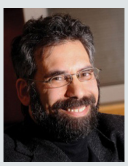
Fall 2021, Vol. 16 Issue 1

APAM NEWS

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

Image: The Mary Rose, Henry VIII's Favorite Warship (see page 8 for details)



Dear APAM Community,

In this issue, we proudly celebrate the accomplishments of our students, faculty, scientists, and alumni. Fall 2021 marks my first semester as the new Chair of APAM, and before describing all the wonderful achievements of our community, I need to thank our outgoing chair, Prof. Irving Herman, for his tireless service to the department. Prof. Herman has been department chair for a total of nine years, but the past three have presented unforeseen challenges on a daily basis. However, through his steadfast leadership the APAM community has met these challenges and continues to adapt and thrive. We are forever grateful.

In Fall 2021, APAM faculty members were recognized for their contributions, leadership, and excellence. Nanfang Yu was named an Optica Fellow, Carlos Paz-Soldan received the APS Stix Award, and Simon Billinge is part of a team who received a Google Research Award for Inclusion. Katayun Barmak, Daniel Bienstock, Qiang Du, and Carlos Paz-Soldan and colleagues received notable grants to advance their research.

This newsletter also highlights Simon Billinge's research on the Mary Rose and artificial intelligence, Renata Wentzcovitch's research on quantum phase transition deep within the Earth's lower mantle, Nanfang Yu's and Michal Lipson's research on optical phase modulators, Latha Venkataraman's new method for 'green chemistry', and Adam Sobel's research on extreme weather.

Also included in this edition are recent publications, faculty and research scientist news, student presentations, and alumni updates.

We conclude this newsletter by mourning the loss of one of the founding faculty members of the Department, Thomas C. Marshall, Professor *Emeritus* of Applied Physics. We celebrate his legacy as a scientist, educator, and leader.

Marc Spiegelman
APAM Department Chair

In this Issue

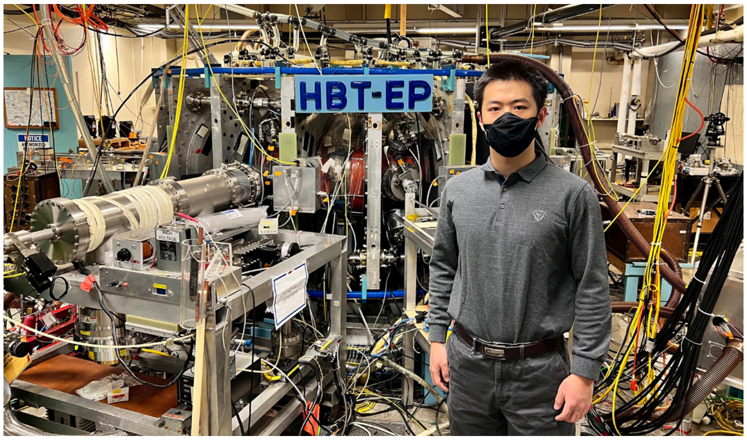


Image: Yumou Wei, with the High Beta Tokamak-Extended Pulse (HBT-EP) device in the Columbia Plasma Physics Lab

A Dimensionality Reduction Algorithm for Mapping Tokamak Operational Regimes Using a Variational Autoencoder (VAE) Neural Network

A new paper by Yumou Wei, and members of the Columbia Plasma Physics Lab, was published in Nuclear Fusion describing the use of machine learning methods to reduce the complex multi-dimensional operation space of a tokamak fusion reactor to a much simpler representation.

In tokamak experiments, a disruption is a dramatic event which rapidly terminates a plasma discharge. During a disruption, confinement of the hot plasma inside the reactor chamber is lost, dumping its energy onto the vessel wall and potentially causing damage to the machine through the resulting magnetic force and thermal load. For this reason, the ability to reliably predict and subsequently avoid or mitigate disruptions is important for the operation of the ITER tokamak and future fusion reactors.

At the Columbia Plasma Physics Lab, PhD student **Yumou Wei** developed an algorithm to predict disruptions using a deep learning algorithm called a variational autoencoder (VAE). A VAE is an unsupervised learning algorithm which is capable of learning meaningful data representations in a reduced dimensional latent space. It uses the encoder-decoder neural network framework while performing stochastic sampling and other techniques in order to learn a meaningful representation. VAEs have been successfully demonstrated in numerous scientific and engineering fields such as image processing and anomaly detection as well as in the physical sciences.

To implement the VAE model, Yumou and the research group (led by **Profs. Gerald Navratil and Michael Mauel**) collected and compiled a dataset consisting of diagnostic signals from over 3,000 plasma discharges from the High Beta Tokamak-Extended Pulse (HBT-EP) device. This dataset was used to train a VAE model, and using the trained encoder network, the data were mapped onto a two-dimensional latent space from the original seven-dimensional signal space. Within this latent space, each plasma discharge forms a continuous trajectory, and multiple operational boundaries can be identified, corresponding to different causes of disruption. Knowledge of the plasma's current location in relation to operational boundaries within the latent space provides an intuitive way for the machine operator to not only predict an imminent disruption but to also perform disruption avoidance by steering the trajectory away from the boundary. The group demonstrated this control technique through multiple pre-programmed control experiments performed on HBT-EP and showed this technique allowed the plasma to consistently avoid the oncoming disruption and to extend its lifetime.

Article: "A dimensionality reduction algorithm for mapping tokamak operational regimes using a variational autoencoder (VAE) neural network," Y. Wei et al 2021 *Nucl. Fusion* 61 126063, doi.org/10.1088/1741-4326/ac3296

Huang Selected as CKGSB Fellow

Kuang Huang has been named a Cheung Kong Graduate School of Business (CKGSB) fellow for a second year! Kuang is a PhD student in Applied Mathematics in **Prof. Qiang Du**'s CM3 Group. In recent years, he has collaborated with a number of researchers at Columbia Engineering, including students and faculty from civil engineering and engineering mechanics, computer science and mechanical engineering on various projects. The CKGSB fellowship from Columbia Engineering will support his research ranging from the modeling of autonomous vehicles to video-based learning, using mathematics and AI.

Bok Young Kim

Synchronization of Nonsolitonic Kerr Combs

Bok Young Kim's paper, "Synchronization of nonsolitonic Kerr combs," has been published by *Science Advances*.

Synchronization is a natural phenomenon that can occur with coupled nonlinear oscillators and is a process that allows the operating frequencies to become identical. In this article, synchronization is demonstrated between to two optical frequency combs generated using normal group velocity dispersion (GVD) coupled microresonators. Generation in the normal GVD regime allows for access to optical pulse structures with extremely high generation efficiency and flatter spectral profiles. Usually, separate combs will not be identical even if they are generated in an identically designed microresonator due to fabrication and environmental fluctuations. However, synchronization allows for the two combs to overlap in their comb lines and be coherently combined. By synchronizing two nonsolitonic normal GVD combs, the high generation efficiency of a single comb can be maintained while doubling its power per line. Because a comb can only be generated within a certain range of pump power before transitioning to other comb states (multi-pulse), this technique is useful to utilize more pump power and generate higher comb line powers that might not be in the range of a single microresonator-based comb. Applications of microresonator-based frequency combs such as data communications and spectroscopy could benefit immensely from these high comb-line powers that are otherwise inaccessible without the use of additional amplifiers.

Bok Young Kim is a PhD student in Prof. Alexander Gaeta's Quantum and Nonlinear Photonics Group. Other authors on the paper include **Dr. Jae K. Jang** (APAM), **Dr. Yoshitomo Okawachi** (APAM), **Dr. Xingchen Ji** (Electrical Engineering), **Prof. Michal Lipson** (Electrical Engineering/APAM), and **Prof. Alexander Gaeta** (APAM).

Article: "Synchronization of nonsolitonic Kerr combs", B.Y. Kim et al, *Science Advances*, Oct 20, 2021, Vol 7, Issue 43, doi.org/10.1126/sciadv.abi4362

APAM Presents Research at APS Division of Plasma Physics Meeting

(Left to Right) Dr. Jeff Levesque, David Arnold, Prof. Jerry Navratil, Prof. Mike Mauel, Dr. Ian Stewart, Yumou "William" Wei, Boting Li, and Alex Saperstein

Columbia University graduate students, scientists, and faculty traveled to Pittsburgh, PA to attend the 63rd Annual Meeting of the APS Division of Plasma Physics (DPP). This was the first "hybrid" meeting convened by the American Physical Society (APS) since the beginning of the pandemic. From November 8-12, 2021, over 800 plasma physicists from the U.S. attended in-person and more than 1,200 physicists participated remotely, making the meeting the world's largest devoted to plasma physics. Members of Columbia University presented 65 presentations on topics ranging from astrophysics, Alfvén waves, and fusion energy science. Immediately prior to the APS-DPP Meeting, Columbia University students also participated in an expert satellite meeting on active control of MHD modes in toroidal fusion devices. This was the 25th expert meeting on MHD stability control, including 5 previously hosted by Columbia University.

Highlights of the meeting were invited presentations from Columbia graduate students. At the MHD Stability Control Workshop, **Juan Riquezes**, working with **Dr. Steve Sabbagh** (PhD '90), spoke on the topic of "Cross-machine Investigation of Mode Locking and Forecasting of Rotating MHD modes for DECAF," and **Jalal Butt** described "ELM and confinement transition identification events for Disruption Event Characterization and Forecasting." **Alex Battey**, working with **Prof. Jerry Navratil** and **Dr. Jeremy Hanson** (PhD '09), report latest results showing "Simultaneous Control on Multiple RWMs on DIII-D Device." Working with **Prof. Carlos Paz-Soldan**, **William Boyes** presented his "Stability of Diverted DIII-D Negative Triangularity Plasmas." Representing the HBT-EP Tokamak Research group, graduate student **Rian Chandra** described his research "Real-time tomographic inversion as an observer for GPU based plasma control." In addition to these student presentations, **Dr. Jeff Levesque** (PhD '12) presented "Active mode control using current-injecting electrodes in a tokamak;" **Dr. Oak Nelson** described "Stability of the n = 0 resistive wall mode in a negative triangularity DIII-D;" **Dr. Veronika Klevarova** described "Pre-disruptive warning generation for the DECAF code based on locked mode critical amplitude scaling;" and **Dr. Steven Sabbagh** reported "Progress on Disruption Event Characterization and Forecasting Including Real-Time Implementation."

Mel Abler '21

Dr. Mel Abler (PhD '21), recent graduate of Columbia's plasma physics program working with **Prof. Mike Mauel**, was invited to present their doctoral research to the full APS-DPP audience. Dr. Abler's invited lecture was titled, "Characterizing Intermittent Turbulent Wave Kinetics and Three-Wave Coupling in Dipole-Confined Plasma." The lecture presented a new paradigm for characterizing this turbulence by measuring the time-evolution of the fluctuation power spectrum and the instantaneous bispectrum using the continuous wavelet transform and computing the statistical properties of turbulent wave kinetics. Also invited to speak to the APS-DPP was **Prof. Carlos Paz-Soldan**, who described "Pathways to Transient Control in Tokamak Plasmas" in recognition of receiving the 2021 Thomas H. Stix Award for Outstanding Early Career Contributions to Plasma Physics Research.

The Annual Meeting of the APS-DPP also provided opportunities for students to meet with physicists from around the country as they presented posters of their research progress. A special benefit of attending an "in-person" physics conference, the traditional Columbia Plasma Physics Laboratory Reunion could be held during the meeting once again. Former students could share stories of their time at Columbia with current students, and everyone could share the excitement of discovery in plasma physics.

Alumni Featured in Career Services Events

By Kristen Henlin, APAM Career Placement Officer

The APAM Department continued our alumni chat series during the Fall 2021 semester. We hosted undergraduate and graduate students for various discussions within their given fields. During September, students had the opportunity to connect with **Will Martin** (MS '19, Medical Physics), a Medical Physicist at Montefiore Medical Center, and **Datong Zhang** (PhD '16, Applied Physics), a Technical Manager at ASML.

In October, Applied Mathematics alumnus **Chaim Eisenbach** (BS '20, Applied Mathematics) shared his experience as a Senior Consulting Analyst at Accenture. **Preston Bradham** (MS '19, Applied Mathematics) spoke to the department about his path as a Senior Consultant at EY. **Michael Berkson** (MS '18, Materials Science) also shared his experience as a Research Engineer at The Johns Hopkins Applied Physics Laboratory. We wrapped up the month with an Alumni chat from **Aysha Khan** (MS '19, Applied Mathematics), a member of the Engineering Staff at Lockheed Martin.

In November, the APAM Department hosted **Kai Pak** (MS '18, Applied Physics), a Data Scientist at NASA Jet Propulsion Laboratory. We also connected with **Colton Smith** (MS '19, Applied Mathematics), a Quantitative Analyst at Millennium.

Our department also had the unique opportunity to host APAM alumni at our first virtual Career Fair in October. **Aimee Moses** (M.S. '20, Applied Mathematics), a Machine Learning Engineer at Expedition Technology, spoke with SEAS students about opportunities within her company. We also had the pleasure of collaborating with **Rachael Keller** (PhD '21, Applied Mathematics), a Data Scientist at Dynetics Inc., regarding student recruitment.

If you are interested in collaborating with APAM for a virtual career event, or if you have full-time/part-time or summer internships available, please reach out to Kristen Henlin at kah2247@columbia.edu.

(Student & Alumni News continued on pages 13-14)

New Device Modulates Visible Light—Without Dimming It—with the Smallest Footprint and Lowest Power Consumption

Visible-spectrum, compact, power-efficient, low-loss phase modulator is a breakthrough in integrated photonics; the device will improve LIDAR for remote sensing, AR/VR goggles, quantum information processing chips, implantable optogenetic probes, & more

By Holly Evarts, Originally published by Columbia Engineering

Over the past several decades, researchers have moved from using electric currents to manipulating light waves in the near-infrared range for telecommunications applications such as high-speed 5G networks, biosensors on a chip, and driverless cars. This research area, known as integrated photonics, is fast evolving, and investigators are now exploring the shorter—visible—wavelength range to develop a broad variety of emerging applications. These include chip-scale light detection and ranging (LIDAR), augmented/virtual/mixed reality (AR/VR/MR) goggles, holographic displays, quantum information processing chips, and implantable optogenetic probes in the brain.

The one device critical to all these applications in the visible range is an optical phase modulator, which controls the phase of a light wave, similar to how the phase of radio waves is modulated in wireless computer networks. With a phase modulator, researchers can build an on-chip optical switch that channels light into different waveguide ports. With a large network of these optical switches, researchers could create sophisticated integrated optical systems that could control light propagating on a tiny chip or light emission from the chip.

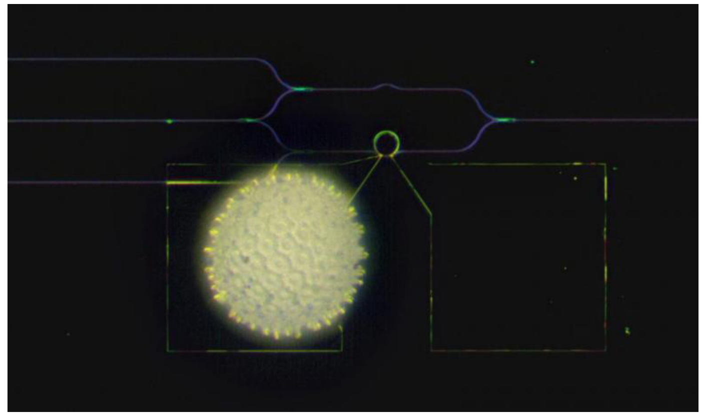
But phase modulators in the visible range are very hard to make: there are no materials that are transparent enough in the visible spectrum while also providing large tunability, either through thermo-optical or electro-optical effects. Currently, the two most suitable materials are silicon nitride and lithium niobate. While both are highly transparent in the visible range, neither one provides very much tunability. Visible-spectrum phase modulators based on these materials are thus not only large but also power-hungry: the length of individual waveguide-based modulators ranges from hundreds of microns to several millimeters, and a single modulator consumes tens of milliwatts for phase tuning. Researchers trying to achieve large-scale integration—embedding thousands of devices on a single microchip—have, up to now, been stymied by these bulky, energy-consuming devices.

"Our work can inspire future effort where people can implement strong over-coupling in a wide range of resonator-based devices to enhance light-matter interactions, for example, for enhancing optical nonlinearity, for making novel lasers, for observing novel quantum optical effects, while suppressing optical losses at the same time."

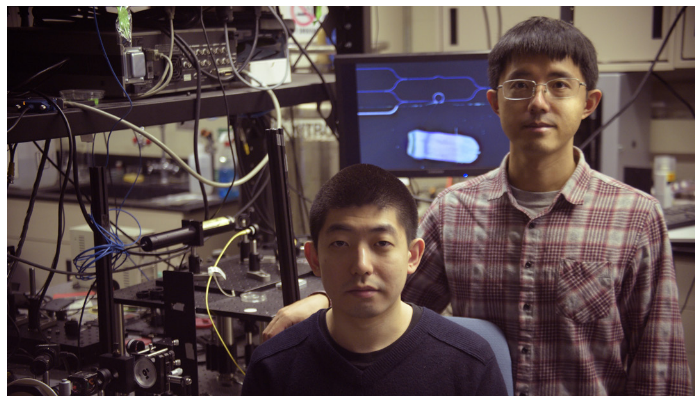
- Michal Lipson
Eugene Higgins Professor of Electrical Engineering & Professor of Applied Physics

Columbia Engineering researchers announced that they have found a solution to this problem—they've developed a way based on micro-ring resonators to dramatically reduce both the size and the power consumption of a visible-spectrum phase modulator, from one millimeter to 10 microns, and from tens of milliwatts for π phase tuning to below one milliwatt. The study was published by *Nature Photonics*.

"Usually the bigger something is, the better. But integrated devices are a notable exception," said **Nanfang Yu**, associate professor of applied physics, co-principal investigator (PI) on the team, and an expert in nanophotonics. "It's really hard to confine light to a spot and manipulate it without losing much of its power. We are excited that in this work we've made a breakthrough that will greatly expand the horizon of large-scale visible-spectrum integrated photonics."



(Above) A visible-spectrum phase modulator (the ring at the center of a radius of 10 microns) is much smaller than a grain of pollen of the morning glory. Image credit: Heqing Huang & Cheng-Chia Tsai/Columbia Engineering (Below) PhD student, Heqing Huang, & Prof. Yu



Conventional optical phase modulators operating at visible wavelengths are based on light propagation in waveguides. Yu worked with his colleague **Michal Lipson**, who is the leading expert on integrated photonics based on silicon nitride, to develop a very different approach.

"The key to our solution was to use an optical resonator and to operate it in the so-called 'strongly over-coupled' regime," said Lipson, co-PI on the team and Eugene Higgins Professor of Electrical Engineering and professor of applied physics.

Optical resonators are structures with a high degree of symmetry, such as rings that can cycle a beam of light many times and translate tiny refractive index changes to a large phase modulation. Resonators can operate under several different conditions and so need to be used carefully. For example, if operating in the "under-coupled" or "critical coupled" regimes, a resonator will only provide a limited phase modulation and, more problematically, introduce a large amplitude variation to the optical signal. The latter is a highly undesirable optical loss because accumulation of even moderate losses from individual phase modulators will prevent cascading them to form a circuit that has a sufficiently large output signal.

To achieve a complete 2π phase tuning and minimal amplitude variation, the Yu-Lipson team chose to operate a micro-ring in the "strongly over-coupled" regime, a condition in which the **(Continued on page 5)**

"Micron-Scale, Efficient, Robust Phase Modulators at Visible Wavelengths," Guozhen Liang, Heqing Huang, Aseema Mohanty, Min Chul Shin, Xingchen Ji, Michael Joseph Carter, Sajan Shrestha, Michal Lipson, and Nanfang Yu, *Nat. Photon.* 15, 908–913 (2021) doi.org/10.1038/s41566-021-00891-y

Yu Named 2022 Optica Fellow

Nanfang Yu

Professor Nanfang Yu has been named a 2022 Optica Fellow "for the invention and development of metasurfaces and their application to imaging and cooling".

The Class of 2022 Fellows selected by Optica (formerly OSA) are those "who have served with distinction in the advancement of optics and photonics" and were recognized for "their contributions to education, research, engineering, business and serving the community." (Optica.org)

Nanfang Yu is an Associate Professor of Applied Physics at the Department of Applied Physics and Applied Mathematics, Columbia University. His lab conducts experimental research on "flat optics", which are nanostructured low-dimensional materials that can control light in previously unimaginable ways.

Prof. Yu and his students work on three research themes related to flat optics: (1) metasurfaces, which are engineered 2D metamaterials that can control light waves propagating in free space in arbitrary ways, (2) integrated photonics, where light propagation and control are confined within networks of waveguides on a chip, and (3) biophotonics and bioinspired optical materials. The vision of Yu's research is to replace conventional bulky optical devices and systems with their "flat" counterparts and to understand the life history of living systems from the point of view of photonics.

Before joining the faculty at Columbia University, Prof. Yu was a Research Associate in the School of Engineering and Applied Sciences at Harvard University from 2009-2012. He received his Ph.D. in Engineering Sciences from Harvard University in 2009, and his B.S. in Electronics from the Department of Electronics at Peking University, Beijing, China, in 2004.

Prof. Yu is the recipient of 2017 Defense Advanced Research Projects Agency (DARPA) Director's Fellowship, 2016 Office of Naval Research (ONR) Young Investigator Program Award, and 2015 DARPA Young Faculty Award.

New Device Modulates Visible Light—Without Dimming It—with the Smallest Footprint and Lowest Power Consumption

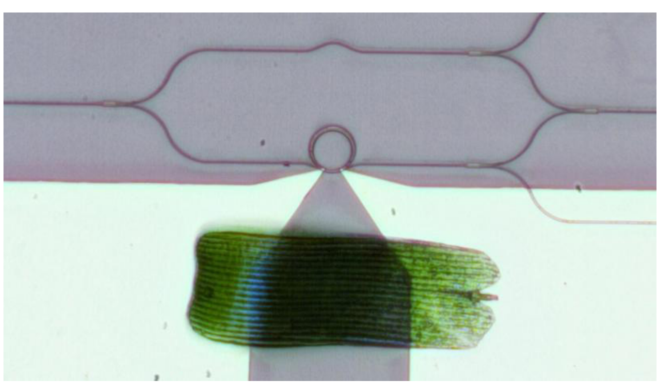
(Continued from page 4)

coupling strength between the micro-ring and the "bus" waveguide that feeds light into the ring is at least 10 times stronger than the loss of the micro-ring. "The latter is primarily due to optical scattering at the nanoscale roughness on the device sidewalls," Lipson explained. "You can never fabricate photonic devices with perfectly smooth surfaces."

The team developed several strategies to push the devices into the strongly over-coupled regime. The most crucial one was their invention of an adiabatic micro-ring geometry, in which the ring smoothly transitions between a narrow neck and a wide belly, which are at the opposite edges of the ring. The narrow neck of the ring facilitates the exchange of light between the bus waveguide and the micro-ring, thus enhancing the coupling strength. The ring's wide belly reduces optical loss because the guided light interacts only with the outer sidewall, not the inner sidewall, of the widened portion of the adiabatic micro-ring, substantially reducing optical scattering at the sidewall roughness.

In a comparative study of adiabatic micro-rings and conventional micro-rings with uniform width fabricated side by side on the same chip, the team found that none of the conventional micro-rings satisfied the strong over-coupling condition—in fact, they suffered very bad optical losses—while 63% of the adiabatic micro-rings kept operating in the strongly over-coupled regime.

"Our best phase modulators operating at the blue and green colors, which are the most difficult portion of the visible spectrum, have a radius of only five microns, consume power of 0.8 mW for π phase tuning, and introduce an amplitude variation of less than 10%," said Heqing Huang, a graduate student in Yu's lab and first author of the paper. "No prior work has demonstrated such compact, power-efficient, and low-loss phase modulators at visible wavelengths."

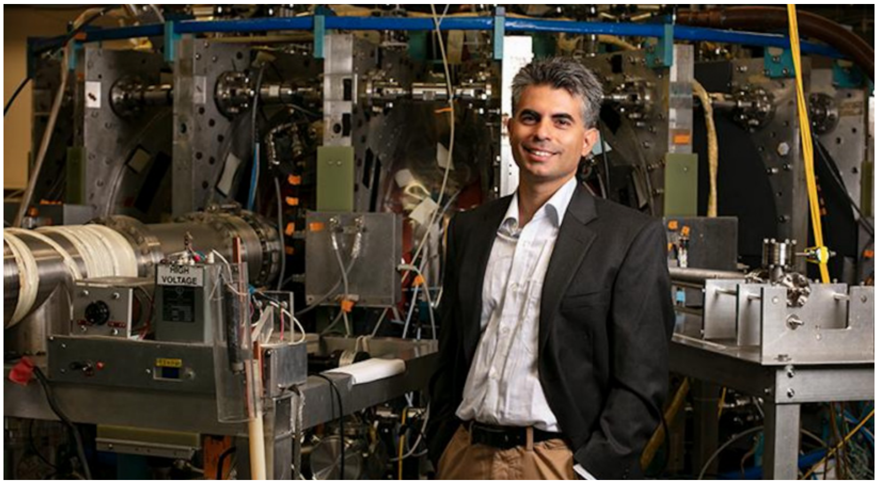


A visible-spectrum phase modulator (the ring at the center of a radius of 10 microns) is tinier than a butterfly wing scale. Image credit: Heqing Huang and Cheng-Chia Tsai/Columbia Engineering

The devices were designed in Yu's lab and fabricated in the Columbia Nano Initiative cleanroom, at the Advanced Science Research Center NanoFabrication Facility at the Graduate Center of the City University of New York, and at the Cornell NanoScale Science and Technology Facility. Device characterization was conducted in Lipson's and Yu's labs.

The researchers note that while they are nowhere near the degree of integration of electronics, their work shrinks the gap between photonic and electronic switches substantially. "If previous modulator technologies only allow for integration of 100 waveguide phase modulators given a certain chip footprint and power budget, now we can do that 100 times better and integrate 10,000 phase shifters on chip to realize much more sophisticated functions," said Yu.

The Lipson and Yu labs are now collaborating to demonstrate visible-spectrum LIDAR consisting of large 2D arrays of phase shifters based on adiabatic micro-rings. The design strategies employed for their visible-spectrum thermo-optical devices can be applied to electro-optical modulators to reduce their footprints and drive voltages, and can be adapted in other spectral ranges (e.g., ultraviolet, telecom, mid-infrared, and terahertz) and in other resonator designs beyond micro-rings.



Carlos Paz-Soldan

Paz-Soldan Honored for Contributions to Plasma Physics Research

The award recognizes his "groundbreaking contributions and scientific leadership in the understanding of non-axisymmetric magnetic fields and relativistic electrons in tokamak plasmas."

By Jesse Adams, Originally published by Columbia Engineering

Professor Carlos Paz-Soldan has been named recipient of the 2021 Thomas H. Stix Award for Outstanding Early Career Contributions to Plasma Physics Research from the American Physical Society (APS). The prestigious award, which honors rising researchers who have accomplished outstanding theoretical, experimental, computational, or technical work across the field, recognizes his "groundbreaking contributions and scientific leadership in the understanding of non-axisymmetric magnetic fields and relativistic electrons in tokamak plasmas."

"I'm extremely honored to be recognized with this award," Paz-Soldan said. "It reflects positively on the innovative work being done throughout the fusion community to realize our goal of a new energy source."

Paz-Soldan joined Columbia Engineering's Department of Applied Physics and Applied Mathematics at the start of this year after serving as a staff scientist in General Atomics' Magnetic Fusion Energy Division, for which he conducted research at the DIII-D National Fusion Facility and around the world. His work focuses on solving the scientific and technological challenges of harnessing controlled fusion energy on Earth, particularly problems of tokamak operation, stability, and control.

Established in 2013, the Stix Award includes a $3,000 prize and a place of honor at the APS Division of Plasma Physics' annual meeting this fall.

"Carlos is an outstanding plasma physicist well deserving of this early career recognition," said Gerald Navratil, Thomas Alva Edison Professor of Applied Physics. "We were delighted when he chose to join us this year as a faculty colleague at Columbia University."

Paz-Soldan Receives DOE Awards for Work to Advance Fusion Science & Control at National Facilities

Carlos Paz-Soldan's research group has received two awards from the US Department of Energy (DOE) to advance the scientific and technical state of the art at national US fusion facilities on both coasts.

The first award, entitled "Disruption and ELM Control Research in the DIII-D Tokamak", targets the control of edge-localized mode (ELM) instabilities occurring at the plasma edge as well as unintended fast plasma quenches (called disruptions), both of which ultimately have adverse effects on plasma-facing components. The DIII-D Tokamak device, located in San Diego, CA, is a pioneering facility in both of these areas and possesses a comprehensive suite of measurement capabilities to advance the state of the art.

The second award, entitled "Resistive Stability and Shape Optimization Research in NSTX-U", also targets instability control and configuration research at the National Spherical Torus Experiment Upgrade (NSTX-U), located in Princeton, NJ. The resistive stability work targets developing models and algorithms to deal with asymmetries arising from device assembly and manufacturing, while the configuration research explores the application of plasma shapes whose cross sections resemble a bowtie.

These awards complement Prof. Paz-Soldan's existing DOE awards to build a comprehensive understanding of tokamak edge instability control by leveraging data from international facilities, as well as understanding the frontiers of science with regards to relativistic electron dynamics in fusion reactor prototypes. Both awards provide research opportunities for doctoral students and early career researchers.

Team led by Bienstock Wins $530,000 in DOE's Grid Optimization Competition

Group places high in competition, which is focused on developing software management solutions for power grid problems.

Daniel Bienstock

By Holly Evarts,
Originally published by Columbia Engineering

Daniel Bienstock, Liu Family Professor of Industrial Engineering and Operations Research and professor of applied physics and applied mathematics, and his team, including colleagues from Northwestern University and Artelys, a French software company, won the second-place prize of $530,000 in the U.S. Department of Energy's Advanced Research Projects Agency-Energy's (ARPA-E) Grid Optimization (GO) Competition.

ARPA-E funds early-stage projects related to energy and the grid, with an eye toward potential startups. This GO competition focused on the Alternating Current Optimal Power Flow problem, a complex computational task used to decide how to operate a power grid network so as to safely and robustly meet electricity demand at minimum cost in large geographical areas, such as New York State, New England, California, or Texas. Teams had to develop software to handle a large number of test cases involving very large networks.

This task gives rise to a complex computation that combines engineering, physics, mathematics, and computer science. There were 21 competitors and two rounds. The computation was so complex that scoring the competitors took about two months. Said Bienstock, "The idea is to break down barriers to empower widespread, fast adoption of emerging grid technologies to save billions of dollars in the energy sector. We were really happy to win the first round and come in second in the second."

Multidisciplinary Research Team Awarded $1.2M NSF Grant to Improve Traffic Management in Real Time


Qiang Du

Originally published by Columbia Engineering

Professors Sharon Di (Civil Engineering), **Qiang Du** (Applied Mathematics), Gil Zussman, and Zoran Kostic (both Electrical Engineering) were recently awarded a $1.2 million grant from the National Science Foundation's Cyber Physical Systems (CPS) program for their proposal "CPS: Medium: Hybrid Twins for Urban Transportation: From Intersections to Citywide Management."

With this funding, the team will create a virtual replica, or digital twin, of New York City that will continuously learn and dynamically update itself as the city traffic environment changes in real time. The twin will help traffic managers to monitor traffic patterns as they happen and quickly come up with adaptive management strategies. The researchers will use Columbia's COSMOS, the only beyond-5G testbed in New York City, to get real-time traffic data, leveraging Cosmos's rich sensor data and deep computational capabilities.

The digital twin is a hybrid of both machine learning and traffic modeling, reflecting the team's multidisciplinary approach to how traffic congestion propagates in cities. They will train the system online by taking in real-time data collected from Cosmos sensors, including roadside infrastructure and in-vehicle sensors. With this data, the system can predict traffic conditions, accidents, and mitigate traffic congestion as well as optimize traffic flow so that people can travel across cities with fewer stops at intersections and reduced emission levels.

Du will Present SIAM Invited Address at JMM 2022

Qiang Du will present the SIAM invited address at the Joint Mathematics Meeting (JMM) 2022. JMM is touted as "the largest mathematics gathering in the world" and will take place in Seattle from January 5-8, 2022. Prof. Du will present his talk, "Analysis and Applications of Nonlocal Models," on January 6, 2022. JMM is organized by sixteen mathematics related societies and associations, including the American Mathematical Society (AMS), American Statistical Association (ASA), and Society for Industrial and Applied Mathematics (SIAM), among others.

Prof. Du is the faculty leader of the Computational Mathematics and Multiscale Modeling (CM3) group in the APAM Department at Columbia Engineering and he is also affiliated with the Data Science Institute. He has earned numerous honors, including the USACM Hughes Medal, the Feng Kang prize in Scientific Computing, and both the Outstanding Paper prize and SIGEST Award from SIAM. He is also a fellow of SIAM, AMS and the American Association for the Advancement of Science (AAAS). He is the editor-in-chief of the *SIAM Journal of Applied Mathematics* and the founding co-editor-in-chief of *Communications of the American Mathematical Society*, while also serving on the editorial board of more than a dozen international journals.

Barmak and Colleagues Win the Prestigious NSF DMREF Award for Microstructure by Design


Katayun Barmak

Katayun Barmak, Philips Electronics Professor of Applied Physics and Applied Mathematics and Materials Science and Engineering, and her colleagues, Professor Yekaterina Epshteyn, Department of Mathematics, University of Utah, Professor Chun Liu, Department of Mathematics, Illinois Institute of Technology, and Professor Jeffrey Rickman, Department of Materials Science and Engineering and Department of Physics, Lehigh University, won a 4-year $1.8 million National Science Foundation 'Designing Materials to Revolutionize and Engineer our Future' (DMREF) award to integrate grain growth experiments, data analytics, simulation and theory. The grant is jointly funded by the Division of Mathematical Sciences and the Division of Materials Research.

Most technologically useful materials are polycrystalline microstructures composed of a myriad of small monocrystalline grains delimited by grain boundaries. An understanding of the evolution of grain boundaries and associated grain growth (coarsening) is essential in determining the properties of materials across multiple scales. Despite tremendous progress in formulating microstructural models, however, current descriptions do not fully account for various grain growth mechanisms, detailed grain topologies and the effects of different time scales on microstructural evolution. As a result, conventional theories have limited predictive capability. The goal of the project is to develop a predictive theory of grain growth in polycrystalline materials through the construction of novel, closely integrated data-driven numerical simulation and mathematical modeling combined with data analytics, analysis, and a set of critical experiments. This interdisciplinary project, requiring the complementary expertise of applied mathematicians and materials scientists, is firmly aligned with the Materials Genome Initiative. The new knowledge and tools that will emerge from the project will have a profound impact on the performance and reliability of polycrystalline materials used in many technologically useful systems and structures, thereby expediting advanced materials development and deployment. Predictive computational algorithms and data will be made available and accessible to other researchers. For the training of the next-generation materials workforce, in addition to mentoring of graduate and undergraduate students, the PIs will participate in outreach activities and will continue to work towards increasing diversity and broadening participation within STEM.

Grain growth is a very complex process and may be viewed as the anisotropic evolution of a large metastable network. One of the main thrusts of the project will be to uncover possible stochastic processes that define the evolution of various statistical measures of grain growth, discover relations among them, and establish links to materials properties. Results from structure-preserving numerical simulations alongside critical sets of experiments and new experimental data will be invaluable in navigating the modeling and analysis. The project will also create and employ specific data analysis techniques for the study of dynamic evolution of grains in experimental and computational systems with the goal of validating and further refining the microstructural models. This component of the project, will lead to a) the development of new materials informatics methods, b) innovative stochastic differential equations/differential equations models of grain growth, c) new mathematical and numerical analysis techniques for coarsening systems, as well as d) improved computational tools. In turn, the results of combined data analytics, modeling and analysis will be used to guide the design of subsequent experiments. Experimentally, grain growth will be examined in prototypical metallic thin films. As most elemental metals and many metallic alloys have cubic structures, the proposed studies will have broad applicability.

Researchers Use New X-ray Technique to Conserve Henry VIII's Favorite Warship

International team applied new method developed at Columbia Engineering and the European Synchrotron Radiation Facility to discover potentially harmful substances within the Mary Rose's wooden remains

By Holly Evarts, Originally published by Columbia Engineering.

A multidisciplinary team of researchers from Columbia Engineering, European Synchrotron Radiation Facility (ESRF), University of Sheffield, Mary Rose Trust, and the University of Copenhagen used a new X-ray technique developed by Columbia and ESRF to discover that there are zinc-containing nanoparticles lodged within the wooden hull of the Mary Rose, Henry VIII's favorite warship. These nanoparticles are leading to deterioration of the remains of the ship, which sank in battle in 1545 and was raised from the Solent in 1982. The Tudor ship and its collection of 10,000 artifacts are now housed in the Mary Rose museum in Portsmouth, UK.

The new technique--computed tomography PDF (ctPDF)--used to examine the ship's remains was originally developed in a study co-authored by Columbia Engineering/Brookhaven National Laboratory and ESRF members of the team to study catalysts and batteries. When approached by Serena Cussen, chair in functional nanomaterials at the University of Sheffield, **Simon Billinge**, a materials scientist at Columbia who helped develop the method for his studies using a synchrotron at Brookhaven, thought ctPDF might be a good way to see what was going on inside the remains of the ship. Billinge's group imaged how X-rays scattered through sample cross sections at the nanoscale and then precisely characterized the nature of the materials hidden deep in the Tudor wood. Comparing the resulting images pixel by pixel allowed them to determine that over centuries the wood had become riddled with nanoparticles of zinc sulfide.

> ***"Our results were like a microscale archeological dig where, by studying the location and composition of the deposits, we could see how the bacteria colonised the wood and what they ate.***
>
> ***- Simon Billinge***
> ***Professor of Materials Science & Applied Physics & Applied Mathematics***

"It was especially exciting to get a glimpse into the history of the Mary Rose in the years since it sank," said Billinge, who has a joint appointment at the U.S. Department of Energy's Brookhaven National Laboratory and is a co-author of the paper published today by Matter. "The zinc sulphide deposits come from anaerobic bacteria living in the wood as it sat sunk in the seabed--they are essentially bacteria poop. Our results were like a microscale archeological dig where, by studying the location and composition of the deposits, we could see how the bacteria colonised the wood and what they ate."

The team also found polymer deposits within the ship's wood. The polymer was sprayed on the ship to help preserve its remains after it was raised from the seabed 39 years ago, when it was thought that the polymer would lend mechanical stability. However, there is some recent evidence that this polymer can itself degrade and act as a source of degrading acids to the materials that surround it.

The new X-ray technique now enables researchers to track the polymer within the ship's wood--a vital step in developing conservation strategies. The new method could inform future strategies to preserve the Mary Rose and other important archaeological discoveries.

"This is the first time that we have used the technique of X-ray total scattering with computed tomography to successfully study cultural heritage samples at the nanoscale. This work opens doors to new experiments in the domain of conservation," said Marco Di Michiel, scientist in charge of beamline ID15 at ESRF.

Efforts are now underway to understand in detail the degradation effects these zinc-based particles may have had on the Mary Rose and how they might be neutralized.

Images of the Mary Rose above and on the cover were originallly published by Columbia Engineering. The study is titled "Location and characterization of heterogeneous phases within Mary Rose wood." https://doi.org/10.1016/j.matt.2021.09.026

Faculty Updates & New Publications

A recent paper, "Electrodeposition of Cu(111) onto a Ru(0001) seed layer for epitaxial Cu interconnects," by **Prof. Katayun Barmak** and colleagues, was a featured article on the cover of the *Journal of Applied Physics*' October issue. https://doi.org/10.1063/5.0063418

An article published by Brookhaven National Laboratory, "Uncovering Hidden Local States in a Quantum Material," features research by **Prof. Simon Billinge** and colleagues. "By heating the material, scientists discovered states of local broken symmetry, which may enable the technologically relevant properties—such as those for quantum computing and electronics—that arise at much-lower temperature." https://bit.ly/3mwAy6z

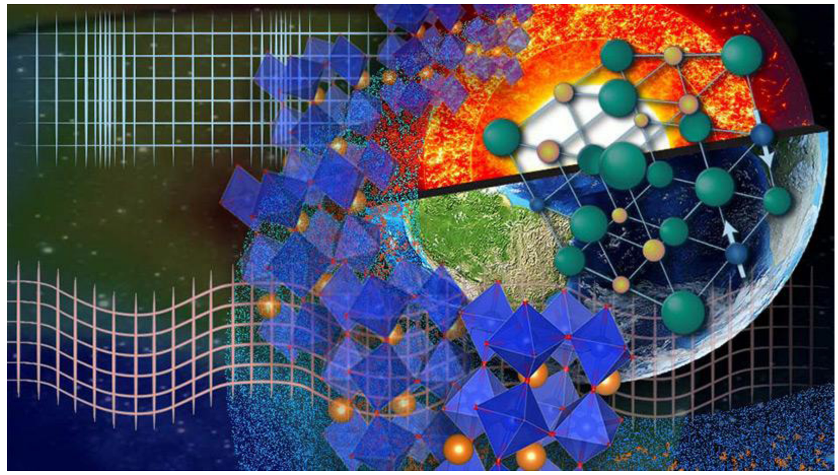
Prof. Allen Boozer was featured in the *APS* article, "Passive-aggressive: New coil stands ready to tame runaway electrons," about the SPARC tokamak. Prompted by a theoretical idea from Prof. Boozer, the SPARC design includes an innovative new coil structure which promises fully passive protection from the threat of runaway electrons. https://bit.ly/3oxLaDy

A new *Nature Electronics* article, "High carrier mobility in graphene doped using a monolayer of tungsten oxyselenide," features research by an interdisciplinary team of researchers from Columbia University (including **Prof. Michal Lipson**) and Sungkyungkwan University. The team has "introduced a clean technique to dope graphene via a charge-transfer layer made of low-impurity tungsten oxyselenide (TOS)." https://doi.org/10.1038/s41928-021-00657-y

Prof. Michael Mauel was featured in the *Newsweek* article, "World's Most Powerful Magnet Will Help Recreate the Sun's Power on Earth," about the first ITER Central Solenoid module. https://bit.ly/34HXBVH

In the article "ENSO-Based Predictability of a Regional Severe Thunderstorm Index," published by *Geophysical Research Letters*, **Prof. Michael Tippett** and his colleague, Dr. Chiara Lepore (LDEO), use "coupled climate model forecasts of Niño 3.4 and a regional (Texas, Oklahoma, Arkansas, and Louisiana) tornado environment index (TEI) to examine the modulation of US severe thunderstorm activity by the El Niño-Southern Oscillation (ENSO)." https://doi.org/10.1029/2021GL094907

Quantum Phase Transition Detected on a Global Scale Deep Inside the Earth



Spin transition discovered in the Earth's mantle; finding will improve understanding the Earth's interior, and enable better understanding of tectonic events including volcanic eruptions and earthquakes.

By Holly Evarts, Originally published by Columbia Engineering

The interior of the Earth is a mystery, especially at greater depths (> 660 km). Researchers only have seismic tomographic images of this region and, to interpret them, they need to calculate seismic (acoustic) velocities in minerals at high pressures and temperatures. With those calculations, they can create 3D velocity maps and figure out the mineralogy and temperature of the observed regions. When a phase transition occurs in a mineral, such as a crystal structure change under pressure, scientists observe a velocity change, usually a sharp seismic velocity discontinuity.

In 2003, scientists observed in a lab a novel type of phase change in minerals--a spin change in iron in ferropericlase, the second most abundant component of the Earth's lower mantle. A spin change, or spin crossover, can happen in minerals like ferropericlase under an external stimulus, such as pressure or temperature. Over the next few years, experimental and theoretical groups confirmed this phase change in both ferropericlase and bridgmanite, the most abundant phase of the lower mantle. But no one was quite sure why or where this was happening.

In 2006, Columbia Engineering Professor Renata Wentzcovitch published her first paper on ferropericlase, providing a theory for the spin crossover in this mineral. Her theory suggested it happened across a thousand kilometers in the lower mantle. Since then, Wentzcovitch, who is a professor in the applied physics and applied mathematics department, earth and environmental sciences, and Lamont-Doherty Earth Observatory at Columbia University, has published 13 papers with her group on this topic, investigating velocities in every possible situation of the spin crossover in ferropericlase and bridgmanite, and predicting properties of these minerals throughout this crossover. In 2014, Wenzcovitch, whose research focuses on computational quantum mechanical studies of materials at extreme conditions, in particular planetary materials predicted how this spin change phenomenon could be detected in seismic tomographic images, but seismologists still could not see it.

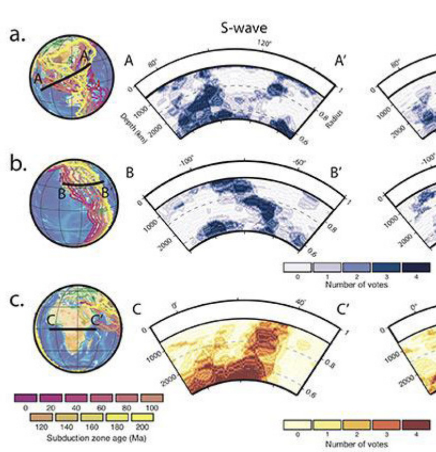


Figure: Spin crossover signature: disappearing plates and plumes. Cold, subducting oceanic plates are seen as fast velocity regions in (a) and (b), and warm rising mantle rock is seen as slow velocity regions in (c). Plates and plumes produce a coherent tomographic signal in S-wave models, but the signal partially disappears in P-wave models.

Working with a multidisciplinary team from Columbia Engineering, the University of Oslo, the Tokyo Institute of Technology, and Intel Co., Wenzcovitch's latest paper details how they have now identified the ferropericlase spin crossover signal, a quantum phase transition deep within the Earth's lower mantle. This was achieved by looking at specific regions in the Earth's mantle where ferropericlase is expected to be abundant. The study was published October 8, 2021, in *Nature Communications*.

"This exciting finding, which confirms my earlier predictions, illustrates the importance of materials physicists and geophysicists working together to learn more about what's going on deep within the Earth," said Wentzcovitch.

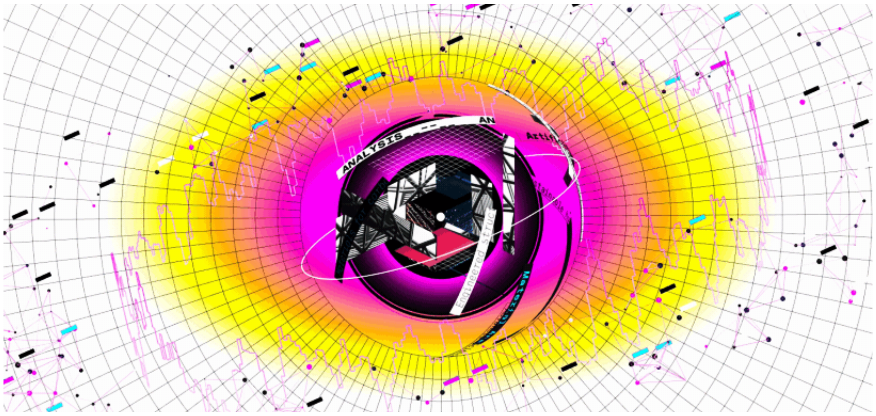
Spin transition is commonly used in materials like those used for magnetic recording. If you stretch or compress just a few nanometer-thick layers of a magnetic material, you can change the layer's magnetic properties and improve the medium recording properties. Wentzcovitch's new study shows that the same phenomenon happens across thousands of kilometers in the Earth's interior, taking this from the nano- to the macro-scale.

"Moreover, geodynamic simulations have shown that the spin crossover invigorates convection in the Earth's mantle and tectonic plate motion. So we think that this quantum phenomenon also increases the frequency of tectonic events such as earthquakes and volcanic eruptions," Wentzcovitch notes.

There are still many regions of the mantle researchers do not understand and spin state change is critical to understanding velocities, phase stabilities, etc. Wentzcovitch is continuing to interpret seismic tomographic maps using seismic velocities predicted by ab initio calculations based on density functional theory. She is also developing and applying more accurate materials simulation techniques to predicting seismic velocities and transport properties, particularly in regions rich in iron, molten, or at temperatures close to melting.

"What's especially exciting is that our materials simulation methods are applicable to strongly correlated materials--multiferroic, ferroelectrics, and materials at high temperatures in general," Wentzcovitch says. "We'll be able to improve our analyses of 3D tomographic images of the Earth and learn more about how the crushing pressures of the Earth's interior are indirectly affecting our lives above, on the Earth's surface."

"Seismological expression of the iron spin crossover in ferropericlase in the Earth's lower mantle," Shephard, G.E., Houser, C., Hernlund, J.W. et al. *Nat. Commun.* 12, 5905 (2021). https://doi.org/10.1038/s41467-021-26115-z



Think Like an Engineer

Using AI to invent stronger, more sustainable materials

By Matthew Hutson, originally published by Columbia Engineering Magazine

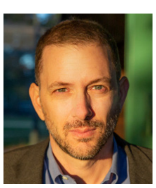
Scientists have used artificial intelligence, particularly machine learning, to sift through their experimental data, searching for patterns that might reveal something new about the world.

But as the technology matures, AI is increasingly seen less as a smart spreadsheet and more as a creative co-pilot, helping researchers design experiments, collect data, and build data analysis tools. In the world of materials research, such computational collaborators could lead to wondrous new compounds. Even more wondrous: using them to train AI to think like an engineer.

One problem users of machine learning face is a lack of sufficient data with which to train the model. That's especially true in scientific and engineering fields, where data is collected by run ning experiments and recording the results in notebooks. "Sometimes people use electronic notebooks, but the notebooks don't talk to each other," says **Simon Billinge**, professor of materials science and applied physics and applied mathematics. "The data we need [to fashion smarter experiments] is not sitting in a database anywhere." He wondered if he could rewire the whole process.

Billinge's group, working with chemists at Stony Brook University and Oak Ridge National Laboratory, tackled that problem by training AI to speed up data collection. Billinge typically uses AI to determine the chemical structure of manufactured materials. In this proof of concept, he gave his AI an "inverse" problem: Instead of predicting an experiment's results, he wanted to find a process to get those results—for instance, particular mixtures of copper and oxygen. Once he came up with a method to put that process on autopilot, his machine repeatedly tweaked its own "knobs"—altering temperature and gas ingredi ents—while measuring the results. It used each result to decide what to try next, a process called adaptive learning.

"We want the machine to develop a chemical intuition, and share its insights to help us fine-tune ours," says Yevgeny Rakita Shlafstein, a postdoc research scientist in Billinge's lab. This first demonstration was simple, but it made it into the prestigious Journal of the American Chemical Society, Billinge notes, "showing people that this is what their future looks like." **Read the full article at: https://bit.ly/3p4Ankt**



Sobel on Tropical Storm Henri, Extreme Weather & Climate Talks

Adam Sobel, Professor of Applied Physics and Applied Mathematics and Professor of Earth and Environmental Sciences, wrote several articles for *The New York Times*, *Bulletin of the Atomic Scientists*, and *CNN Opinion* about Tropical Storm Henri, extreme weather, and recent climate talks. He was also featured by numerous other media outlets. Links to the articles are available at: **https://www.apam.columbia.edu/sobel-news**

Sobel is the author of *Storm Surge: Hurricane Sandy, Our Warming Planet, and the Extreme Weather of the Past and Future* and host of the podcast *Deep Convection*. He recently joined the Board of Advisors of Jupiter, the leading provider of predictive data and analytics for climate risk and resilience.

Billinge Mentors Student-Led Team That Wins $60,000 Google Research Award for Inclusion

Project will improve computational capabilities for researchers in East Africa through a local organization that trains PhD students in materials science

By Allison Chen, published by Columbia Engineering

Simon Billinge

Simon Billinge, professor of materials science and applied physics and applied mathematics, jointly mentored a student-led team—with Columbia University undergraduate researcher **Jaylyn C. Umana**— that received a $60,000 Google Research Award for Inclusion Research Program grant. Their award-winning proposal is aimed at connecting African scientists to state-of-the-art computing tools for materials discovery and innovation on the free-to-access Google cloud platform through the Joint Undertaking for an African Materials Institute–Open Computing Facility (JUAMI-OCF).

Many African nations fall into the category of high to extreme risk on the Climate Change Vulnerability Index, and research efforts are generally carried out outside of sub-Saharan Africa. JUAMI-OCF is focused on finding advanced, sustainable, stable, and equitable energy solutions for sub-Saharan African countries that need reliable access to energy to improve and sustain their quality of life. The goal is to build technological innovations in energy and sustainability that will be implemented in local communities, driven by African researchers and institutions.

Billinge's team is centered on the co-development between researchers in East Africa and the United States of accessible Density Function Theory (DFT) capabilities, an important tool allowing materials researchers to understand and explore material properties. DFT requires significant computational resources and expertise that are not universally available, especially in Africa.

"Our hope is that this project will enable high-impact computational materials and sustainability research," Billinge said. "We plan to build accessible onboarding tools for complex DFT calculations, hold educational workshops on the use of this tool, and foster a collaborative US and East African community of DFT users. And, in the long term, we hope to establish a computational materials science and sustainability program covering all of East Africa."

A workshop at the University of Rwanda, Kigali

Latha Venkataraman, Vice Provost for Faculty Affairs, Gussman Professor of Applied Physics, Professor of Chemistry

Electrifying Chemistry

Latha Venkataraman pioneers a new method for 'green chemistry'

Originally published by Columbia Engineering Magazine

For years, applied physicist **Professor Latha Venkataraman** sought to create electronic circuits, each just a single molecule—research she hoped could help lay the groundwork for revolutionary advances across nanotechnology. What she didn't expect was how this research recently uncovered a whole new way to catalyze reactions, known as electric-field-driven chemistry. Taking this breakthrough as its premise, Columbia's new National Science Foundation Center for Chemistry with Electric Fields launched last year with Venkataraman at the helm. Together with her team, Venkataraman now seeks to turn a moment of serendipity into a host of novel techniques that could potentially transform the field by using dramatically less energy without toxic catalysts or by-products.

What's the big idea driving your research?

My lab has traditionally been interested in understanding how current flows through molecules. In order to do that, we've developed experimental methods to attach single molecules to metal electrodes. A couple of years ago, we realized we were creating large electric fields at the sharp tips of the electrodes in the vicinity of the molecules and that these fields were driving chemical reactions, allowing us to study both the electronic characteristics of the reactants and the product formed. In other words, we found that the electric fields were actually doing chemistry.

Past theoretical research had predicted electric fields could drive chemical reactions: certain structures in enzymes are thought to catalyze reactions much better than other structures due to electrically charged ions organized around where the reactions occur. But no one had managed to clearly show this phenomenon occurring in a solution with an externally controlled field until our experiments. These preliminary results became the basis of our center.

This is one aspect of fundamental research that's really fulfilling, how it opens up pathways previously unimagined. Having been trained as an experimental physicist, I never thought I would be seeking better ways to catalyze chemical reactions.

How is electric-field-driven chemistry poised to make a major impact?

There are two things we think electric fields can do: they can lower the amount of energy needed for a chemical reaction to make a product, and they drive chemical reaction selectivity, enabling formation of a specific type of product that wouldn't be formed without the field.

Our center aims to discover how reactions can be driven by electric fields, while also figuring out the reaction mechanism itself. Once we prove that different classes of reactions can be catalyzed by electric fields, we'll move on to figuring out how to do that at scale.

What are some recent center developments you find electrifying?

We have some preliminary results for quite a few reactions where we think electric fields have catalyzed synthesis. We're now trying to understand exactly what products we are making and to demonstrate that it is really the field that is driving reactivity and not something else. Since we are doing these experiments with very small amounts of reactants, we yield minute amounts of products which are not trivial to characterize with standard chemical techniques. Identifying these products is like solving a puzzle, pushing the limits of our characterization tools to figure out what they are. This is really exciting.

Dynamic Control of Photon Lifetime for Quantum Random Number Generation

APAM Research Scientist **Dr. Yoshitomo Okawachi**'s paper, "Dynamic control of photon lifetime for quantum random number generation," was published by *Optica*. The work is a collaboration between Prof. Alexander Gaeta's Quantum and Nonlinear Photonics Group and Prof. Michal Lipson's Nanophotonics Group. Other authors **Bok Young Kim** (APAM PhD Candidate), **Yun Zhao** (EE PhD Candidate), **Dr. Xingchen Ji** (CISE Postdoctoral Research Scientist), **Prof. Michal Lipson** (Higgins Professor of Electrical Engineering and Professor of Applied Physics), and **Prof. Alexander Gaeta** (Rickey Professor of Applied Physics & Materials Science and Professor of Electrical Engineering.

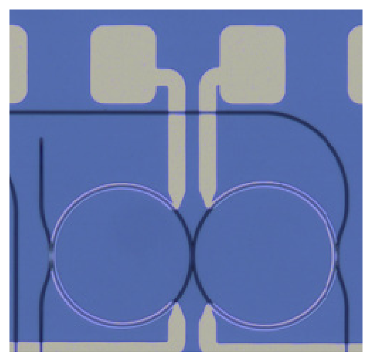


Figure: Microscope Image of SiN coupled-ring device. The mode interaction position is thermally tuned via integrated heaters to turn on and off the degenerate parametric oscillator for random number generation.

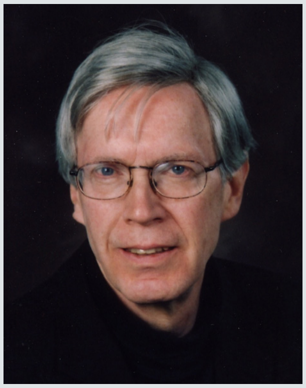
In a passive cavity geometry, there exists a trade-off between resonant enhancement and response time, which is inherently limited by the cavity photon lifetime. The authors present a compelling approach to achieving frequency-selective, dynamic control of the cavity photon lifetime using a coupled-ring geometry. The photon lifetime is tuned by controlling the spectral position of an avoided mode-crossing using thermo-optic tuning with integrated resistive heaters.

This effect is used to achieve fast turn-on and turn-off of a degenerate parametric oscillator to achieve on-chip true random number generation using continuous-wave pump lasers. The authors achieve generation rates of 500 kbit/s and verify the randomness using the NIST Statistical Test Suite. The scheme allows for overcoming the Q-limited generation rate that exists in a single microresonator, and the coupled-ring system reduces the overall complexity since the pump lasers do not require external modulation using an acousto-optic modulator and an amplified RF driver, as demonstrated previously. Numerical modeling of the coupled-ring system indicates that the approach can readily achieve tunable reduction in photon lifetime by more than 100x, offering a promising path towards the realization of generation rates exceeding 1 Gbits/s and the development of a chip-scale, scalable high quality entropy source for cryptography applications.

"Dynamic control of photon lifetime for quantum random number generation," Yoshitomo Okawachi, Bok Young Kim, Yun Zhao, Xingchen Ji, Michal Lipson, and Alexander L. Gaeta, Optica 8(11), 1458-1461 (2021) https://doi.org/10.1364/OPTICA.433102

Antonoyiannakis Featured in *Physics Today:* A recent study by Adjunct Associate Research Scientist **Manolis Antonogiannakis** was highlighted by *Physics Today.* The study details how publicity in the science press can be used to predict citation accrual of research papers. **https://bit.ly/3fmztKr**

In Memoriam: Thomas C. Marshall



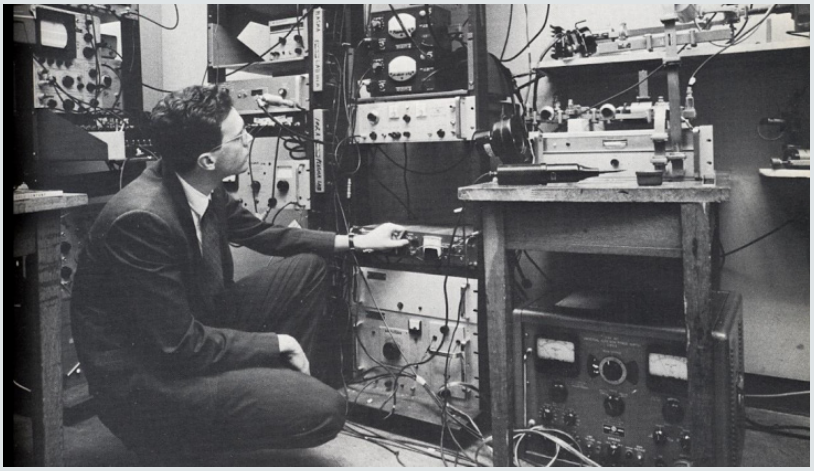
Thomas C. Marshall

Columbia Engineering mourns the loss of Thomas C. Marshall (1935-2021), Professor Emeritus of Applied Physics in the Department of Applied Physics and Applied Mathematics

Professor Thomas C. Marshall received his PhD in physics from the University of Illinois in 1960 and joined Columbia University in 1962 as a professor in the Department of Electrical Engineering. He became a Professor of Engineering Science in 1970 and was a member of the Plasma Physics Committee where he launched ground-breaking experimental research into the physics of plasmas, relativistic electron beams, and free electron lasers. Marshall was one of the nine founding faculty members of the Department in 1978, becoming one of Columbia's first Professors of Applied Physics.

Marshall was awarded Columbia's Great Teacher Award in 1995. During his forty-four years at Columbia, he supervised or co-supervised forty-four doctoral students. During the decade before he retired in 2006, he was the dedicated faculty advisor to students in the Medical Physics Program in the APAM Department.

Working with his students and colleague Professor Perry Schlesinger, Marshall pioneered the development of free electron lasers (FEL), which have been shown to generate very large amounts of power, tunable in bands from the microwave to the visible spectrum and beyond. In the 1970's, the first FEL in the Raman regime was demonstrated in Marshall's Lab. His research also included FEL photonics and led to the production of TW-level ultra-short pulses of radiation.



Thomas Marshall in the 1971 Columbia Engineering Yearbook

In 1985, Marshall published *Free Electron Lasers* (Macmillan, New York, 1985), which provided the first integrated treatment of the operation and characterization of the free-electron laser. Between 1985-87, he served on the APS Study Group on the Science and Technology of Directed Energy Weapons. Called by many "the most important APS study ever done", this study provided a clear technical assessment of the severe limitations of existing candidates for DEWs such as high intensity lasers and energetic particle beams.

FEL physics has a close relationship with laser and accelerator physics, and his research focus included innovation accelerator physics. Marshall explored new methods of accelerating particles using Brookhaven's Accelerator Test Facility (ATF).

In 1999, Marshall proposed the dielectric wake field accelerator. Working with his colleague, Jay Hirshfield, Marshall continued his research at the ATF where he established the fundamental physics of dielectric wake field acceleration. Although retiring from academic duties in 2006, Professor Marshall continued to apply his insights and pursue his remarkable discoveries in beam and accelerator physics and published his last paper in 2018.

Urteaga Named 2021 STAT Wunderkind

Iñigo Urteaga

Dr. Iñigo Urteaga, Associate Research Scientist in the APAM Department, has been named a 2021 STAT Wunderkind in recognition of his work on the development of statistical modeling for mobile health data.

STAT is a leading publication in medical news, and its annual Wunderkind list honors early career scientists who are doing groundbreaking work in their field. This award recognizes the contributions of Dr. Urteaga as part of the multi-disciplinary research carried out along with Prof. Chris Wiggins (APAM) and Prof. Noémie Elhadad (DBMI) on the development of statistical modeling and data science solutions for mobile health data.

The increasing availability of personal mobile health data opens up new opportunities for health insights, increased self-awareness, and informed health and wellness decisions. However, despite the ongoing research in machine learning for healthcare in general, there remain important knowledge gaps on effective statistical techniques that leverage self-tracked mobile data to answer questions related to personalized health.

Dr. Urteaga's most recent applied mathematics work has focused on the realm of self-tracked health data, where physiological and behavioral patterns are entangled. His research encompasses the theoretical understanding, development and implementation of computational statistics and data science techniques for complex healthcare settings, by extending statistical models and inference methods to provide meaningful and robust insights from heterogeneous, dynamic, noisy and incomplete data. Over the last few years, he has contributed to the field of digital phenotyping and statistical predictive modeling for mobile health data.

His research in statistical modeling for healthcare demands not only methodological innovations (that accurately disentangle information from spurious signals) but novel interdisciplinary collaborations (e.g., with mobile health data providers, clinicians and bio-informaticians). **Learn more his ressearch at https://bit.ly/3lU795A**

Alumni Reports

***Originally published in Columbia Engineering Magazine**

Steven Belenko (BS ‘68) writes: “After receiving my PhD from Columbia in experimental psychology, I spent my career doing research on different aspects of substance abuse, crime, and the criminal justice system. Since 2006, I have been a professor at Temple University, and am currently principal investigator for two research grants aimed at increasing access to treatment for people in the criminal justice system with opioid use disorders.”*

Siu-Wai Chan (BS ’80) writes: “I was so looking forward to celebrating my reunion this past June and had planned a number of ideas for making connections and engagements. Because of COVID-19, the reunion had to go virtual. I did ‘meet up’ with a number of classmates, but missed many others terribly. Catching up and exchanging the latest news was really wonderful among those that showed up online. I have been teaching at SEAS for the last 30 years and was the first woman of color to become a SEAS professor. In my Presidential Faculty Fellow-winning essay to the NSF years ago, I wrote that I wished to be an MVP (Most Valuable Professor). I am still working towards that goal. You are welcome to make suggestions on how I can achieve this status.”*

Jeremy Cohen (MS ’05) writes: “After many years living in New York and Chicago, I settled in Minneapolis with my wife and two kids. In 2016, I left my job at a large consulting firm and founded Solstice Strategy Group, a boutique strategy consulting firm serving companies across the life sciences sector. We work with companies of all sizes, but have a passion for supporting early-stage companies that are taking the long journey of bringing a product to market.”*

Mike Farmer (BS ‘82) writes: “I moved from the University of Michigan-Flint to Kettering University, where I am the department head of computer science. Kettering has the same small classes that I remember at Columbia. It’s a co-op school, so the students get lots of hands-on experience, both in their work and in our classes, where many labs are tied to the lectures. This is my sixteenth year in academia after 20 years in the aerospace and, later, automotive industries.”*

Medlina Han Williams (PhD ‘10) was named one of Ad Age’s 2021 “40 Under 40” honorees. Dr. Han is Chief Data Scientist at Dstillery.

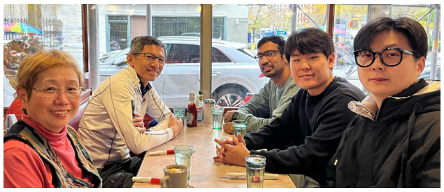
Ben Levitt (PhD ‘04), Director of Research and Development at Zap Energy, reflected on the path that led him through the world of physics into fusion technology development on the *Titans of Nuclear* Podcast.

Ta Li (BS ‘69) was selected for the 2021 American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME) Presidential Citation Award, which recognizes extraordinary and dedicated service in furtherance of the goals, purposes, and traditions of AIME. His citation will read: ‘For his unswerving and sustained dedication to AIME in building its prosperity and in support of its Member Societies.’ *

Manju Prakash (PhD ’85) writes: “After completing my dissertation in plasma turbulence in fusion devices, I actively pursued a research and teaching career in investigating the nature of plasma processes in a variety of physical systems (e.g., astrophysical plasmas, space plasmas, many-particle systems, and most recently, cosmological plasma formed in the early universe after the Big Bang). My graduate research at Columbia shaped my academic career considerably. Currently, I am affiliated with the mathematics department at Stony Brook University in New York. During the spring 2020 semester, I was scheduled to present on Hubble Tension problems in cosmology during the April American Physical Society Meeting. However, the meeting was canceled due to COVID-19-related concerns. There were no opportunities to travel during the summer. Instead, I dedicated my efforts to advancing understanding of cosmological plasmas in an indoor setting. I attended a Zoom workshop called The Frontiers of Event Horizon Scale Accretion organized by the Kavli Institute of Theoretical Physics in Santa Barabara, California. I also attended many Zoom presentations hosted by the Aspen Center for Physics during the summer. Staying at home helped me to strengthen my bonds with loved ones.”*

Douglas Rigdon (BS ‘70) retired in 2001 from the National Nuclear Security Agency as Director of Laboratory Programs for Sandia National Laboratories and Los Alamos National Laboratory. He joined the Georgia Tech Research Institute providing support in computer simulation of high energy lasers to the Air Force Research Laboratory. He retired again in 2017 and lives in the Dallas-Fort Worth area studying mitigation techniques for global warming effects.”*

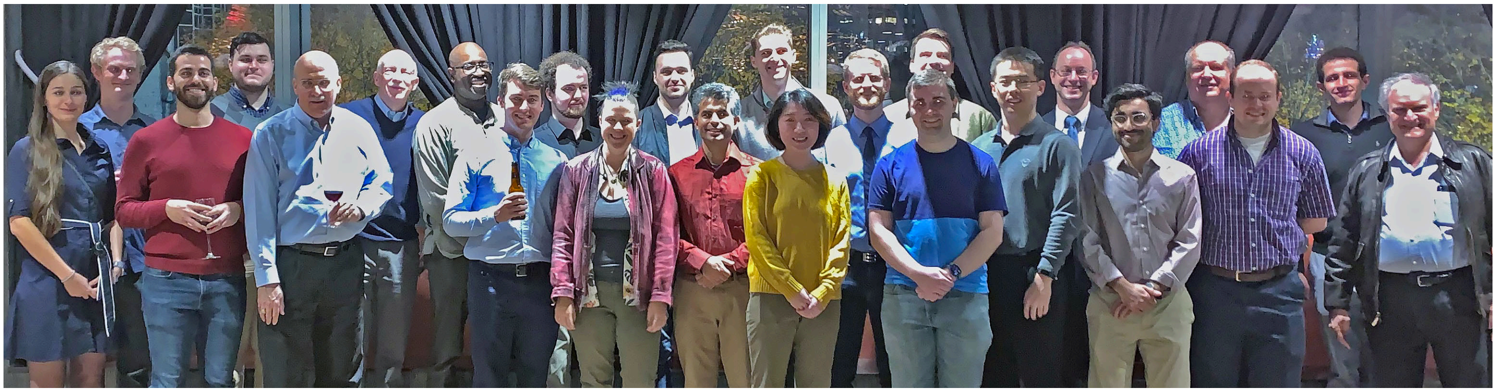
Srimant Routray (MS ’80) writes: “So far, I have set foot on all 7 continents and cruised in 4 major oceans during various trips. My most memorable moment was standing on the steps of two famous towers situated in two continents separated by the dark-blue waters of the Atlantic Ocean: O’Brien’s Tower marks the highest point of the Cliffs of Moher, Ireland, and Cabot Tower is situated at the highest point of Signal Hill overlooking the Atlantic Ocean in St. John’s, Newfoundland in Canada. The distance between these two towers is approximately 2000+ nautical miles. It was truly a blessing.”*



Siu-Wai Chan with Jack Tsai & members of Prof. Chan’s research group - Jay Piyush Shah, Hong Jun Kim & Haolan Sun

Jack Tsai (PhD ‘00) writes: “I graduated from Columbia class 2000. It has been 22 years since I left Columbia. I felt very fortunate to have done my degree in Materials Science. Since 2000, my job has taken me to many places. I have spent my first 15 years in hard disk drive industry where I worked on developing hard disk drives (10 GB back in 2000 to 1TB by the time I left in 2016). Since 2016, I have transitioned my work to sensors in particular LiDAR for self-driving car or Autonomous Vehicle. I am currently with Solar Energy Industry, working on making the hardware for renewable energy and doing relatability testing in order to make them more reliable and more robust.”

Below: Group photo of plasma physicists attending the Columbia Plasma Physics Laboratory Reunion Dinner



Applied Physics Students Explore Technologies to Confront Climate Change

This semester, the theme of the Applied Physics Undergraduate Seminar was "Applied Physics Confronting our Climate Future," building on a central theme of our University and School.

During the seminar students heard from experts on climate, policy, and energy technology, and they followed the COP26 discussions in Glasgow. Paul Dabbar, former Undersecretary of Science at the Department of Energy, spoke about "Trends in Energy Technology and R&D" and the arch of discovery-to-applied research. Prof. Carlos Paz-Soldan described research progress in fusion energy development. Dr. Matt Bowen presented a lecture titled "The Uncertain Future of Nuclear Energy in the United States." Prof. Adam Sobel explained the workings of modern climate science and offered views on policy and technology solutions to climate change. Prof. Michael Mauel, host for the seminar, introduced greenhouse physics and guided discussion of the science and readiness of new energy technologies.

After our students heard from experts, they examined potential technologies that contribute towards a sustainable climate future. Based on student interest, they formed five "Technology Study Teams", conducted research, and prepared 20 minute presentations with an accompanying narrative to inform their classmates on what they learned.

Each Team prepared and practiced their presentations, and classmates provided enthusiastic feedback with revisions to help each Team improve the clarity of their presentations. The final presentations reflected exceptional team work, careful physics calculation, and thoughtful understanding the pros and cons of new energy tech.

The five team with their topics and student members are:

"Geo-Engineering Group: Aerosol Release to the Stratosphere" by Bethan Cordone, Ken Chen, Nick Holfester, Matt Stafford & Jacob Vider

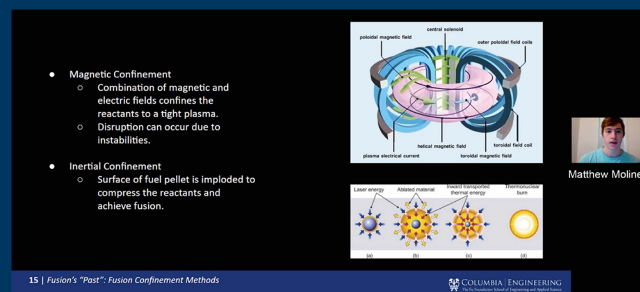
"Fission and Fusion as Carbon-Free Energy" by Matthew Molinelli, Samuel Morgan, Patrick Park, Anshul Singhvi, Freddie Zhu

"Carbon Dioxide Air Sucking Technology" by Casy Li, Zachary Briscoe, Kallee Gallant, Qian Liu, Ethan Levitt

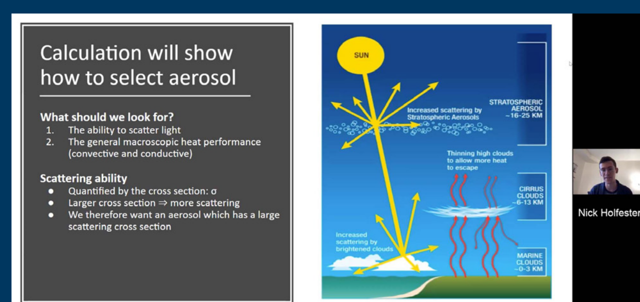
"Alternative Utilization of Solar Energy with Molecular Solar Thermal Energy Storage" by Michael Liu, Scott Kim, Serena Luo, Miguel Caro, Xzavier Seto

"How Dynamic Charging and New Battery Technologies Will Boost the Transition to EVs" by Shuhang Li, Yi Tao, Katharina Gallmeier, Will Kim, & Andrew Loevinger

Group photo of the Solar Energy Study Team (Michael Liu, Scott Kim, Serena Luo, Miguel Caro, Xzavier Seto)



Matthew Molinelli introducing fusion energy as part of the Nuclear Energy Study Team (Samuel Morgan, Patrick Park, Anshul Singhvi, Freddie Zhu)



Nick Holfester explaining the impact of scattering from atmospheric aerosoles as part of the Geo-Engineering Study Team (Bethan Cordone, Ken Chen, Matt Stafford, Jacob Vider)

Contributing Authors

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