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The Fu Foundation School of Engineering and Applied Science

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# APAM NEWS

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

Dear APAM Family:

It has been a wonderful term for APAM!

In this issue, we highlight the research and entrepreneurship achievements of our undergraduate students; several were honored for their efforts (James Borovilas, Joseph Lee, Marco Andrés Miller). It also highlights our burgeoning interactions with APAM alumni.

We present new APAM research, ranging from that in atmospheric science and climate change, nano- and catalytic materials, and porous polymers, and to the upcoming work on quantum science. Faculty ran very successful on-campus workshops on coastal flooding (Kyle Mandli) and on fusion (Gerald Navratil). Adam Sobel testified before Congress on extreme weather.

We are so proud that several of our faculty received awards and other recognitions this term (Siu-Wai Chan, Qiang Du, Alexander Gaeta, Michal Lipson, I.C. Noyan, Lorenzo Polvani, Latha Venkataraman, and Renata Wentzcovitch)!

The APAM community also fondly remembers the life of our friend and colleague of many years, Jimmy Florakis.

With best wishes for a productive and brilliant new year!

Best,
Irving P. Herman
Chair, APAM

**Image: Dr. Rei Chemke and Prof. Lorenzo Polvani provide new evidence on the reliability of climate modeling. See page 9 for more details. Image credit: NASA**

## OTREC Atmospheric Science Field Campaign

**Prof. Adam Sobel**, along with APAM atmospheric science graduate students, **Melanie Bieli** and **Zane Martin**, took part in the NSF-sponsored Organization of Tropical East Pacific Convection (OTREC) field campaign in August and September, which was conducted by an international team of atmospheric scientists and based in Costa Rica and Colombia.

A field campaign is a coordinated scientific effort to take targeted measurements over a specific period, to answer questions that can't be answered using data from the routine global operational network. In OTREC, the primary platform is an airplane, the National Center for Atmospheric Research GV (pronounced "gee five") whose primary instruments in this instance are a downward-pointing cloud radar and a large number of dropsondes (essentially the same as radiosondes, but without the balloon, so that they fall down from the plane instead of rising up from the ground). The aircraft observations are being supplemented by additional radiosonde launches and other surface-based observations from several sites in Costa Rica and Colombia.

The goal of OTREC is to better understand atmospheric convection – tall systems of rain-producing clouds – on both sides of Central America, over both the eastern Pacific and western Caribbean. At these longitudes, the sea near and south of the equator is typically quite cold relative to the rest of the Tropics, but very warm a bit further north (such as near Liberia, Costa Rica, where the largest group of OTREC scientists is based). The strong spatial contrast in sea surface temperature between these two adjacent regions is unique in the Tropics, and provides an ideal environment to test hypotheses about what controls the convection and associated rainfall in the intertropical convergence zone (ITCZ), or climatological belt of rainy weather, as well as the weather systems that pass through it. Yet there are very few in situ atmospheric measurements made in this region, due to the absence of land masses, so OTREC will fill an important gap during this special two-month period. The lessons learned will help us understand both the day-to-day weather and the long-term climate of this region and, by extension, the globe.

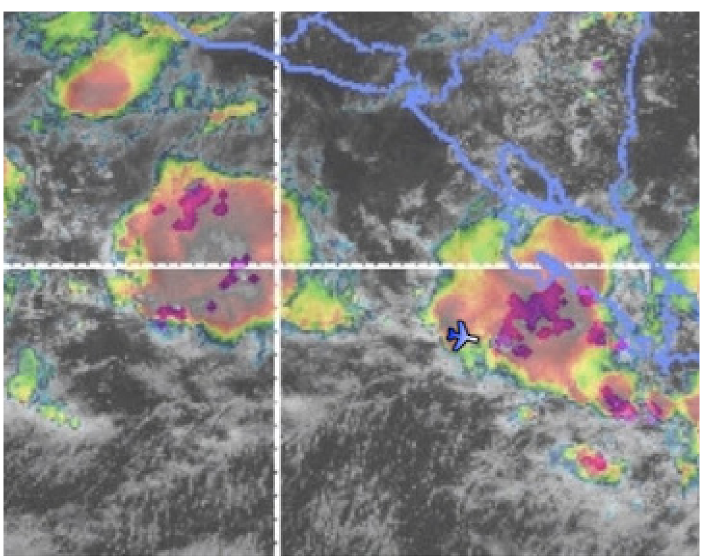


**Image: Combined visual and infrared satellite image showing NCAR GV position at 10:25 local time (1625 UTC). Purple crosses are lightning flashes. (Adam Sobel)**

## Field Report from Melanie Bieli


**Melanie Bieli & the NCAR G-V**

I arrived in Costa Rica last Sunday, three days after defending my PhD thesis. Since then, I have tried to make weather forecasts for the OTREC operations region, I got excited when thunderstorm were rolling in and their downdrafts brought some much anticipated cool gusts, I had fun monitoring our first research flight form the ground and sifting through the incoming data, I got to be on a research flight myself, and I brushed up on my cloud naming skills. Plus, of course, I've been bathing in post-defense bliss!

OTREC is my first field campaign - I spent the last few years mostly sitting in front of my laptop, never actually experiencing the warm, moist tropical atmosphere in which tropical cyclones (the subjects of my PhD research) can form. My tools were modeling, theory and statistics, and while I used and processed a lot of existing data, I was never involved in collecting any new data. But after barely a week I think I can already say that I won't regret participating in OTREC! And here's why:

### Science becomes "more real"

Even if I haven't seen a tropical cyclone here, at least I get to see their "natural habitat." Having that direct connection helps build physical intuition and acts like a curiosity booster, it makes me think and ask questions about all aspects of tropical weather (much more so than I would if I were sitting in my office in New York!).

### The zen of watching the weather

I have definitely not reached zen level yet, but paying attention to the weather is exciting and relaxing at the same time - not just watching the weather (no matter how spectacular that can be!), but also learning how numerical weather model output, soundings and satellite images map onto eyeball weather observations.

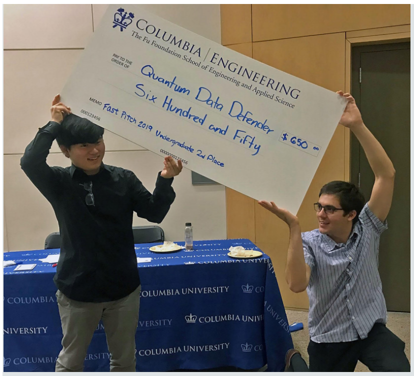
### Appreciate the data!

As a consumer of data, it is quite eye-opening to see how much planning and effort is involved in gathering data in the field. You (or at least I) just don't think about this when your data download script is finally working and the bits are flowing in. Growing your own food makes you savor it more, and the same is true for data!

### People

While OTREC's primary purpose is to advance science, I find that the personal connections I've made add enormous value to my time here. Sometimes it's things like a yoga class or trips to the supermarket that can lead to (scientific) friendships and collaborations. The social value of field campaigns is not something any grant proposal would talk about, but it is as real as their scientific value!

**To learn more about the OTREC field campaign, read Prof. Adam Sobel's & Zane Martin's blog entries at: https://bit.ly/2YqrRgt**




## Applied Physics Undergraduates Explore Entrepreneurship & Win 2nd Place in Fast-Pitch Competition

Entrepreneurship and Innovation in applied physics was the theme for this semester's Applied Physics Undergraduate Seminar. Applied physics majors from the Classes of 2020 and 2021 met each week to learn from alumni, faculty, and entrepreneurs how high-tech ideas can move from the lab to become successful companies.

This year's seminar included presentations from **Dr. Richard Post** (Applied Physics Ph.D. 1973), who co-founded and served as CEO of Applied Science and Technology (Astex) - a leading maker of equipment for semiconductor and thin film production; Dr. Don Smith, who co-founded Energetiq Technology, Inc., maker of the world's brightest source of ultra-violet light; and Dr. Bob Mumgaard, CEO of Commonwealth Fusion Systems (CFS), the newest and largest private company advancing high-field superconducting technology for fusion energy. From Columbia University, the students heard from Professors **Chris Wiggins**, **Nanfang Yu**, **Michal Lipson**, and **Michael Mauel**, who organized this year's seminar.

In addition to hearing from successful entrepreneurs, each senior created a start-up concept, researched their idea, and presented their start-up concept to their classmates. After several weeks of discussions and refinement, students organized into three teams and developed three 60-second "fast-pitch" presentations and business plans for the Columbia Fast Pitch Competition 2019. Fast Pitch is Columbia Engineering's campus-wide annual elevator pitch competition where teams of both graduate and undergraduate students have 60 seconds to sell their business ideas to a panel of judges to win up to $5,000 for your idea.

The three teams from Applied Physics at this year's Fast-Pitch Competition were:

Quantum Data Defender (Student Team: **Joseph Lee** and **James Borovilas**) licenses guaranteed secure data transmission using a scheme built upon entangled photons and cesium based quantum repeaters.

Drone Zone (Student Team: **Alex Herron, Marco Andrés Miller, Xuxin Zhang,** and **Isaac Ruble**) provides accurate and up-to-date water and snow resource data measured by a fleet of drones equipped with remote sensors.

HyperGlass (Student Team: **Sunand Raghupathi, Zicheng Liu,** and **Unique Divine**) integrates and markets a computer without a screen: combining wearable AR glass separated from the computer and/or smartphone for a "cool fashionable design" for portable computing.

All three presentations from Applied Physics were outstanding and well-presented in 60 seconds to a panel of six judges from the worlds of business and finance. Special congratulations go to Quantum Data Defender, presented by **Joseph Lee** and **James Borovilas**, who were awarded the 2nd Place Undergraduate Prize and $650.00. (See photo above)

## Liu Wins American Crystallographic Association Student Presenter Award

**Applied Physics PhD candidate, Chia-Hao (Timothy) Liu, from Prof. Simon Billinge's lab, won a prestigious student presenter award at the annual meeting of the American Crystallographic Association in Covington, Kentucky. Liu received the Margaret C. Etter Student Lecturer Award for his presentation on the interdisciplinary paper, "Exploring the symmetry encoding in atomic pair distribution functions (PDF) with convolutional neural network (CNN)." Other authors on the paper included APAM alumnus, Dr. Yunzhe Tao ('19 Applied Math), along with Columbia Engineering faculty members Prof. Daniel J. Hsu (Computer Science), Prof. Qiang Du (Applied Math), and Prof. Simon J. L. Billinge (Materials Science & Engineering).**

## Student Spotlight: Zane Martin

Atmospheric science graduate student, **Zane Martin,** traveled to Trieste, Italy, this summer to attend the 2nd International Centre for Theoretical Physics Summer School on Theory, Mechanisms and Hierarchical Modelling of Climate Dynamics. Martin commented, "The school focused on convective organization and aggregation in radiative-convective equilibrium models and observations: a fast-evolving research area in atmospheric science with a myriad of possible applications for improving our understanding of the atmosphere and perhaps even how the climate will change as the world warms." In September, Martin then traveled to Costa Rica for with Prof. Sobel and Melanie Bieli for the OTREC Field Campaign, intensively researching convection in the east Pacific and western Caribbean.

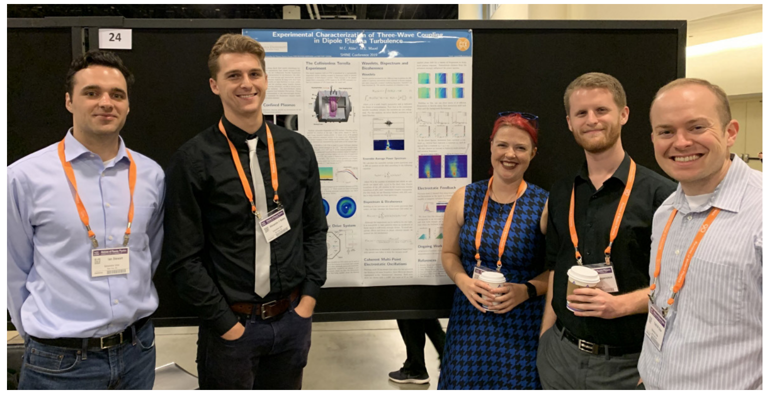

After Martin receives his PhD sometime next year, he plans to continue his atmospheric research and start teaching the next generation of climate scientists. Over the long run, he hopes to contribute to both understanding and mitigating global warming. "To the extent that it's appropriate as a scientist, I'd love to participate more directly at the national or international level on work relating to limiting the impacts of climate change," he said. "Prof. Sobel is a role model in that regard, connecting with many different aspects of the field, seeing problems from different dimensions, and communicating with a wide range of audiences. He's helped me recognize the large role academics can play beyond writing papers and publishing."

## Columbia Researchers Attend Meeting of the APS Division of Plasma Physics

by Prof. Michael Mauel

Students, scientists, and faculty presented their research at the 61st Annual Meeting of the APS Division of Plasma Physics, October 21-25, 2019. This year's meeting was located in Fort Lauderdale, Florida, where over 2,500 scientists from around the world gathered to present and learn the latest research in plasma physics and fusion science.

A highlight of the meeting was **Dr. Andrea Garofalo** (Ph.D. Columbia 1997) who presented the opening plenary lecture titled "Understanding the MHD challenges for ITER Q=10 operation at reactor relevant conditions." Garofalo reported the recent discovery how controlling the outer shape of the toroidally-confined plasma increases the expected fusion power output from ITER, the world's largest experiment.



**(left-right) Ian Stewart, Alex Battey, Mel Abler, Alex Saperstein, & Todd Elder**

Another highlight was the presentation by **Marco Andrés Miller** (APAM 2020) who presented his summer research results in collaboration with the Princeton Plasma Physics Laboratory. The title of Marco's presentation was "A machine learning algorithm for the nonlinear Fokker-Planck-Landau collision operator in XGC." Marco showed how to use machine learning to create a fast and efficient computer simulation of plasma collisions for fusion experiments. More than 100 undergraduate students presented their research at the APS Meeting, and Marco Andrés Miller was awarded a "Best Undergraduate Poster Award" from Prof. David Newman (University of Alaska) and chair of the APS Division of Plasma Physics.

**Marco Andrés Miller & Prof. David Newman**

Many other students and scientists presented their research results, including **Todd Elder** "Magnetic nulls in interacting dipolar fields", **Mel Abler** "Experimental Characterization of Three-Wave Coupling in Dipole Plasma Turbulence", **Ian Stewart** "Investigation of turbulence and fast rotating MHD during biased H-mode on HBT-EP", **Alex Saperstein** "Characterizations of Scrape-Off-Layer Currents on HBT-EP Using Movable, Current Sensing Tiles", **Yumou "William" Wei** "High Speed Videography on Plasma Periphery in HBT-EP", **Boting Li** "Tangential Extreme Ultraviolet and Soft X-Ray (EUV/SXR) Diagnostic System on the HBT-EP Tokamak", **John Brooks** "Mode suppression in HBT-EP using active feedback and a quadrature bias probe array", and **Dr. Jeff Levesque** (Ph.D. Columbia 2012) "Active Control of Kink Modes Using a Non-magnetic, Extreme Ultraviolet Sensor Array".

**Student & Alumni News continues on pages 14-16**

## Alumni Reports

**Originally published by *Columbia Engineering Magazine***

**Sean Blanton** (BS '91, Applied Physics) is moving to Citadel, LLC, after four years at proprietary trading startup Radix Trading, LLC. Both firms are in Chicago.

**Xinpei Geng** (MS'19, Materials Science & Engineering) writes: "After graduating from Columbia, I joined Huawei as a chip engineer—it's a critical time because the company's facing a lot of pressure from the US government. I'm now working on the development of a CPU chip for servers, and traveling is a part of my life. I do believe what I learned from Columbia can help me go through all these difficulties."

**Ed Gerstenhaber** (BS '68, Nuclear Engineering) writes: "I recently finished my first season working as an AARP volunteer doing tax returns for seniors and low income people. I am in my ninth year as a 'standardized patient' (definition on Google if you're curious) for the University of Pittsburgh School of Medicine. And then there's biking!"

**Anthony Gong** (BS '15, Applied Mathematics) is enrolled in a master of science program.

**Manju Prakash** (PhD '85, Applied Physics) writes: "I was invited to participate in the 2019 summer research program on turbulent life of cosmic baryons at the Aspen Center for Physics in Aspen, Colorado. This provided me an opportunity to investigate the history of the early universe using primordial gravitational wave signals generated by the hydro-magnetic turbulence excited in the early universe, potentially carrying imprints of the processes that took place microseconds or less after the universe was born. The meetings took place in the scenic mountains where participants focused on exploring new ideas and forging collaborations for future research in plasma turbulence."

**William Quirk** (BS '67, Applied Physics) was elected in 2018 to his fourth two-year term in the California State Assembly. He represents Southern Alameda County in the East San Francisco Bay Areas. He is running again in 2020.

**Andrew Salthouse** (BS' 69, Nuclear Engineering) retired in 2016 after 40 years as a lab assistant and junior analyst.

**Changmin Shi** (MS '19, Materials Science & Engineering) writes: "Since graduating from Columbia, I have been a PhD student at the Department of Materials Science and Engineering at the University of Maryland, College Park. Columbia Engineering indeed cultivated in me the critical thinking and problem solving skills that I need to pursue my PhD and future career goals. I would like to take this opportunity to give thanks to materials science and engineering professors at Columbia for giving me such excellent skills and igniting my passion for my research in the future."

**Robert Siegfried** (MS '78, Metallurgy) writes: "I'm still a full professor at Adelphi teaching computer science. My son, Jason, is graduating from Adelphi in computer science (of course) this January. My wife, Kathy, Jason, and I continue to live in Oceanside on the south shore of Long Island after weathering Superstorm Sandy."

**Jingyi Zhuang** (MS '19, Materials Science & Engineering) entered the Columbia Department of Earth and Environmental Sciences.

## Sobel Testified Before Congress on Extreme Weather

**Originally published by *Columbia Engineering***

**Adam Sobel** testified before congress on September 26, 2019, as part of the hearing on "Understanding, Forecasting, and Communicating Extreme Weather in a Changing Climate." He told the House Science, Space, and Technology Committee that much of the evidence is already in when it comes to linking global warming with increasingly extreme weather.

Sobel, a professor of applied physics and applied mathematics, also heads up Columbia University's Initiative on Extreme Weather and Climate. The *State of the Planet* (news from the Earth Institute) recapped the testimony, in which Sobel gives a clear picture of current understanding of the connection between climate change and extreme weather events like hurricanes and heat waves. From their piece:

*He described heat waves as the best understood type of extreme weather event, and said research linking heatwaves to global warming is substantive. "When any heat wave occurs today, it is likely that global warming made it more likely, more intense or both."*

*He also conveyed science's understanding about the way climate change is impacting the intensity and frequency of hurricanes.*

*"Hurricane risk is increasing due to climate change," he said. "Storm surge-driven coastal flooding is certainly becoming worse due to sea-level rise. We know little, though, about how hurricane frequency — the total number of storms per year — changes with warming."*

Sobel also touched on impacts to tornadoes, storm surge flooding, and coral reefs.

## Celebrating Faculty Excellence

APAM faculty members were honored at the 2019 Faculty Excellence celebration hosted by Columbia Engineering Dean, Mary Boyce, as the start of the fall semester.

**Michal Lipson**, the Higgins Professor of Electrical Engineering and Professor of Applied Physics, was recognized for her election to the National Academy of Sciences (NAS), for receiving the NAS Comstock Prize in Physics, and for winning the 2019 Institute of Electrical and Electronics Engineers (IEEE) Photonics Award.

**Alexander Gaeta**, the David M. Rickey Professor of Applied Physics and Materials Science and Professor of Electrical Engineering, was recognized for winning the 2019 Optical Society Charles Hard Townes Award and for his election as an IEEE Fellow.

**I.C. Noyan**, Professor of Materials Science and Engineering and of Earth and Environmental Engineering, was recognized for winning the 2019 Hanawalt Award.

**Latha Venkataraman**, Vice Provost for Faculty Affairs, was recognized as the new Lawrence Gussman Professor of Applied Physics and Professor of Chemistry.

**Siu-Wai Chan**, Professor of Materials Science and Engineering, was recognized for her election as an American Physical Society (APS) Fellow.

**Kui Ren**, Professor of Applied Mathematics, received tenure.

**Kyle Mandli** was recognized for his promotion to Associate Professor (tenure track) of Applied Mathematics.

## Recent Faculty Achievements

### Du Named 2020 AMS Fellow

**Qiang Du, the Fu Foundation Professor of Applied Mathematics, was named a 2020 Fellow of the American Mathematical Society (AMS). The AMS Fellows program "recognizes members who have made outstanding contributions to the creation, exposition, advancement, communication, and utilization of mathematics."**

### Gaeta Named Highly Cited Researcher

**Alexander L. Gaeta, the David M. Rickey Professor of Applied Physics and Materials Science and Professor of Electrical Engineering, was recently named a 2019 Highly Cited Researcher by the Web of Science Group. Fewer than 0.1%, of the world's researchers, across 21 research fields, have earned this exclusive distinction.**

### Mandli Named to NCAR Interdisciplinary Program

**Kyle Mandli, Associate Professor of Applied Mathematics, was named to a new interdisciplinary program from the National Center for Atmospheric Research (NCAR). He is one of nine early career faculty members from U.S. universities chosen to work with NCAR scientists to investigate the impact of climate change and natural hazards on coastal areas with the goal of building greater societal resilience. Mandli, an expert on storm surge, will focus on creating better forecasting and predictive capabilities for coastal flooding due to storms, while other researchers will look at topics ranging from human health to marine resource management.**

### Sobel Presented at Oasis Conference

**Adam Sobel, Professor of Applied Physics and Applied Mathematics and of Earth and Environmental Sciences, spoke on "Current risk level for Tropical Cyclone North America (TCNA)" at the Oasis Conference - The good, the bad, and the ugly in Hatfields, London.**

### Weinstein - NSF Distinguished Lecture Series

**Michael Weinstein, Professor of Applied Mathematics and Professor of Mathematics, was invited to speak at the NSF Distinguished Lecture Series in Mathematical and Physical Sciences in January 2020 at their headquarters in Alexandria, VA. He will give a talk "On the mathematical theory of graphene and its artificial analogues."**

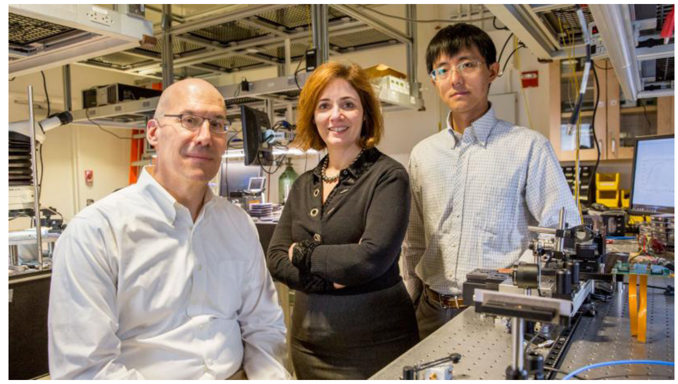
### Wentzcovitch Elected Chair of APS Division of Computational Physics

**Renata Wentzcovitch was elected Chair of APS Division of Computational Physics for 2019-2020. She is a Professor of Materials Science and Engineering in the Applied Physics and Applied Mathematics Department, Earth and Environmental Sciences, and Lamont-Doherty Earth Observatory at Columbia University. Her research is devoted to computational quantum mechanical studies of materials at extreme conditions, especially planetary materials. She addresses electronic, structural, and vibrational properties from a fundamental and inter-related perspective.**

## Gaeta, Lipson, and Yu Win NSF Grants to Advance Quantum Research

**by Holly Evarts, originally published by *Columbia Engineering***

*Researchers propose a new approach—using a photonic-chip platform based on silicon nitride—to attain highly entangled photon states, essential to quantum computing and technology*



**Professors Alexander Gaeta, Michal Lipson, and Nanfang Yu**

Columbia Engineering researchers, collaborating with colleagues at the University, have won two grants from the National Science Foundation (NSF) for research that has the potential to transform quantum research. The Columbia projects are among the first to be chosen for federal funding for quantum research since the announcement of the National Quantum Initiative Act, signed into law by President Trump last December. Out of 200 pre-proposals for this funding opportunity, only 19 grants were awarded by the NSF.

Co-PIs **Alexander L. Gaeta** and **Michal Lipson** (both Applied Physics and Applied Mathematics and Electrical Engineering), together with Ana Asenjo-Garcia (Physics), won a four-year, $1.44 million grant for their proposal, "All-Photonic Quantum Network." Their proposal takes a new approach to attaining highly entangled photon states by using a photonic-chip platform based on silicon nitride.

Large-scale connections among many particles at the quantum level, known as qubit entanglement, are essential for the development of quantum computers and networks, and applications in quantum computing, communications, and sensing. Current, intensely studied approaches to generate qubit entanglement use neutral atoms, ions, or superconducting circuits, and rely on strong qubit-qubit interactions. But researchers have found that successfully entangling these matter-based qubits has been very challenging because the entire system is highly sensitive to any environmental perturbations or losses and thus must be completely isolated for a time long enough to process and perform measurements on the qubits. The proposed system is based on silicon nitride, for which Lipson's group has demonstrated the lowest losses for any chip-based platform.

"If we are successful, the techniques and devices we develop will be revolutionary, as large multipartite-entangled, or cluster, states are a tremendous resource for universal, measurement-based quantum computers where computation occurs by simply making single-qubit measurements," says Gaeta, David M. Rickey Professor of Applied Physics and of Materials Science and professor of electrical engineering.

**"Our project could open the door to the realization of all-photonic quantum networks and repeaters, thus connecting quantum devices, instruments, and machines, that are critical for enabling quantum information technology"**

**- Michal Lipson**

The main bottleneck to realizing a one-way quantum computer has been the difficulty in generating these large cluster states and doing so with reasonable probability. To address these challenges, Columbia's team brings world-class expertise in theoretical quantum optics (Asenjo-Garcia), experimental quantum and nonlinear photonics (Gaeta), and chip-based nanophotonics (Lipson). They plan to create an integrated photonics platform that can generate highly entangled states of light at higher rates and with higher fidelity that what has previously been demonstrated. These highly entangled states form scalable photonic building blocks for generating cluster states for quantum computers and quantum networks.

The silicon-nitride photonic platform has significant advantages over other materials such as silicon by offering record low losses. The rate of entangled photon generation will be dramatically increased by leveraging recent advances in massively parallel photonic on-chip devices that can generate and convert photons within a well-defined spectral grid with high efficiency, and can store light on-demand for timescales on the order of hundreds of nanoseconds with high efficiency, using massively parallel micron-size devices.

"Our project could open the door to the realization of all-photonic quantum networks and repeaters, thus connecting quantum devices, instruments, and machines, that are critical for enabling quantum information technology," says Lipson, Eugene Higgins Professor of Electrical Engineering and professor of applied physics. "For example, such a scheme would enable measurement-based universal computation, where computation occurs by performing single-qubit measurements on a highly-entangled resource state."

A second NSF grant was awarded to a proposal put forward by Principal Investigator Sebastian Will (Physics), and Co-PIs Asenjo-Garcia (Physics) and **Nanfang Yu** (Applied Physics and Applied Mathematics). One of two that received a "high priority" ranking, the theoretical ideas behind the project—"Enhancing Quantum Coherence by Dissipation in Programmable Atomic Arrays"—constitute a paradigm shift in the fundamental understanding of light-matter interactions. The convergence between Will's experimental expertise with ultracold atomic systems, Asenjo-Garcia's novel theoretical ideas, and the groundbreaking hologram technology developed by Yu gives the team an edge in the race to transform light-matter interfaces. If the team can successfully achieve its goal, the result could redefine the limits of quantum applications and devices, including optical lattice clocks, quantum sensors, and quantum memories. *(More details about this grant is available on page 8.)*

The National Quantum Initiative Act has created a multiagency federal program to accelerate quantum research and development for economic and national security. It allocates $1.2 billion in government funds to advance the application of quantum physics to real-world problems in the United States over the next five years.

"We're excited to be at the forefront of this exciting initiative that will transform quantum science and technology," Gaeta adds. "We hope our work will provide a path to solving computationally complex problems, providing communication security, and enhancing navigation, imaging, and other sensing technologies in ways that are impossible using current, conventional hardware."

## Porous Polymer Coatings Dynamically Control Light and Heat

**by Holly Evarts, originally published by *Columbia Engineering***

*New inexpensive, scalable design takes advantage of the optical switchability of porous polymers; could be used for heating, cooling, and lighting buildings, as well as camouflage applications*

Buildings devote more than 30% of their energy use to heating, cooling, and lighting systems. Passive designs such as cool roof paints have gone a long way toward reducing this usage, and its impact on the environment and climate, but they have one key limitation—they are usually static, and thus not responsive to daily or seasonal changes.

Columbia Engineering researchers have developed porous polymer coatings (PPCs) that enable inexpensive and scalable ways to control light and heat in buildings. They took advantage of the optical switchability of PPCs in the solar wavelengths to regulate solar heating and daylighting, and extended the concept to thermal infrared wavelengths to modulate heat radiated by objects. Their work was published by *Joule*.

"Our work shows that by wetting PPCs with common liquids like alcohols or water, we can reversibly switch their optical transmittance in the solar and thermal wavelengths," says **Jyotirmoy Mandal**, lead author of the study and a former PhD student in the lab of **Yuan Yang**, assistant professor of materials science and engineering. "By putting such PPCs in hollow plastic or glass panels, we can make building envelopes that can regulate indoor temperatures and light."

The team's design is similar to smart windows, but with a higher optical switchability, and is built using simpler, inexpensive materials that could make it implementable at large scales. It builds upon earlier work that demonstrated a paint-like fluoropolymer coating with nano-to-microscale air voids that can cool down buildings. That coating was static, however. "In places like New York, which sees warm summers and harsh winters, designs that can switch between heating and cooling modes can be more useful," says Yang.

The team began their work on optically switching PPCs serendipitously, when Mandal noticed that a few drops of alcohol spilled on a white fluoropolymer PPC turned it transparent. "What we saw was the same mechanism that causes paper to turn translucent when wetted, but at a near-optimal level," says Mandal. "The physics of this has been previously explored, but the drastic switching we saw led us to explore this particular case, and how it can be used."

**Above: The porous polymer coatings, which switch from white to transparent when wetted, can be put into plastic enclosures to make panels that control light and temperatures of buildings.**

A porous material like paper appears white because the air in the pores has a different refractive index (~1) to that of the porous material (~1.5), causing them to scatter and reflect light. When wetted by water, which has a refractive index (~1.33) closer to the material, scattering is reduced and more light goes through, making it translucent. Transmission increases when the refractive indices are closely matched. The researchers discovered that their fluoropolymer (~1.4) and typical alcohols (~1.38) have very close refractive indices.

"So when wetted, the porous polymer becomes optically homogenous," says Yang. "Light is no longer scattered, and passes through — much like it would through solid glass — the porous polymer becomes transparent."

Because of the near-perfect refractive-index matching of alcohols and the fluoropolymer, the team could change the solar transmittance of their PPCs by ~74%; for the visible part of sunlight, the change was ~80%. Although the switching is slower than in typical smart windows, the transmittance changes are considerably higher, making PPCs attractive for controlling daylight in buildings.

The researchers also investigated how optical switching could be used for thermoregulation. "We imagined roofs that are white during the summer to keep buildings cool, and turn black during the winter to heat them," says Yang, "This can greatly reduce air-conditioning and heating costs of buildings."

To test their idea, the researchers put panels containing PPCs on toy houses with black roofs. One panel was dry and reflective, while the other was wet and translucent, showing the black roof underneath. Under sunlight on a summer noon, the white roof became cooler than the ambient air by ~3˚C/5˚F, while the black one became much hotter, by ~21˚C/38˚F.

The team also explored switching in the thermal infrared wavelengths, and observed a novel switching between "icehouse" to "greenhouse" states by wetting infrared-transparent polyethylene PPCs. When dry, the porous polyethylene PPCs reflect sunlight but transmit radiated heat, behaving like an "icehouse". Wetting the PPCs makes them transmit sunlight, and, because typical liquids absorb thermal wavelengths, block radiated heat, like a greenhouse. Because they modulate both solar and thermal radiation, they can regulate heat during both day and night.

"Although obtained simply, the transition is quite unusual compared to switching in other optical systems, and is perhaps the first time it has been reported," says Mandal.

Yang's team also tested other potential applications, such as thermal camouflage and paints that respond to rain. The latter could be used to cool or heat buildings in Mediterranean climate zones and the Californian coast, which see dry summers and rainy winters. The researchers are now looking at ways to scale up their designs, and explore opportunities to deploy and test them at large scales.

"Given the scalability and performance of the PPC-based designs, we are hopeful that their applications will be wide-spread," says Yang, "in particular, we are excited by their potential applications on building facades."

Mandal, who is now doing postdoctoral research as a Schmidt Science Fellow at the University of California, Los Angeles, adds, "We deliberately chose commonly available polymers and simple designs for our work. The goal is to make them locally manufacturable and implementable in developing countries, where they would have the greatest impact."

**Jyotirmoy Mandal, Mingxin Jia, Adam Overvig, Yanke Fu, Eric Che, Nanfang Yu, and Yuan Yang, "Porous Polymers with Switchable Optical Transmittance for Optical and Thermal Regulation," *Joule* 3, 1–12, December 18, 2019**

## Polvani Named AGU Fellow & Appointed to Endowed Professorship

**Lorenzo Polvani**, professor of Applied Physics and Applied Mathematics and of Earth and Environmental Sciences, has been named a 2019 American Geophysical Union (AGU) Fellow. The AGU is an international, nonprofit scientific association "whose mission is to promote discovery in Earth and space science for the benefit of humanity" (AGU website) and their Fellow program recognizes members who have made exceptional contributions to the field. Only 1% of AGU members are chosen for this honor in any given year and Polvani, also with the other 61 fellows, was recognized at the Fall 2019 AGU Meeting in San Francisco, CA.

Polvani has been appointed to an endowed professorship. Effective January 1, 2020, Polvani will be the Maurice Ewing and J. Lamar Worzel Professor of Geophysics in the Fu Foundation School of Engineering and Applied Science. Columbia Engineering Dean Mary Boyce wrote, "The Ewing Worzel Professorship recognizes research excellence within Columbia Engineering in the area of geophysics. We are so pleased to honor Professor Polvani's leading research efforts in atmospheric and climate science with the distinction of this professorship."

## Columbia Team Receives $2M for Quantum Research Aimed at Stabilizing Atomic Excitation

**by Jessica Guenzel, originally published by Columbia University Fundamental Science News**

A team of Columbia University scientists has been awarded $2 million to execute a project aimed at extending the excited state lifetime of atoms, allowing for new technological innovation and advancing the field of quantum science.

The project is among the first to be chosen for federal funding for quantum research since the announcement of the National Quantum Initiative Act, signed into law by President Trump last December. The act provides for a coordinated federal program to accelerate quantum research and development for economic and national security. It allocates $1.2 billion in government funds to advance the application of quantum physics to real-world problems in the United States over the next five years.

Out of 200 pre-proposals for this funding opportunity, only 19 grants were awarded by the National Science Foundation (NSF). Of those, the proposal put forth by Principal Investigator Sebastian Will (Physics), and Co-PIs Ana Asenjo-Garcia (Physics), and **Nanfang Yu** (Applied Physics) was one of two that received a "high priority" ranking.

"It's an honor," said Will, an assistant professor of physics. "This is a really unique opportunity to connect fundamental science and engineering advances and turning them into novel technology. It's a chance to work on breakthroughs that have true potential to change the way we control the quantum world."

The theoretical ideas behind the project constitute a paradigm shift in the fundamental understanding of light-matter interactions. The convergence between Will's experimental expertise with ultracold atomic systems, Asenjo-Garcia's novel theoretical ideas, and the groundbreaking hologram technology developed by Yu gives the team an edge in the race to transform light-matter interfaces. If the team can successfully achieve its goal, the result could redefine the limits of quantum applications and devices, including optical lattice clocks, quantum sensors, and quantum memories.

The funding, spread out over three years, will be used to build an apparatus that can trap individual atoms and allow for them to be rearranged in an arbitrary way, including 3-D structures, rings, and lines. The goal is to arrange those individually trapped atoms in an array such that they "talk" to each other by exchanging light particles, or photons, which will keep the atom in an excited state. The atom traps, formed by intense laser beams, will be generated in a novel way utilizing holographic surfaces that can shape laser beams with the utmost precision and flexibility.

When light, at a frequency chosen to excite the atom, hits an atom in the ground state, it causes an electron of the atom to jump to a higher energy level. The atom, wanting to return to the ground state, tries to lose the excitation by discarding the photon attained from the light. Finding ways to keep atoms in the excited state for a longer period of time is critical to making quantum physics useful to technology, Will explained. This is key to building things like very accurate clocks or quantum computers.

The researchers believe they can arrange several atoms in very close proximity to each other—.5 micrometers or less—in a way that, when an atom tries to eject a photon in an effort to return to the ground state, the photon interacts with a neighboring atom. If things are tuned correctly, the interaction will prevent the atom from losing its excitation. This longer storage of the photon enhances quantum coherence and helps to stabilize the "quantumness" of the array.

"This project brings together experimental and theoretical atomic physics techniques with quantum engineering expertise," said Bogdan Mihaila, the NSF program officer overseeing this Quantum Idea Incubator research grant. "If successful in protecting collective quantum states from decay, overcoming a key limitation of existing quantum systems, this effort will demonstrate an important step forward for developing quantum memory and quantum sensors. That would achieve a primary goal of Quantum Leap, one of NSF's 10 Big Ideas for Future Investments."

"It's brilliant to see exceptional early-career leadership in quantum science as recognized by this very competitive funding award," said Peter de Menocal, dean of the School of Arts & Sciences' Division of Natural Sciences. "We continue to make strategic investments in this discipline based on its great promise to benefit society by transforming computing, communications, and sensing. This research extends a long tradition of quantum leadership at Columbia beginning with Nobel Laureate Professor I.I. Rabi's pioneering experiments in quantum mechanics."

Columbia has a long and distinguished history of making extraordinary scientific contributions in physics. For more than a century, Columbia was a leader in physics theory and research, and many modern scientific and technological developments, including nuclear energy, atomic physics, molecular beams, lasers, x-ray technology, semiconductors, superconductors, and supercomputers, were built on the foundations of relativity and quantum mechanics influenced by Columbia University physicists.

"We're excited to be part of a rebirth of quantum optics at Columbia," Will said, explaining that the university provides unique opportunities for interdisciplinary collaborations with the collective experience and knowledge to translate fundamental science into quantum devices. "It is exciting to be working in a field where science and technology breakthroughs are ahead of us."

## Chemke & Polvani Provide New Evidence on the Reliability of Climate Modeling

**By Nicole deRoberts, Lamont-Doherty Earth Observatory,**
**Originally published by Columbia Engineering**

*Observational data of equatorial circulation pattern confirms that the pattern is weakening, a development with important consequences for future rainfall in the subtropics*

**Clouds from deep convection over the tropical Pacific ocean, photographed by the space shuttle. Such convective activity drives the Hadley circulation of the atmosphere. Photo credit: NASA**

For decades, scientists studying a key climate phenomenon have been grappling with contradictory data that have threated to undermine confidence in the reliability of climate models overall. A new study, published today in Nature Geoscience, settles that debate with regard to the tropical atmospheric circulation.

The Hadley circulation, or Hadley cell—a worldwide tropical atmospheric circulation pattern that occurs due to uneven solar heating at different latitudes surrounding the equator—causes air around the equator to rise to about 10-15 kilometers, flow poleward (toward the North Pole above the equator, the South Pole below the equator), descend in the subtropics, and then flow back to the equator along the Earth's surface. This circulation is widely studied by climate scientists because it controls precipitation in the subtropics and also creates a region called the intertropical convergence zone, producing a band of major, highly-precipitative storms.

**"It's a big problem if the models are wrong because we use them to project our climate and send our results to the IPCC and policy makers and so on."**

**- Rei Chemke**

The study, headed by **Rei Chemke**, a Columbia Engineering postdoctoral research fellow, together with Professor **Lorenzo Polvan**i, addresses a major discrepancy between climate models and reanalyses regarding potential strengthening or weakening of the Hadley circulation in the Northern Hemisphere as a consequence of anthropogenic emissions.

Historically, climate models have shown a progressive weakening of the Hadley cell in the Northern Hemisphere. Over the past four decades reanalyses, which combine models with observational and satellite data, have shown just the opposite—a strengthening of the Hadley circulation in the Northern Hemisphere. Reanalyses provide the best approximation for the state of the atmosphere for scientists and are widely used to ensure that model simulations are functioning properly.

The difference in trends between models and reanalyses poses a problem that goes far beyond whether the Hadley cell is going to weaken or strengthen; the inconsistency itself is a major concern for scientists. Reanalyses are used to validate the reliability of climate models—if the two disagree, that means that either the models or reanalyses are flawed.

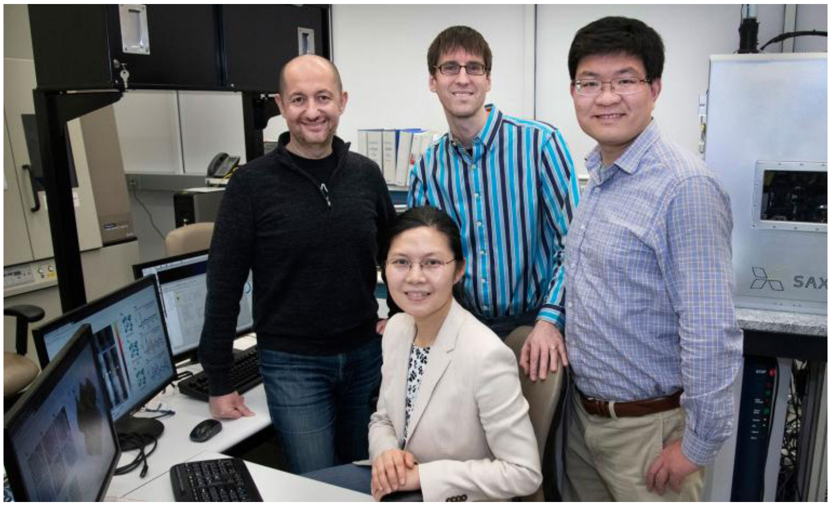
Lead author Chemke, a NOAA Climate and Global Change postdoctoral fellow, explains the danger of this situation, "It's a big problem if the models are wrong because we use them to project our climate and send our results to the IPCC (Intergovernmental Panel on Climate Change) and policy makers and so on."

To find the cause of this discrepancy, the scientists looked closely at the various processes that affect circulation, determining that latent heating is the cause of the inconsistency. To understand which data was correct—the models or the reanalyses—they had to compare the systems using a purely observational metric, untainted by any model or simulation. In this case, precipitation served as an observational proxy for latent heating since it is equal to the net latent heating in the atmospheric column. This observational data revealed that the artifact, or flaw, is in the reanalyses—confirming that the model projections for the future climate are, in fact, correct.

The paper's findings support previous conclusions drawn from a variety of models—the Hadley circulation is weakening. That's critical to understand, says Polvani, a professor of applied physics and applied mathematics and of earth and environmental sciences who studies the climate system at the Lamont-Doherty Earth Observatory. "One of the largest climatic signals associated with global warming is the drying of the subtropics, a region that already receives little rainfall," he explained. "The Hadley cell is an important control on subtropical precipitation. Hence, any changes in the strength of the Hadley cell will result in a change in precipitation in that region. This is why it is important to determine if, as a consequence of anthropogenic emission, the Hadley cell will speed up or slow down in the coming decades."

But these findings resonate far beyond the study in question. Resolving contradictory results in scientific research is critical to maintaining accuracy and integrity in the scientific community. Because of this new study, scientists now have added confidence that models are reliable tools for climate predictions.

**The study is titled "Opposite Tropical Circulation Trends in Climate Models and in Reanalyses." Authors are: Rei Chemke (Department of Applied Physics and Applied Mathematics, Columbia Engineering) and Lorenzo M. Polvani (Department of Applied Physics ad Applied Mathematics, Columbia Engineering; Department of Earth and Environmental Science, and Lamont-Doherty Earth Observatory, Columbia University). The study was supported by the NOAA Climate and Global Change Postdoctoral Fellowship Program, administered by UCAR's Cooperative Programs for the Advancement of Earth System Science (CPAESS). Lorenzo Polvani is grateful for the continued support of the U.S. Nat. Sci. Foundation.**



Brookhaven Lab scientists Fang Lu (sitting), (left to right, standing) Oleg Gang, Kevin Yager, and Yugang Zhang in an electron microscopy lab at the Center for Functional Nanomaterials. The scientists used electron microscopes to visualize the structure of nanocubes coated with DNA.

# Nanoscale Sculpturing Leads to Unusual Packing of Nanocubes

**Originally published by Columbia Engineering and the U.S. Department of Energy's Brookhaven National Laboratory**

*Understanding this behavior is key to engineering new materials with specific desired properties*

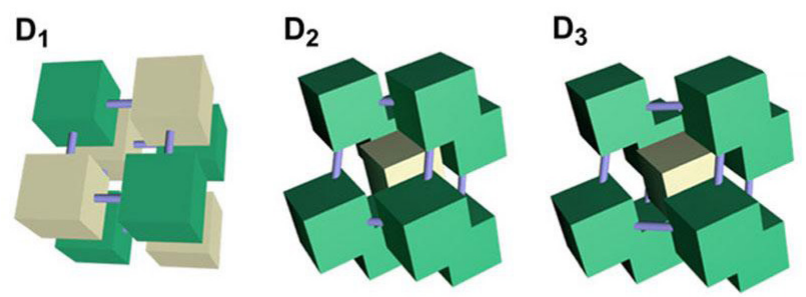
From the ancient pyramids to modern buildings, various three-dimensional (3D) structures have been formed by packing shaped objects together. At the macroscale, the shape of objects is fixed and thus dictates how they can be arranged. For example, bricks attached by mortar retain their elongated rectangular shape. But at the nanoscale, the shape of objects can be modified to some extent when they are coated with organic molecules, such as polymers, surfactants (surface-active agents), and DNA. These molecules essentially create a "soft" shell around otherwise rigid nano-objects. When the nano-objects pack together, their original shape may not be entirely preserved because the shell is flexible—a kind of nanoscale sculpturing.

Now, a team of scientists from Columbia Engineering and the U.S. Department of Energy's (DOE) Brookhaven National Laboratory has shown that cube-shaped nanoparticles, or nanocubes, coated with single-stranded DNA chains assemble into an unusual "zigzag" arrangement that has never been observed before at the nanoscale or macroscale. Their discovery is reported in the May 17 online issue of Sciences Advances.

"Nanoscale objects almost always have some kind of shell because we intentionally attach polymers to them during synthesis to prevent aggregation," explained co-author **Oleg Gang**, professor of chemical engineering and applied physics and materials science at Columbia Engineering and leader of the Soft and Bio Nanomaterials Group at the Center for Functional Nanomaterials (CFN)—a DOE Office of Science User Facility at Brookhaven Lab. "In this study, we explored how changing the softness and thickness of DNA shells (i.e., the length of the DNA chains) affects the packing of gold nanocubes."

Gang and the other team members—Fang Lu and Kevin Yager of CFN; Yugang Zhang of the National Synchrotron Light Source II (NSLS-II), another DOE Office of Science User Facility at Brookhaven; and Professor Sanat Kumar, Thi Vo, and Alex Frenkel of Columbia's Department of Chemical Engineering—discovered that nanocubes surrounded by thin DNA shells pack in a similar way to that expected on the macroscale, with the cubes arranged in neat layers oriented directly above one another. But this simple cubic arrangement gives way to a very unusual type of packing when the thickness of the shells is increased—rendering the shell "softer."

"Each nanocube has six faces where it can connect to other cubes," explained Gang. "Cubes that have complementary DNA are attracted to one another, but cubes that have the same DNA repel each another. When the DNA shell becomes sufficiently 'soft,' the cubes arrange into what looks like a zigzag pattern, which maximizes attraction and minimizes repulsion while remaining packed as tightly as possible."

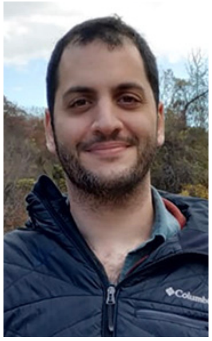



Depending on the thickness of the DNA shell, the nanocubes assemble into a simple cubic lattice with a face-to-face orientation (d1), a body-centered tetragonal lattice with a zigzag orientation (d2), or a body-centered cubic lattice with a zigzag orientation (d3). The green and beige colors represent nanocubes with noncomplementary DNA.

"This kind of packing has never been seen before, and it breaks the orientational symmetry of cubes relative to the vectors (directions of the x, y, and z axes in the crystal) of the unit cell," said first author Fang Lu, a scientist in Gang's group. "Unlike all previously observed packings of cubes, the angle between cubes and these three axes is not the same: two angles are different from the other one."

A unit cell is the smallest repeating part of a crystal lattice, which is an array of points in 3D space where the nanoparticles are positioned. Shaped nanoparticles can be oriented differently relative to each other within the unit cell, such as the by their faces, edges, or corners. The zigzag packing that the scientists observed in this study is a kind of nanoscale compromise in which neither relative orientation "wins." Instead, the cubes find the best arrangement to co-exist in an ordered lattice based on whether they have the same or complementary DNA (i.e., repelling or attracting each other accordingly).

In this case, two different lattice types can occur: body-centered cubic (BCC) and body-centered tetragonal (BCT). Both BCC and BCT have similar placements of particles in the center and corners of the cubes, but BCC has unit cell sides of equal length while BCT does not. To visualize the shape of the cubes and their packing behavior, the scientists used a combination of electron microscopy at the CFN and small-angle x-ray scattering (SAXS) at the former X9 beamline of NSLS and the Complex Materials Scattering beamline of NSLS-II. The electron microscopy studies require that the materials are taken out of solution, but SAXS can be conducted in situ to provide more detailed and precise structural information. (continued on page 15)



## Sagiv Joins Applied Mathematics Faculty

**Amir Sagiv** is the newest member of the Applied Mathematics faculty. He received his B.Sc. in Mathematics and Physics from the Hebrew University of Jerusalem (2009), and later received his M.Sc. (2016) and Ph.D. (2019) in Applied Mathematics at Tel Aviv University, both under the supervision of Gadi Fibich and Adi Ditkowski.

A main facet of his research is the study of random dynamics and time-reversal breaking in nonlinear optics. This work combines elements of both mathematical analysis and physical modelling, as well as extensive use of numerical simulations. The study and development of such simulations, and specifically numerical analysis of uncertainty-quantification (UQ) problems, is in itself a fascinating field in which computation, statistics, approximation, and transport theory all play a roll. Dr. Sagiv teaches graduate and undergraduate courses in analysis and PDEs, and multivariate calculus.

## Understanding Cobalt Oxide - A Promising Artificial Photosynthesis Catalyst

For many years, scientists have sought to unlock the principles of photosynthesis, nature's energy source, to apply to humanity's energy challenges. These efforts eventually culminated in the demonstration of artificial photosynthesis (AP), in which the sun's energy is harnessed to transform water and carbon dioxide into high-energy fuels. Both natural and artificial photosynthesis depend on the action of catalysts, substances that orchestrate the critical bond-breaking and bond-making steps during fuel generation. While AP has been widely studied and tested, a lack of detailed information on the workings of the catalysts is still a major barrier to AP device improvement.

**Simon Billinge**, Professor of Materials Science and Applied Physics and Applied Mathematics, along with a team of scientists from UC Berkeley, Lawrence Berkeley National Laboratory, SLAC National Accelerator Laboratory, Rensselaer Polytechnic Institute, and Brookhaven National Laboratory, have made important progress in understanding one of the most promising AP catalysts, cobalt oxide. They converted a well-understood (though unstable) catalyst, a Co4O4 cubane, into a metal-organic framework (MOF), dramatically increasing its stability and allowing them to unlock mechanistic insight for the improvement of cobalt oxide catalysts. This is a meaningful step in the understanding and rational tuning of materials for AP to meet the energy crisis facing society. Their findings were recently published in *PNAS*.

**"Stabilization of reactive $Co_4O_4$ cubane oxygen-evolution catalysts within porous frameworks", Andy I. Nguyen, Kurt M. Van Allsburg, Maxwell W. Terban, Michal Bajdich, Julia Oktawiec, Jaruwan Amtawong, Micah S. Ziegler, James P. Dombrowski, K. V. Lakshmi, Walter S. Drisdell, Junko Yano, Simon J. L. Billinge, and T. Don Tilley, *PNAS*, June 11, 2019 116 (24) 11630-11639. https://doi.org/10.1073/pnas.1815013116**

## Navratil Hosts the 24th Workshop on MHD Stability Control

**Gerald A. Navratil,** the Thomas Alva Edison Professor of Applied Physics, hosted the *24th Workshop on MHD Stability Control* at Columbia University's Faculty House from October 28-30, 2019. The workshop theme was "Key MHD Control Issues on the Path Towards a Compact Fusion Pilot Plant." The workshop embraced the focus of the Community Planning Process, building on the National Academy recommendation that, "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."

## 2019 NY Scientific Data Summit

APAM faculty and researchers presented research at the 2019 New York Scientific Data Summit, which was jointly co-organized by the Computing Systems for Data-Driven Science center in the Columbia Data Science Institute and Brookhaven National Laboratory's new Computational Science Initiative.

The event, which took place on Columbia University's main campus from June 12-14, featured speakers from six regional universities (including Columbia University, Rutgers University, Stony Brook University, Yale University, Princeton University, and the University of Pennsylvania); four national labs (Brookhaven National Laboratory, Oak Ridge National Laboratory, Argonne National Laboratory, and Lawrence Berkeley National Laboratory); major institutes (Flatiron, NASA GISS); a major local lab (DE Shaw Research); major company (Cray); and several other top universities (Cambridge University, University of Texas - Austin, University of Chicago, TU Dresden, and Max Planck Institute Dresden).

**Gavin Schmidt**, Director, NASA Goddard Institute for Space Studies, presented the keynote lecture on "Challenges in Climate Science in an Era of Big Data." **Michael Tippett,** Associate Professor of Applied Mathematics, (along with Qidong Yang and Chia-Ying Lee from Columbia University and Lamont-Doherty Earth Observatory) presented on "Improved Forecasts and Understanding of Hurricanes." Kun Wang spoke on "A Multiscale Meta-Modeling Game for Fluid-Infiltrating Porous Media," (joint work with **Qiang Du**, the Fu Foundation Professor of Applied Mathematics and Wai-Ching Sun from Columbia University), and APAM Adjunct Professor, **David Keyes**, who is a Professor of Applied Mathematics and Computational Science and the Director of Extreme Computing Research Center at KAUST, presented the final keynote lecture on "The Convergence of Big Data and Large-Scale Simulation: Leveraging the Simulation-Data-Edge Continuum for Science."

## Workshop on Future Directions for Enabling Coastal Storm Flooding Prediction for High-Resolution Forecasts and Climate Scenarios

**Kyle Mandli**, Associate Professor of Applied Mathematics, hosted the Workshop on Future Directions for Enabling Coastal Storm Flooding Prediction for High-Resolution Forecasts and Climate Scenarios at Columbia University from Oct. 25-26.

The growing threat from coastal flooding is recognized as one of the most dangerous and frequent natural hazards to the world's coastal communities. The purpose of the workshop was to both discuss the current state-of-the-art in coastal flood prediction, but also where research effort should be spent to better address the hazard. Speakers at the event, as well as a set of panels, outlined the history of the field as well as current short-comings of modeling efforts including representation of wind-waves, precipitation based flooding, and the fluid mechanics near coastal structures.

Featured speakers included Brian Blanton, Director of Environmental Initiatives and Coastal Oceanographer at the Renaissance Computing Institute and the University of North Carolina at Chapel Hill; Andrew Kennedy, a Professor in the Department of Civil and Environmental Engineering and Earth Sciences in the College of Engineering at the University of Notre Dame; Saeed Moghimi, a NOAA/UCAR Scientist in the Office of Coast Survey at the National Ocean Service; and Don Resio, Professor and Director of the Taylor Engineering Research Institute in the College of Computing, Engineering and Construction, at the University of North Florida. This workshop was co-sponsored by the Columbia Initiative on Extreme Weather and Climate and the APAM Department.

## APAM in the News

**Kate Marvel**, APAM Associate Research Scientist at NASA GISS, was recently featured in *The New York Times* article, "Her Message About Climate Change: It's Not Too Late," by By Katie Robertson. Dr. Marvel is committed to spreading the word about climate science and her TED Talk on the subject drew more than a million viewers.

**Adam Sobel**, Professor of Applied Physics and Applied Mathematics and of Earth and Environmental Sciences, wrote several articles on extreme weather for the *The New York Times* including, "Are Clues to the Coming Winter Blowing in the Autumn Wind?" and "A Storm Expert's View: Dorian's Damage Remains Impossible to Predict." Sobel was also featured in the *Miami Herald* article, "If the scale didn't stop at 5, would Hurricane Dorian have been a Category 6 storm?"; the LiveMint article, "Living on the edge in India's coastlines" by Vivek Menezes; in the *Esquire* article, "The Climate Crisis Movie Isn't Out Yet, But We Just Saw the Trailer," by Jack Holmes; and in the USA Today article, "End of civilization: climate change apocalypse could start by 2050 if we don't act, report warns," by Elizabeth Weise. Sobel was also featured on Sea Change Radio in the podcast, "Adam Sobel: Science In The Eye Of The Hurricane."

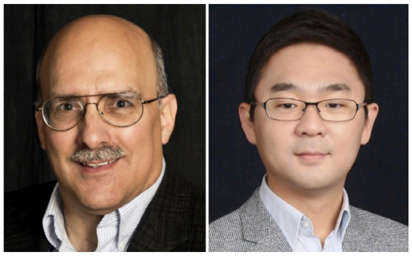
**Chris Wiggins**, Associate Professor of Applied Mathematics and Systems Biology, was featured in the Domino articles, "Data Ethics: Contesting Truth and Rearranging Power" and "Data Science at The New York Times" by Ann Spencer. The first article covers a data ethics seminar Wiggins presented at Berkeley, while the second article describes "how the Data Science group at The New York Times helped the newsroom and business be economically strong by developing and deploying ML solutions."

**Nanfang Yu**, Associate Professor of Applied Physics, was featured in the online and print July 25th edition *The Economist* in the article, "How to make a flat lens - cover its surface with tiny antennae." The article highlights his research which is making "magnifying lenses that are flat, and thinner than a hair."

**Photo: Adam Sobel** and **Kate Marvel**, were mentioned in the online PBS original feature, "I'm a college student who met the world's top climate scientists. Here are 5 things I learned." Sobel and Marvel served on a kick-off panel at the *Workshop on Correlated Extremes*, hosted by Columbia's Initiative on Extreme Weather and Climate. The workshop focused on correlated climate extremes and their rapidly growing impact on climate and atmospheric dynamics, boundary-layer meteorology, statistics, climatology, policy, and social sciences.


**(left-right) Adam Sobel, Michael Oppenheimer (Princeton), Sarah Perkins-Kirkpatrick (UNSW) & moderator, Kate Marvel**

## Sabbagh to Lead $7.6 Million International Grant on Sustained Tokamak Operation



**(left-right) Dr. Sabbagh & Dr. Park**

APAM senior research scientist and adjunct professor **Dr. Steven A. Sabbagh** will lead an expanded joint international grant from the U.S. Department of Energy (DOE) to study high performance tokamak plasma disruption prediction and avoidance in the long-pulse Korea Superconducting Tokamak Advanced Research (KSTAR) device located in Daejeon, South Korea. The expanded grant research will add further physics studies, real-time data acquisition, and plasma control to the device to understand how plasma disruptions can be largely eliminated in a tokamak. The granted funding expands past support by 130%. APAM associate research scientist **Dr. Young-Seok Park** will be lead researcher on the project for Columbia. This effort, which directly addresses a Tier 1 (highest priority) element of the U.S. magnetic fusion program as defined by the DOE, is a joint international effort comprised of three U.S. institutions (Columbia University, the Princeton Plasma Physics Laboratory (PPPL), and Nova Photonics, Inc.) and the National Fusion Research Institute in Daejeon, South Korea. Dr. Sabbagh is lead principal investigator (PI) for the overall project and institutional PI for Columbia, with Dr. Mario Podesta and Dr. Fred Levinton as institutional PIs for PPPL and Nova Photonics, respectively. The present grant covering three years exceeds $7.6 million for all three institutions, with the Columbia research component increasing by 63% compared to past funding. Drs. Sabbagh and Park will conduct the research full time at PPPL in close coordination with Dr. Sabbagh's present Columbia U. group researchers, including **Dr. John (Jack) Berkery** and **Dr. James M. Bialek** of APAM, two APAM post-doctoral researchers **Dr. Yanzheng Jiang** and **Dr. Jae Heon Ahn**, and two APAM graduate students **Juan Riquezes** and **Jalal Butt**. The project also aims to bring in a new APAM post-doctoral researcher.

The prediction and avoidance of tokamak disruptions, which stop plasma operation in the device, comprise a present "grand challenge" problem facing magnetic fusion for this leading magnetic confinement system. The research is of critical importance to the field, and while challenging, the goals of this exciting research are tractable and rewarding. The present expanded research effort is enabled by the prudent guidance and strong support of the DOE to create a joint research effort, including national and international partners, to tackle such high priority research issues. The present work builds on the successful, award-winning Columbia APAM group effort at PPPL to allow analysis of data from multiple tokamak devices, leveraging the advanced, unique capabilities of the high performance, long pulse superconducting KSTAR device (at high aspect ratio) and low aspect ratio ("spherical tokamak") plasmas in NSTX at PPPL and the Mega-Ampere Spherical Tokamak (MAST) at the Culham Centre for Fusion Energy (CCFE). These devices represent the greatest range of aspect ratio of high performance tokamaks in the world today, allowing plasma theory to be validated over a wide range of this important device parameter. The devices also have world-class diagnostics and multi-megawatt auxiliary heating systems. The present research is the natural progression of past research by Columbia APAM scientists, evolving the research by directly applying the plasma stability, transport, and control physics knowledge gained in the past decade to disruption event characterization and forecasting (DECAF).

The new grant is organized into four elements:

1) Analysis of the chains of events leading to disruptions in a long pulse, high performance superconducting tokamak, and forecasting the onset of such events. This effort includes a full supporting physics research effort using the present set of excellent diagnostic data on KSTAR to produce advanced plasma equilibrium, stability, and transport analyses required to support DECAF analysis. These supporting capabilities were constructed during our prior research effort on KSTAR funded by the DOE.

2) Reduction and/or direct implementation of these physics models to allow their use in real-time for disruption prediction during the long-pulse operation of the KSTAR device (~ 100 seconds).

3) Implementation and analysis of real-time diagnostic capabilities on KSTAR for disruption prediction and avoidance. This effort will bring significant new capabilities allowing real-time measurements of key plasma parameters such rotation profile, magnetic field pitch angle and internal magnetic perturbation profiles, electron temperature and electron temperature fluctuation profiles, evolution and decomposition of rotating magnetohydrodynamic modes, and energetic particle-driven mode onset and evolution. These measurements will allow the physics models to assess how close the plasma state is from being disrupted.

4) Creation and implementation of control algorithms that will steer the plasma away from possible disruption to preferred, sustained operational states.

This multi-institutional effort by Columbia U. APAM, PPPL, and Nova Photonics researchers will create a world-leading capability on the KSTAR device, uniquely produced by a united group effort. It further extends the reach of our international team of Columbia APAM researchers and students on devices around the globe.

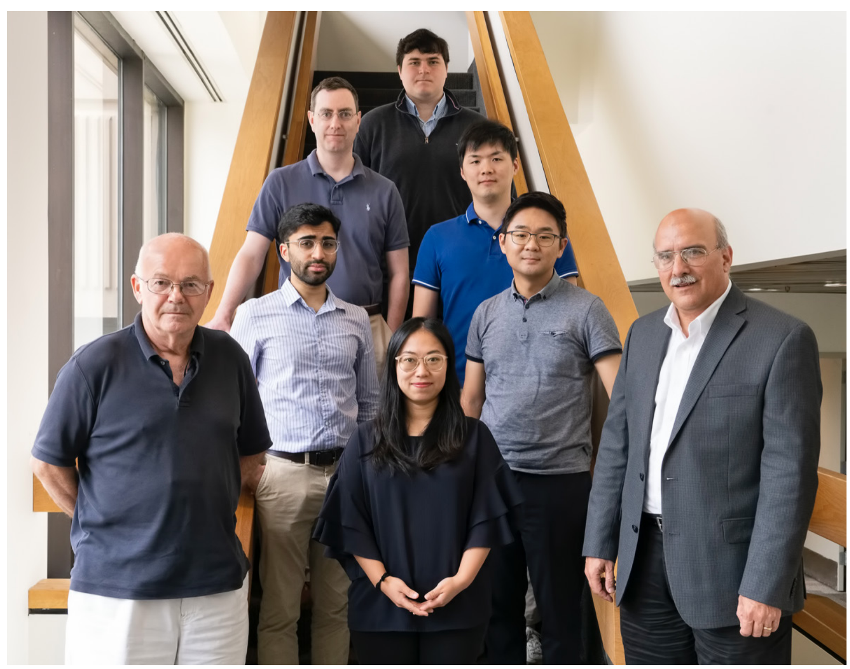


**Photo: The Columbia University APAM research team on tokamak plasma disruption prediction and avoidance: From the left in each row, bottom to top: Dr. James Bialek, Dr. Yanzheng Jiang, Prof. Steven A. Sabbagh, Mr. Jalal Butt, Dr. Young-Seok Park, Dr. Jack Berkery, Dr. Jae Heon Ahn, Mr. Juan Riquezes.**

## Zang Named Regional Blavatnik Post-Doctoral Award Finalist

**Dr. Yaping Zang**, a former postdoctoral research scientist in **Prof. Latha Venkataraman**'s group, was selected as a Regional Blavatnik Post-Doctoral Award Finalist. She was recognized for "Innovatively using electrochemistry and electrical fields in conjunction with Scanning Tunneling Microscopy techniques to drive single-molecule chemical reactions, providing deeper mechanistic insight and opening new avenues for electro-catalysis."

Dr. Zang is a physical chemist working in the interdisciplinary fields of molecular electronics and chemistry, and has developed novel methodologies to study electrically driven chemical reactions at a single-molecule level. Using electrochemistry or electrical fields instead of toxic or expensive reagents to promote chemical reactions can potentially revolutionize the way compounds and materials are synthesized. Dr. Zang has developed an innovative methodology to electrically manipulate chemical reactions of individual molecules utilizing a scanning probe microscope. With this technique, Dr. Zang discovered a range of reactions which can be driven electrochemically or by strong electric fields. In particular, one of her significant achievements was the coupling of two anilines (a precursor in the manufacture of polyurethane) to form an azobenzene compound. The large variety of anilines which can be coupled together by this technique give rise to a whole family of azobenzene derivatives, which are important chemical intermediates in industry. This research pushes the frontier of our mechanistic understanding of electro-catalysis and paves the way towards environmentally friendly synthesis of industrially relevant materials.

The Blavatnik Regional Awards recognize outstanding researchers in Life Sciences, Physical Sciences & Engineering, and Chemistry. They select one winner in each category, who is awarded 30K in unrestricted funds; and two finalists in each category, who each receive 10K.

### Nanoscale Sculpturing Leads to Unusual Packing of Nanocubes

**(Continued from page 10)**

In this study, the scattering data were helpful in revealing the symmetries, distances between particles, and orientations of particles in the 3D nanocube structures. Theoretical calculations performed by the Kumar Group at Columbia confirmed that the zigzag arrangement is possible and rationalized why this kind of packing was happening based on the properties of the DNA shells.

The team is now eager to determine whether soft-shelled nano-objects that are not cubes or have more than one shape also pack together in unexpected ways.

"An understanding of the interplay between shaped nano-objects and soft shells will enable us to direct the organization of objects into particular structures with desired optical, mechanical, and other properties," said Kumar, the Bykhovsky Professor of Chemical Engineering.

*Brookhaven National Laboratory is supported by the Office of Science of the U.S. Department of Energy. The Office of Science is the single largest supporter of basic research in the physical sciences in the United States, and is working to address some of the most pressing challenges of our time. For more information, please visit* **science.energy.gov**.

## Career Events Featuring APAM Alumni

The APAM Department had the pleasure of hosting fourteen unique employers for career oriented events this semester, nine of which were led by APAM alumni. Our career events ranged from roundtable discussions on transitioning out of academia to informational sessions on how to land an interview.

Medical Physics students had the opportunity to connect with **John L McLean** (MS '04, Medical Physics) from BioMed Associates, **George Pavlonnis** (MS '01, Medical Physics) CEO of Accelerated Medical Physics Services, and **Jacob Kamen** (PhD '91, Medical Physics) Chief Radiation and Laser Safety Office at Mount Sinai Health System.

Students were given tips on breaking into the field of Data Science at Ebay and Bank of America from APAM alumni **Yuri Brovman** (PhD '11, Applied Physics) and **Meninder Purewal** (PhD '08, Applied Mathematics). Students also learned about life at Bloomberg Tradebook from **Yurij Baransky** (PhD '87, Applied Physics). **Kelley Litzner** (MS '08, Applied Physics) spoke with undergraduate and graduate students about the Emerging Technologies Laboratory at Lockheed Martin, and **Endri Mani** (MS '15, Materials Science and Engineering) hosted a talk about "Machine Learning in Finance" at RBC Capital Markets. If you are interested in assisting APAM students in navigating their next steps in the spring semester, reach out to Career Placement Officer, **Kristen Henlin**, at kah2247@columbia.edu.

## 2019 Plasma Physics Reunion Dinner

The annual Columbia University Plasma Physics Reunion Dinner took place on October 22$^{nd}$ in Fort Lauderdale, FL, during the 2019 Fall APS Plasma Physics Annual Meeting. The dinner, organized by **Ryan Sweeney** (PhD '17), was attended by APAM plasma physics and applied physics alumni including **Dennis Boyle** (BS '08), **Wilkie Choi** (PhD '17), **Philip Efthimion** (PhD '77), **Andrea Garofalo** (PhD '97), **Alexander Glasser** (MS '15), **Brian Grierson** (PhD '09), **Kenneth Hammond** (PhD '17), **Paul Hughes** (PhD '16), **Ben Israeli** (BS '17), **Royce James** (MS '03), **Ilon Joseph** (PhD '05), **David Maurer** (PhD '00), **Daisuke Shiraki** (PhD '12), and **John Wright** (BS '91). The dinner was also attended by current APAM graduate students **Mel Abler**, **Alexander Battey**, **John Brooks**, **Rian Chandra**, **Todd Elder**, **Boting Li**, **Juan Diego Riquezes**, **Alex Saperstein**, **Ian Stewart,** and **Yumou (Wiliam) Wei**; current APAM research staff members **Chris Hansen**, **Jack Berkery**, **Jeff Levesque** (PhD '12), and **Jeremy Hanson** (PhD '09); APAM professors **Michael Mauel** and **Gerald Navratil**; and guests, Jeanne Courval, Piero Martin, Josh Saha, and Victoria Saha.

**Above: The 2019 Plasma Physics Reunion Dinner**

**Save the date: The 2020 Columbia Engineering Alumni Weekend will take place from June 4-6. For details, see: engineering.columbia.edu/alumni/reunion**

**In Memoriam: James "Jimmy" Florakis passed away on October 31, 2019. He worked for nearly 50 years at Columbia University and for more than 30 years with the APAM Department as the supervisor of both the Applied Physics and Medical Physics teaching labs. Prof. Gerald Navratil commented, "Hiring Jimmy was one of the best choices I've ever made, as he was instrumental in setting up our new teaching laboratory, maintaining it for decades, and helping to train many generations of undergraduates and graduate students. Even after his retirement, he came back for several years to continue his valuable work in the laboratory. His ready smile and always upbeat 'can-do' attitude made him a pleasure to work with, and I know he will be greatly missed by all who were fortunate enough to know him."**

## 2019 Undergraduate Research Symposium

Five APAM students presented research posters at the 8th Annual Undergraduate Research Symposium organized by Columbia Engineering.

**Edita Bytyqi, SEAS '21, Applied Physics**

*Targeted Correction of Point-Like Aberrations with High-Order Thermal Compensation*

Large scale interferometry has a crucial role in detecting gravitational waves which provide us with information about the early universe. The key to a good interferometer is its sensitivity which is directly proportional to the circulating power inside its cavities. The Laser Interferometer Gravitational Wave Observatory (LIGO) uses Fabry-Perot cavities to achieve high circulating power from the resonant build-up of a low power input. However, due to point-like aberrations located at the end mirrors, the amplitude of the resonant fundamental mode in the cavity is significantly limited. A large fraction of the circulating power is scattered into higher order modes (HOMs) which increase the cavity loss as they approach resonance. The most problematic HOM in the LIGO interferometers is the 7th order mode, which we try to actuate. We propose a thermal compensation system consisting of a heater and a spherical reflector which reduces the effect of point absorbers by centrally heating the mirror at 1.9 cm wide spots. The produced heat pattern allows for actuation of the cavity losses by reducing the heat gradient across the mirrors. While we were able to achieve the desired heat focus, further testing and a consideration of LIGO noise requirements is necessary to obtain a more effective design. Eventually, an array of these heating elements could be used to actively actuate for different HOMs. **(Supervisor: Jon Richardson, Aidan Brooks, Rana X Adhikari, LIGO, Caltech**)

**Mikhaela Diaz, SEAS '22, Applied Math**

*Identifying nontoxic concentrations of sodium selenate for therapeutic intervention of blast traumatic brain injury*

Traumatic brain injury (TBI) is a major health concern worldwide and there is growing evidence that exposure increases the risk for neurodegeneration. Preclinical TBI studies have reported impaired cognitive behavior associated with increased tau phosphorylation, which is also implicated in the pathology of Alzheimer's Disease. Protein phosphatase 2A (PP2A) is the major phosphatase responsible for dephosphorylating tau. The aim of this study is to identify a range of nontoxic concentrations of sodium selenate (SS) to increase PP2A activity as a potential therapeutic intervention for cognitive impairments post-TBI. Rat organotypic hippocampal cultures (OHSCs) were treated either with full serum alone (negative control), 10 mM glutamate (positive control), or SS at different concentrations. The cultures were exposed to a single blast TBI 2 hours after treatment and cell death was measured using propidium iodide staining 24 hours after injury. Cultures treated with either full serum alone or 10 and 50 μM SS exhibited less than 5% cell death. On the other hand, glutamate and 100 μM SS treatment induced more than 30% cell death in these cultures. Our study shows that SS at certain concentrations is nontoxic to the tissue cultures. Future work will include performing western blots to quantify changes in PP2A and tau phosphorylation protein expression in these cultures. Additionally a phosphatase assay will be used to quantify changes in PP2A activity. Since there are no FDA approved drugs to treat the neurological consequences of TBI, this study can help develop novel therapeutics targeting tau pathology post injury. **(Supervisors: Barclay Morrison and Sowmya Sundaresh, Johnson & Johnson Summer Scholar, Neurotrauma & Repair Lab, Columbia Engineering)**

**Ava Doyle, SEAS '22, Applied Physics**

*Mapping the Stellar Density of the Milky Way Disk*

We map the star density in the Milky Way disk by collecting star data from stellar surveys, statistically determining the distance of each star, then graphically representing the density of stars in the Milky Way. In data from Sloan Digital Sky Survey (SDSS) Data Release 14 and the Panoramic Survey Telescope and Rapid Response System (Pan-ST ARRS) Data Release 2, potential substructure has been identified and linked to galactic wiggles, the Hercules Aquila Cloud, and the Hercules Halo Stream. (Supervising Faculty: Dr. Heidi Newberg, Department of Physics, Applied Physics, and Astronomy, Rensselaer Polytechnic Institute)

**Joseph Lee, SEAS '21, Applied Physics**

*Quantum Inspired Algorithms for Quantum Chemistry*

In quantum chemistry, chemists can use the Hartree-Fock ground state energy calculations to achieve about 99% accuracy to the exact values. However, quantum chemists aim to achieve chemical accuracy, requiring at least four digits of accuracy. We explore the possibility of using the Gottesman-Knill theorem with results from Bravyi et al. and Bennink et al. to run a quantum-inspired algorithm for solving the energies of the quantum chemical systems completely classically. We specifically focus on a solid state model known as the half-filled Hubbard Model. We create a quantum circuit based off of the unitary coupled cluster (UCC) approach in quantum chemistry and restrict ourselves to small rotations and Clifford operations. These limited operations allow us to run the circuit on a classical computer in reasonable time. Prior work by Nam et al. have shown that the UCC ansatz required only Clifford operations and small angle rotations for energy calculations of the water molecule.

In future work, we will run these quantum circuits for the half-filled cases of the four site Hubbard Model and beyond. We will then check the overlap with known ground state energy values to see how accurate our results are. We would like this algorithm to work for any value of Coulomb repulsion. Our initial state will take the form of the ground state vector when Coulomb repulsion is equal to zero. Then, the UCC operation will be applied to this initial product state. The angles in the UCC will be adjusted according to the set Coulomb repulsion values. **(Supervisor: Jim Freericks, Georgetown Physics Department, Materials Physics REU)**

**Michael Wahrman, SEAS '21, Applied Physics**

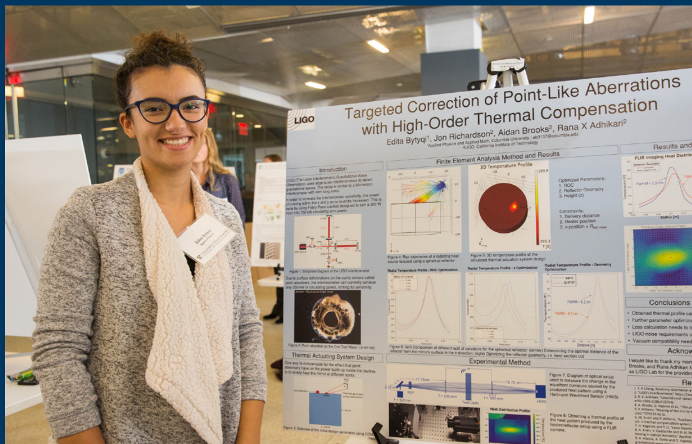
*Optimizing Superconducting Radiofrequency Cavities for Particle Accelerators*

The Facility for Rare Isotope Beams (FRIB) at Michigan State University has been under construction and, once completed, will produce rare isotope beams at higher levels of power than ever before. A crucial part of this facility is the superconducting linear accelerator, capable of accelerating heavy ion beams, including uranium ions, up to 200 MeV /u beam energy with 400 kW beam power. Along with FRIB construction, research and development have begun for future energy upgrades to double the heavy ion beam energy, which allows higher isotope production yield. In order to do this, carefully crafted, niobium cavities are used to generate the accelerating gradient up to 17.5 MV/m. The FRIB Superconducting Radiofrequency (SRF) group optimizes the performance of these cavities. To quantify cavity performance, physicists use a quality factor that relates power loss to electromagnetic field strength.

To have a good quality factor, the temperature-independent residual component of the RF surface resistance needs to be minimized. We experimentally studied the effect of cool down speed on the trapped magnetic flux on the superconducting niobium surfaces. In addition, the electromagnetic fields need to be uniformly distributed among five cells to prevent potential field emission/quench at a low accelerating gradient due to unpredictable, high-electric/magnetic field in a particular cell. We measured field flatness and tuned the cavity such that the field is uniformly distributed.

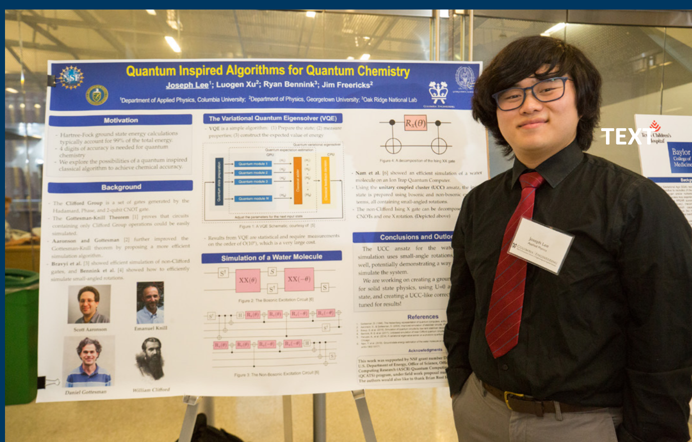
We found that a faster cool down speed caused more of the magnetic field to be expelled from the cavity, which potentially improves cavity performance. Additionally, we were able to achieve 98% uniformity of cell-to-cell field distribution using a manual tuning method. These findings have contributed to our understanding of the various factors that influence cavity performance. Any improvement in the quality factor translates to lower wall dissipation power into liquid helium at the operating accelerating gradient, meaning more efficient operation of the superconducting linear accelerator. **(Supervisor: Peter Ostroumov, REU, NSF Facility for Rare Isotope Beams, Michigan State University)**

## 2019 Columbia Engineering Undergraduate Research Symposium

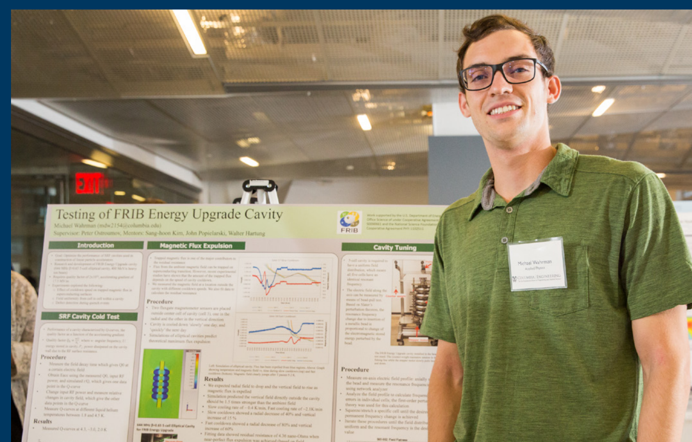



**Edita Bytyqi, SEAS '21, Applied Physics**


**Ava Doyle, SEAS '22, Applied Physics**




**Joseph Lee, SEAS '21, Applied Physics**




**Michael Wahrman, SEAS '21, Applied Physics**

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