the NSF speaks to their confidence in this collaboration between Columbia, NYU, and CUNY. NYCRIN has been an early leader in helping university researchers investigate potential applications of their work. We've demonstrated impact on the local New York City region, but also we've influenced the way that other NSF-supported regional innovation nodes conduct their own similar trainings and research programs."

"Nationwide, the activities of this award include working with researchers within universities interested in exploring application of their work, often pairing a faculty member with an advanced graduate student or postdoctoral researcher. These activities are done with researchers at their home institutions. We've been doing this online for nearly a decade, making the transition to distributed process easier. Over the years, we also now have plenty of data from all the university teams who have gone through the I-CORPS training, which allows us to research early indicators of success for a new company, as well as topics such as research on factors influencing entrepreneurial participation of individuals from underrepresented groups."

Wiggins goes on to say, "It has been a very educational program for me as well, not only in learning how to advise new companies remotely, but in learning the basic lessons of the I-CORPS 'lean startup' curriculum. These include transitioning from developing research that's of interest to fellow experts in a sub-field to learning how to build technology people want."

"This idea goes by many names including 'design thinking', or 'talking to strangers', or 'getting out of the building'. But the basic idea is that there's a special kind of research in understanding what people want, which can be difficult when those people are not necessarily within the technologist's sub-field."

"That kind of research can be very useful to university researchers who want to cross the chasm from mastering peer review to building something people want. Doing that research early in the development of a new corporation can help ensure that all of the innovations that top research universities produce can have the largest and broadest impact."

$2M DOE Award to Develop PowerGrid Risk Dashboard

By Holly Evarts, Originally published by Columbia Engineering

Daniel Bienstock

Three Columbia Engineering professors are integrating their expertise in power grids, optimization, and financial engineering with data science techniques to build a risk dashboard to assess and predict risks to the power grid. A $2.06M Performance-based Energy Resource Feedback, Optimization, and Risk Management (PERFORM) contract with the U.S. Department of Energy's (DOE) Advanced Research Projects Agency-Energy will help support their research.

Independent system operators (ISOs) currently use dashboards to track conditions of the electrical grid, including energy loads and the output of renewable and non-renewable energy. None of those dashboards, however, have the capacity to compute and analyze engineering and financial risks to the power grid.

"Power grid operations will need to be driven by new risk-aware methodologies and algorithms in order to properly address new developments, including renewable energy sources and grid-scale storage, as well as financial hedges in energy markets," says the project's principal investigator, **Daniel Bienstock**, Liu Family Professor of Industrial Engineering and Operations Research and professor of applied physics and applied mathematics.

He stresses that it is also critical that power grid participants—providers of generation, balancing capabilities, and storage, along with price-motivated consumers—come to see risk as an essential attribute to be modeled, priced, and accurately accounted for in operational planning.

The researchers plan to create a dashboard that will help ISOs make sound decisions quickly, in time scales ranging from several minutes to a few days, so that they can dispatch available energy to the places most in need of it at any given moment. It will also guide ISOs and market participants towards a better understanding of renewable energy risks, and how to adequately allocate resources for reducing them. In doing so, the risk-assessing dashboard will make the U.S. power grid more efficient and reliable, and facilitate penetration of renewables.

"Our reliance on risk management techniques constitutes a fundamental shift in the practice of power system modeling," says co-PI Agostino Capponi, an associate professor of industrial engineering and operations research. "We are challenging existing practices by bringing operations research methods based on optimization, financial risk analytics, and modern data science techniques into the hard-core engineering domain of power engineering."

The dashboard will rely on stress-testing statistical factor models and newly designed energy asset and systemic risk metrics to continuously track system and market conditions and proactively dispatch available resources to avoid insecure operations.

"To reconcile technical risks identified using these risk metrics, we will leverage financial risk management instruments to construct hedges against losses under severe or complex energy scenarios," notes co-PI Garud N. Iyengar, Tang Family Professor of Industrial Engineering and Operations Research. "We are aiming to inform ISOs how to use renewable, demand, and storage resources for reducing such risk and compensate these resources accordingly. Our second goal is to educate ISOs on the risk versus cost minimization tradeoff to facilitate increased penetration by renewable resources."

The research team includes Bienstock, Capponi, and Iyengar, all at Columbia Engineering and affiliates of the Data Science Institute; Yury Dvorkin, an assistant professor of electrical and computer engineering at New York University; and Michael Cherktkov, a professor of applied mathematics at the University of Arizona.

The Columbia Engineering project is one of 10 recently announced by the DOE, which is giving $25M to PERFORM teams to develop innovative management systems that represent the relative delivery risk of each asset, like wind farms or power plants, and balance the collective risk of all assets across the grid.

"Ensuring the reliability of our nation's critical energy infrastructure and electric grid is of the utmost importance to America's energy security and national security," Under Secretary of Energy Mark W. Menezes said. "Investing in new technologies and systems that minimize risk and bolster the reliability of U.S. energy will allow us to utilize all of our abundant energy resources in a more integrated and secure manner."

The modern grid relies on conventional, bulk power plants to provide the flexibility to operate power systems reliably. In general, these assets can guarantee available capacity, except in rare events like the sudden loss of power. The existing risk management strategy protects against those rare events and aligns well with conventional technologies. There is a need for this strategy to be reassessed due to new technologies and a shift in the power generation mix. That shift includes an increase in intermittent renewable resources, distributed energy resources, and storage technologies. As emerging technologies are deployed, management systems must be able to leverage all capabilities of these new technologies to maintain a cost-effective reliable grid. PERFORM projects address that need by developing methods to quantify and manage risk at the asset level and at the system level for the grid.

Wiggins on Disrupting Disinformation

(continued from page 8)

My initial reaction to disinformation was to think about technological solutions. However, it's more and more clear to me that this is not just a tech problem, but also one that encompasses the norms around the way people use technology and the way society regulates technology. Disinformation is an existential threat to democracy, and there's just so much we do not understand about the long-term impacts on belief systems and social norms. I don't think the solution is going to be a quick tech fix, but instead a long-term investment in, among other things, changing the way academics do research, and changing the way we educate future technologists about the impact and ethics of their work.

Speaking of, you and your colleagues note that research into disinformation can't be effective until efforts there are much more coordinated. But right out of the gate, a major obstacle to that coordination lies in how universities conduct such human-centered research. Different institutions interpret the ethical guidelines governing human research in substantially different ways. Considering that these guidelines were designed long before the advent of social media, does tackling this problem first require a major update for the digital age?

The Belmont Report, which governs how academics conduct human-centered research, was issued in 1978. Our current disinformation ecosystem operates in a very different context, one in which the information platform companies now shape the landscape—in a way, their product decisions change the underlying effects we researchers wish to study.

Because of this, we can't simply rely on observational data—to truly understand the impact disinformation has on individuals and on society, we need to design interventions and experiments and to collect data on real people and their communications. But that must be done in a way that balances the insights of careful research with an appropriate respect for rights, harms, and justice in the digital age. For instance, how do we respect privacy and consent in the context of using a public Twitter post? How do we assess justice and harms in research on facial recognition?

The information security community faced a similar dilemma a decade ago, which led to a new commission helping researchers understand how information security research can be conducted in a way consistent with society's broader understanding of ethical research. This clears up confusion and doubt by illustrating to researchers, ethical review boards, funders, and policy makers alike how the field can be advanced in a way consistent with ethics. Our paper argues, in part, that a similar consensus would dispel much of the uncertainty that can dissuade disinformation researchers from working to answer crucial questions about effects and causality.

Du's CM3 Group Publications Among SIAM Journals Most Cited Papers

Two papers authored by **Qiang Du**'s CM3 group members and collaborators are among 51 articles listed in *SIAM Journal's* "Top Three Most Cited Papers since 2018" out of the 17 journals published by SIAM.

This list, published in *SIAM News* on November 23rd, included the CM3 group's paper on the mathematics of deep learning, "New Error Bounds for Deep ReLU Networks Using Sparse Grids," which was published in the inaugural issue of the *SIAM Journal on Mathematics of Data Science*. This 2019 study provided a sparse grid based design of deep neural networks (DNN) and showed that such network structure could help lessen the so-called curse of dimensionality.

Another paper on the list, a joint work of Prof. Du and his collaborators, is "Maximum Principle Preserving Exponential Time Differencing Schemes for the Nonlocal Allen-Cahn Equation," published in *SIAM Journal on Numerical Analysis*. The work also motivated further research on time-stepping schemes for more general evolution equations that can preserve physically meaning bounds. A subsequent study by the team will be published in *SIAM Review* in 2021. **https://bit.ly/3mclGHu**

APAM in the News

Michael Mauel, Professor of Applied Physics, was featured on CBS News, "Assembly begins on ITER, a massive scientific project that seeks to replicate the sun's fusion power here on Earth," July 28, 2020. **https://cbsn.ws/37UU2tl**

Adam Sobel, Professor of Applied Physics and Applied Mathematics and of Earth and Environmental Sciences, was featured in several media outlets to discuss climate change, Hurricane Laura, and democracy.

Video: "Tracking Threats as Climate Science, Law & Politics Collide"
Sustain What? Earth Institute Live, Oct. 23, 2020
https://bit.ly/37nyExB

"What science and democracy have in common: us, hopefully"
Bulletin of the Atomic Scientists, Oct. 14, 2020
https://bit.ly/2JQssVV

Video: "Pandemics & Infernos, Presidents & Precedents"
Sustain What? Earth Institute Live, Sept. 16, 2020
https://bit.ly/3r2s5sj

Video: Sobel Discusses Joe Biden's Stance on Climate Change
CNN Newsroom, Sept. 14, 2020
https://bit.ly/2JGvTic

"Our focus has to be on the victims of Hurricane Laura"
CNN, August 28, 2020
https://cnn.it/3n8EpFa

"Does global warming create more hurricanes in the Atlantic?"
The New York Times, August 25, 2020
https://nyti.ms/3gtVSFr

Podcast: Sobel on Hurricane/Tropical Storm Isaisas
Bryan Norcross Podcast, August 4, 2020
https://spoti.fi/3qKiC8X

"Hurricane Makes Landfall in North Carolina"
The New York Times, August 3, 2020
https://nyti.ms/2JKxgwl

Okawachi Elected Optical Society Fellow


Yoshi Okawachi

APAM Research Scientist **Yoshi Okawachi** was elected a fellow of The Optical Society (OSA) "for pioneering contributions to slow light based on stimulated scattering and chip-based optical frequency combs."

"OSA Fellows are members who have served with distinction in the advancement of optics and photonics. Fellows are selected based on several factors, including contributions to education, research, engineering, business and the community." (www.osa.org)

Dr. Okawachi, who works in Prof. Alexander Gaeta's Quantum and Nonlinear Photonics Group, researches optical frequency comb generation in silicon-based waveguides and microresonators, coherent computing based on degenerate optical parametric oscillation in microresonators, parametric nonlinear interactions in photonic devices, slow light, and all-optical signal processing using space-time duality techniques. He received his PhD in Applied Physics from Cornell University in 2008, was named a 2017 OSA Ambassador, and received the 2017 Tingye Li Innovation Prize.

Marvel is Faculty Member in New Climate & Society MA Program


Kate Marvel

Kate Marvel, APAM Associate Research Scientist at the NASA Goddard Institute for Space Studies (GISS), is a faculty member in the new MA in Climate and Society program at Columbia University. It is "a 12-month interdisciplinary graduate program that trains professionals and academics to understand and address the impacts of climate variability and climate change on society and the environment. Through classes and research, students gain knowledge in both climate and social sciences as they relate to climate." **https://climatesociety.ei.columbia.edu/**

Gentine Named Worzel Professor of Geophysics

Pierre Gentine, professor in the Earth and Environmental Engineering and Earth and Environmental Sciences, has been named Maurice Ewing and J. Lamar Worzel Professor of Geophysics in the Department of Earth and Environmental Engineering and Professor of Earth and Environmental Sciences. His appointment, effective January 1, 2021, recognizes his "outstanding research scholarship, teaching, service and leadership in his field and at Columbia Engineering," wrote Dean Mary Boyce and Vice Dean Shih-Fu Chang. Gentine was a "Chu" professor of applied mathematics in the APAM Department from 2009-2011.

His research is aimed at improving simulations of changes in the tropical carbon and hydrologic cycles induced by anthropogenically induced changes such as deforestation and CO2 increase, better predictions of rainfall across multiple temporal and spatial scales and especially better simulations of the forecasting of rainfall and radiation (through cloud cover changes) at the land surface, and enhancement of our predictions of ecosystem responses to droughts and climate extremes, which are expected to become more frequent as climate change progresses. These areas add significantly to the objectives of the department and the School in our efforts to advance engineering and scientific understanding and action to address sustainability and our climate future. Specifically, his research has targeted better understanding of the movement, availability, and quality of water throughout the Earth, on scales ranging from individual rivers and watersheds to the entire globe.

He received his undergraduate degree from SupAéro, the French National Aeronautical and Space Engineering School in Applied Mathematics in Toulouse, France. He obtained a MSc and PhD in civil and environmental engineering from Massachusetts Institute of Technology (MIT) in 2006 and 2010, respectively. As noted, Gentine then had the prestigious limited-term assistant professorship of applied mathematics in APAM from 2009-2011.

Faculty News, continued

Gang Paper Featured on Cover of *Nature Materials*

Research from Professor Oleg Gang and colleagues, "3D nanomaterial crystals with DNA frames," was featured on the cover of *Nature Materials*, Volume 19, Issue 7, July 2020. Prompted by advances in the programmability of DNA nanostructures and their hybridization, the complexity of nanomaterial lattices guided by DNA continues to increase. Read more at: https://go.nature.com/376B97G

Billinge Applies Data Science to Scientific Domains

Research from Professor Simon Billinge and colleagues was published in the article, "Active Reaction Control of Cu Redox State Based on Real-Time Feedback from In Situ Synchrotron Measurements," in the Journal of the *American Chemical Society*.

Abstract: We achieve a target material state by using a recursive algorithm to control the material reaction based on real-time feedback on the system chemistry from in situ X-ray absorption spectroscopy. Without human intervention, the algorithm controlled O_2:H_2 gas partial pressures to approach a target average Cu oxidation state of 1+ for γ-Al_2O_3-supported Cu. This approach represents a new paradigm in autonomation for materials discovery and synthesis optimization; instead of iterating the parameters following the conclusion of each of a series of reactions, the iteration cycle has been scaled down to time points during an individual reaction. Application of the proof-of-concept illustrated here, using a feedback loop to couple in situ material characterization and the reaction conditions via a decision-making algorithm, can be readily envisaged in optimizing and understanding a broad range of systems including catalysis. Read more at https://bit.ly/38bcZrE

Scant Evidence for a Volcanically Forced Winter Warming Over Eurasia Following the Krakatau Eruption of August 1883

Research from Prof. Lorenzo Polvani and Prof. Suzana Camargo was published in the article, "Scant evidence for a volcanically forced winter warming over Eurasia following the Krakatau eruption of August 1883," in *Atmospheric Chemistry and Physics*.

Abstract: A recent study has presented compelling new evidence suggesting that the observed Eurasian warming in the winter following the 1992 Pinatubo eruption was, in all likelihood, unrelated to the presence of volcanic aerosols in the stratosphere. Building on that study, we turn our attention to the only other low-latitude eruption in the instrumental period with a comparably large magnitude: the Krakatau eruption of August 1883. We study the temperature anomalies in the first winter following that eruption in detail, analyzing (1) observations, (2) reanalyses, and (3) models. Three findings emerge from our analysis. First, the observed post-Krakatau winter warming over Eurasia was unremarkable (only between 1σ and 2σ of the distribution from 1850 to present). Second, reanalyses based on assimilating surface pressure alone indicate the existence of very large uncertainties, so much so that a Eurasian cooling is not incompatible with those reanalyses. Third, models robustly show the complete absence of a volcanically forced Eurasian winter warming: here, we analyze both a 100-member initial-condition ensemble and 140 simulations from Phase 5 of the Coupled Model Intercomparison Project. This wealth of evidence strongly suggests that, as in the case of Pinatubo, the observed warming over Eurasia in the winter of 1883–84 was, in all likelihood, unrelated to the Krakatau eruption. This, taken together with a similar result for Pinatubo, leads us to conclude that if volcanically forced Eurasian winter warming exists at all, an eruption with a magnitude far exceeding these two events would be needed to produce a detectable surface warming. Read more at https://bit.ly/2Wl5PeV

Contributing Authors

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We'd love to hear from you and stay connected! Follow us on social media and please send your news and updates to **apam@columbia.edu**

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