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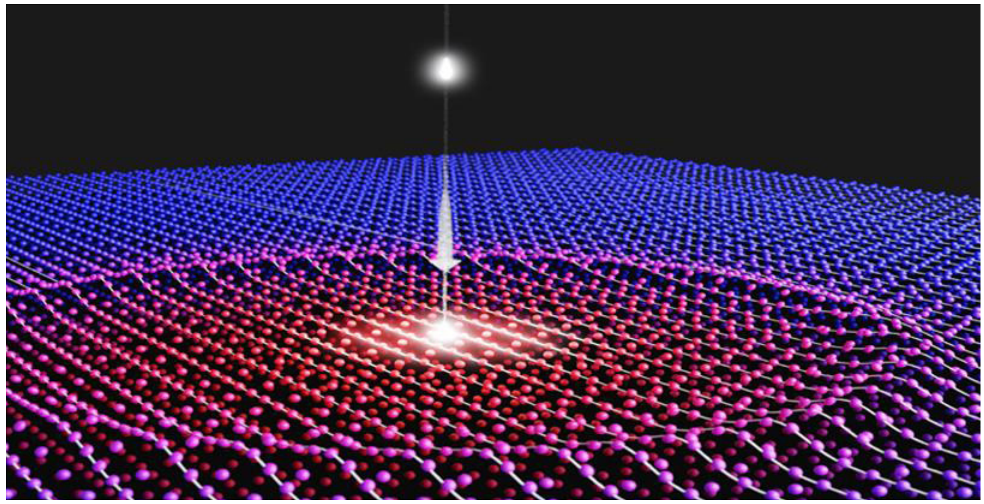
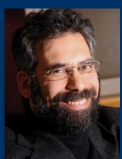
APAM NEWS

School of Engineering & Applied Science, Columbia University
Department of Applied Physics & Applied Mathematics
with Materials Science & Engineering



Message from the Chair



Dear APAM Community,

Greetings and best wishes for the New Year. This newsletter highlights the exceptional activities and accomplishments of our students, faculty, scientists, and alumni throughout the Fall semester. Across all three APAM programs—Applied Physics, Material Science, and Applied Mathematics—faculty and students have been engaged in a wide range of scientific endeavours, including innovations in Plasma Physics and Fusion Energy, novel battery technology, a new start-up for advanced photonic devices and even a knit "flat antenna" for long-wave communication (a security blanket if you will).

This year also saw an extraordinary list of honors for our faculty in all three programs, emphasizing their leadership roles and the interdisciplinary strengths of our faculty and department. Highlights include prestigious fellowships in Applied Physics, Applied Mathematics, and Material Sciences from the APS, the Department of Defense, and the Moore and Simons foundations. Congratulations to all of our awardees.

Finally, as we prepare for another exciting year, I'm thrilled to welcome two new faculty members, Prof. Xueyue "Sherry" Zhang and Prof. Michele Simoncelli, whose expertise in advanced quantum devices and novel computational materials physics will enrich our community and promise to bring exciting new discoveries and innovations.
I encourage you to explore the full newsletter to learn more about these accomplishments and many others.
Together, we are shaping the future of science and engineering. Wishing everyone a year filled with continued achievements, growth, and discovery.

Best,

Marc Spiegelman,
APAM Department Chair

(Above) The schematic shows how the absorption of a laser photon initiates a small change that propagates through the material over time, rather than instantaneously changing the whole material. Credit: Jack Griffiths/Brookhaven National Laboratory

(Above) Early career Columbia Uniersity scientists and students at the 2024 ITER Internation School

Guizzo & Notis Receive Scholarships to ITER International School

The United States Burning Plasma Organization (USBPO) awarded scholarships to two Columbia applied physics doctoral students, **Sophia Guizzo** and **Noah Notis**, to attend the 13th ITER International School, held from December 9-11, 2024, in Nagoya, Japan. The ITER International School invites early career scientists from around the world to prepare for research in the field of nuclear fusion and in research applications associated with the ITER Project. The focus of this year's school is "Magnetic fusion diagnostics and data science".

During the School, Noah made a presentation to participants, titled "Oveview of Diagnostics on HBT-EP," and shared the latest results from Columbia University's research tokamak, HBT-EP, from arrays of magnetic field sensors, hard x-ray detectors, electron temperature measurements using laser scattering and extreme-ultraviolet emission tomography, fast camera videography and machine learning, and scrape-off layer monitors located around the tokamak at the boundary between the plasma and the first wall. Sophia presented results from her research, titled "Electromagnetic system conceptual design for a negative triangularity tokamak."

Fusion Student Delegation (FuSD) Releases First Policy Brief

This summer, the Fusion Student Delegation (FuSD) released their 2024 Policy Brief. The FuSD is a non-partisan organization open to all students who are pursuing an undergraduate or graduate degree interested in fusion energy and science. The FuSD gives students the opportunity to engage Congress, executive agencies, think tanks, and industry groups; to advocate for fusion energy-relevant policy; to analyze existing public policy and write original policy statements; to network with fusion industry leaders, scientific experts, and policymakers in Washington, DC; and to develop delegates' science communication skills.

The first Annual Program of the FuSD was held in Washington, DC, June 1-7, 2024, and was a week-long program of policy workshops, discussions with think tanks, networking events, and meetings with congressional offices. Twelve delegates from twelve university participated, including **Amelia Chambliss**, a Columbia doctoral student working with **Prof. Elizabeth Paul** and studying energetic particle physics in stellarator devices.

This year's FuSD Policy Brief applauded progress in creating an innovative regulatory framework for fusion, supported appropriations for fusion energy research and workforce development, and motivated the 2024 policy statement with a three-part analysis: (I) Research and Innovation, (II) Community Engagement and Workforce Development and Retention, and (III) Regulation and Supply Chain.

CU SIAM Student Chapter News

The Columbia University SIAM Student Chapter (CU SIAM) is back in business! With elections and new officers taking office this past October, CU SIAM has been hard at work to bring you events and news about applied mathematics. Through academic and social events, it hopes to bring the community together in this coming year and beyond.

CU SIAM recently held its inaugural event in collaboration with the Applied Mathematics (AM) Student Seminar, marking an exciting start to what promises to be a vibrant chapter for industrial, applied, and computational mathematics. The event featured a talk by **Remy Kassem** titled "Dispersive Decay Estimates for the SSH Model on the Full and Half Line," offering attendees an engaging introduction to applied mathematics research. Students from various backgrounds were able to explore cutting-edge techniques in dispersive PDE analysis over snacks and refreshments, and thus gain firsthand perspective on the kinds of problems tackled by researchers in the field.

Looking ahead, the chapter is gearing up for future events and attendees can expect more opportunities to connect and prepare for academic and industrial careers. With a growing roster of activities in the pipeline, CU SIAM is excited to continue fostering a dynamic community. Stay tuned for updates on future events and opportunities to engage with the fascinating and diverse world of applied math! If you are interested in CU SIAM, scan the QR code to learn more.

(Above) Prof. Qiang Du, Blake Sisson, Beiji Chen, Yinxi Pan, Jackson Turner, Maria Garmonina, Caio Harmano Maia de Olivera, & Peter Jin

2024-2025 SIAM Officer List:
Faculty advisor: Professor Qiang Du
President: Beiji Chen
Vice President: Peter Jin
Secretary: Yinxi Pan
Treasurer: Blake Sisson
Outreach Chair: Jackson C. Turner
Events Chair: Maria Garmonina
Social Chair: Caio Hermano Maia de Oliveira

IBM Quantum Hosts Applied Physics and Computer Science Students

(Above) Dr. George Tulevski (IBM) explains the operation and configuration of the IBM System Two Quantum Computer to Columbia students

IBM Quantum hosted over thirty applied physics and computer science students to experience first hand the IBM Quantum Think Lab and learn about the latest System Two quantum computer at the IBM Yorktown Research Center. The visit to IBM Quantum was part of this semester's Applied Physics Undergraduate Seminar and included students from Professor Henry Yuen's "Introduction to Quantum Computing" class.

The theme for this year's Applied Physics Undergraduate Seminar is Quantum Science and Technology. Building upon next year's "International Year of Quantum Science and Technology" and the broad student interest in Columbia Quantum Initiative, our students have heard from leading experts in quantum science, both inside Columbia University and outside, who have shared their latest research advancing the science and application of quantum computing and quantum technology.

Students visiting IBM Yorktown were greeted by Dr. George Tulevski (Senior Manager, Think Lab), Bradely Holt (Program Director, Workforce Development Partnerships), Brian Ingmanson (North America Lead, Workforce and Community), and Dr. Oliva Lanes (Global Lead, Quantum Advocacy and Education). Columbia students learned first hand about IBM Research strategy, progress and plans for IBM quantum computing, component breakdown, design, and operation of quantum computers, opportunities for student engagement with IBM quantum users, and open-source learning modules for motivated students.

This student tour highlights the role of Columbia University's Quantum Initiative. **Professors Aravind Devarakonda** and **Henry Yuen** presented to the IBM audience overviews of Columbia's quantum technology research and Columbia's educational programs in quantum computing, including the newly formed Masters of Science in Quantum Science and Technology.

2nd Annual Plasma Undergraduate Poster Symposium: Twelve undergraduates working in the Columbia University Plasma Physics group participated in the 2nd Annual Summer Student Poster Symposium and **Kalen Richardson** was named the winner of the best poster prize! Many of the students were part of the Summer@SEAS program, while others had already been in the Plasma Physics group for a year or more and were continuing their research. The symposium was attended by several advisors in the plasma physics program along with research scientists, post-docs, graduate students, masters students, and other undergraduates. Learn more and view photos at **https://shorturl.at/c5Il2**

Dr. Olivia Lanes from IBM Quantum Visits Applied Physics Undergrads

(Above) Dr. Olivia Lanes (front row, red sweater) met with Columbia students in the Applied Physics Undergraduate Seminar.

Applied Physics undergraduate majors meet during the Fall semester and engage faculty and scientists in lively discussions of timely topics in applied physics. This year's theme for the Applied Physics Undergraduate Seminar is Quantum Science and Technology. With next year being the "International Year of Quantum Science and Technology" and the campus-wide impact of Columbia Quantum Initiative, our students are delighted.

One seminar was presented by **Dr. Olivia Lanes**, Global Lead for IBM Quantum Learning and Education. Dr. Lanes spoke on the topic of "The Future of IBM Quantum: Pioneering the Next Era of Computing." IBM Quantum has been leading the transition of quantum computing from a research frontier to a practical technology. She described the current state of IBM Quantum, its strategic roadmap, and plans for the future of quantum hardware and software. As the lead of IBM's Qiskit educational content, Dr. Lanes also discussed possible near-term application areas and provided students with a short overview of IBM's educational tools for anyone interested in joining the quantum ecosystem.

Other presenters in the weekly Applied Physics undergraduate seminar include **Professors Mike Mauel, Aravind Devarakonda, Latha Venkataraman, Nanfang Yu, Physics Professor Sebastian Will, Mechanical Engineering Professor Jim Schuck, and Xueyue ("Sherry") Zhang** who joined APAM full time in January 2025. Also presenting this semester are **Dr. Yun Zhao**, Columbia scientist working with **Prof. Alex Gaeta**, and **Dr. David Smith,** from University of Wisconsin - Madison, who will present recent work on entangled two-photon spectroscopy of fusion plasma.

In addition to learning the latest about exciting applied physics topics, the graduating seniors prepare end-of-semester research presentations. This year's student topics include "Quantum Chemical Simulation of Metal Hydrides for Cancer Treatment", "Superconductivity and BCS Theory", "Scanning Tunnelling Microscope-Break Junction Conductance Measurement", "Universal Quantum Computation with Magic States", "Magnetic Force Microscopy (MFM) to Probe Superfluid Density", "Physics of Quantum Dots and Applications in Nanoscale Computation", and "Quantum Machine Learning: Core Subroutines, Data Encoding Strategies, and Recent Advances."

Carlos Paz-Soldan

Paz-Soldan Elected 2024 American Physical Society Fellow

Carlos Paz-Soldan, Associate Professor of Applied Physics and Applied Mathematics, has been elected a 2024 Fellow of the American Physical Society. He was recommended for this honor by the American Physical Society Division of Plasma Physics (DPP) for his "groundbreaking contributions and scientific leadership in the understanding and optimization of tokamak plasmas for fusion energy, including non-axisymmetric magnetic fields, plasma shaping, and control of relativistic electrons."

His research interests are motivated by the desire to solve the scientific and technological challenges standing in the way of harnessing controlled fusion energy on earth. His work focuses on controlling the transient off-normal events that can prevent the reliable operation of magnetic fusion device concepts. He is interested in advancing the physical basis of plasma instability phenomena as well as developing the fusion technologies necessary to deploy feasible actuators to achieve control. Prof. Paz-Soldan's group conducts both experimental and computational work to support these goals.

Prior to joining the APAM Department in 2021, he was a staff scientist in the Magnetic Fusion Energy Division at General Atomics, where he advanced the research program of the DIII-D National Fusion Facility as well as other experiments worldwide. He has contributed to a broad range of problems in tokamak operation, stability, and control. These include: understanding the interaction of tokamak plasmas with non-axisymmetric fields used to control core and edge instabilities; the measurement and control of relativistic electron populations; and the conceptualization and design of novel actuators for transient control. He earned his B.Sc.E. from Queen's University at Kingston, Canada in 2007 and his Ph.D. from the University of Wisconsin-Madison in 2012. Prof. Paz-Soldan is the recipient of the Marshall N. Rosenbluth Outstanding Doctoral Thesis Prize in 2013 and the Thomas H. Stix Award for Outstanding Early Career Contributions to Plasma Physics Research in 2021, both from the American Physical Society.

Columbia Engineering colleague and APS Fellow Prof. Michael Mauel stated, "This is wonderful recognition awarded to a great colleague. Carlos is one of the leading experts of his generation in the physics of tokamak confinement for fusion energy. His record of scientific accomplishment is exceptional and his effectiveness as a national leader provide ample justification for this recognition."

2024 Frontiers of Science Award

Qiang Du, the Fu Foundation Professor of Applied Mathematics, is one of the recipients of the 2024 Frontiers of Science Award, granted to authors of the paper "Numerical Methods for Nonlocal and Fractional Models" (*Acta Numerica*, 2020). Among the six authors of this award-winning work are **Dr. Xiaochuan Tian** (Ph.D. 2027, APAM), **Dr. Zhi Zhou** (a former postdoc of the CM3 group at APAM), and Prof. Du. Established by the International Congress for Basic Science (ICBS), the awarded papers were chosen across 42 fields within the three basic sciences—mathematics, theoretical physics, and theoretical computer science and information science—represented at ICBS. Dr. Zhou delivered the award lecture at the 2024 ICBS and accepted the award certificate on behalf of the authors.

Qiang Du

Aravind Devarakonda

Devarakonda Named Moore Fellow in Materials Synthesis

The $1.2 million grant from the Gordon and Betty Moore Foundation will support Devarakonda's efforts to create new kinds of quantum materials

By Ellen Neff, Originally published by Columbia Engineering

Columbia Engineering Assistant Professor **Aravind Devarakonda** has been named a Moore Fellow in Materials Synthesis. The four-year, $1.2 million dollar grant from the Gordon and Betty Moore Foundation will support Devarakondas efforts to synthesize quantum materials with unique physical properties of potential use in emerging quantum technologies, like quantum computers and sensors.

Devarakonda joined Columbia Engineerings Department of Applied Physics and Applied Mathematics in January 2024, after working with Columbia researchers, including physicist Cory Dean and chemist Xavier Roy, as a Simons Junior Fellow since 2021. The goal of his new group is to advance our understanding of the quantum mechanical behavior of solids, and ultimately find ways to tailor their properties, which he hopes to achieve by combining elements of physics, chemistry, and material science.

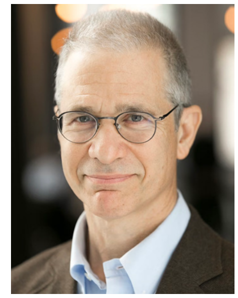
The Moore grant in particular will support Devarakondas efforts to create materials that feature both strong interactions among their electrons and topology a subtle feature of the electrons wavefunction that can be used to create quantum states that are impervious to noisy environments, he explained.

Establishing that a material has these unusual features requires precise physical measurements at cryogenic temperatures approaching absolute zero. But before that, creating materials requires some chemistry intuition.

The periodic table is large, and it can seem daunting to choose what to grow, Devarakonda said. This is where we rely on principles from physics and chemistry, a treasure trove of literature, and our own practical experience gained over time. Once we've picked a target material, based on the chemical makeup we can then choose the appropriate crystal growth technique. Of course, actually synthesizing the chosen material can still be challenging.

Devarakonda also plans to go one step further. With this support from the Moore Foundation we want to go beyond traditional ways of synthesizing materials. We are now afforded the freedom to try and come up with new ways to synthesize them. Devarakonda believes this is where were likely to find the real surprises. I'm optimistic this will reveal classes of materials that have never been seen before.

Weinstein Named Simons Senior Fellow


Michael Weinstein

The Simons Society of Fellows selected Professor **Michael Weinstein** to join their society as a Senior Fellow. Prof. Weinstein was selected "in recognition of his considerable achievements in the field of applied mathematics and many years of distinguished service as both an educator and mentor".

Prof. Weinstein earned his undergraduate degree in mathematics, including a year at ETH-Zurich, at Union College (B.Sc. 1977). He received his M.Sc. and Ph.D. (1982) from the Courant Institute at New York University under the direction of George C. Papanicolaou, with a thesis on the stability of coherent structures and singularity formation described by nonlinear dispersive wave equations. Weinstein was a postdoctoral fellow at Stanford University (1982–1984) with Joseph B. Keller. From 1984 to 1988, he was Assistant Professor of Mathematics at Princeton University. In 1988, he joined the mathematics faculty at the University of Michigan-Ann Arbor as Associate Professor (1988–1992), and then Full Professor (1992–2000). Weinstein was a Member of Technical Staff at Bell Laboratories/Lucent Technologies in the Fundamental Mathematics Research Group from 1998–2004. His interactions with theoretical and applied physicists at Bell Labs inspired a broadening of his work to the applied mathematical aspects of wave phenomena, most recently in field of quantum materials such as graphene. In 2004, Weinstein joined the faculty of Columbia University. He is a SIAM Fellow (Society of Industrial and Applied Mathematics) and a Fellow of the American Mathematical Society. He was awarded the Martin Kruskal Prize by SIAM (2018) for his work on nonlinear waves and coherent structures. Among his past visiting positions, Weinstein was the Bergman Visiting Professor of Mathematics at Stanford University (2018) and a Visiting Member of the Institute for Advanced Study in Princeton (2023-2024). Weinstein has been a Simons Foundation Math + X Investigator since 2015.


Liliana Borcea

Borcea Receives Named Professorship

Liliana Borcea is now the George P. Livanos Professor of Applied Physics and Applied Mathematics. Prof. Borcea joined Columbia July 1 after working, most recently, as the Peter Field Collegiate Professor of Mathematics at University of Michigan, Ann Arbor, where she had taught since 2013. Prior to this, she worked at Rice University and the California Institute of Technology, with visiting professorships across the globe at Istituto per le Applicazioni del Calcolo in Firenze, Italy; Stanford University; and Ecole Normale Superieure in Paris. She has received numerous honors, including multiple NSF fellowships early in her career, the SIAM SIGEST award (2012), the AWM-SIAM Sonia Kovalevsky prize (2017), and the Rothschild Distinguished Visiting Fellowship at the Isaac Newton Institute of Mathematical Sciences of Cambridge University (2023). Professor Borcea was recognized for her excellence with an election to the American Academy of Arts and Sciences (2023).

Billinge Wins Gregori Aminoff Prize


Simon Billinge

Originally published by the Royal Swedish Academy of Sciences

The Royal Swedish Academy of Sciences has named **Simon Billinge**, Columbia University, as the 2025 Aminoff Laureate. He is awarded the prize for his decisive contribution to the further development of the pair distribution function, a tool that is widely used in materials science.

X-ray diffraction is the most accurate method we have for examining the structure of solids with well-ordered atoms, but there is growing interest in understanding nanostructures and less well-ordered systems, not least so we can follow chemical reactions as they are taking place.
The pair distribution function (PDF) is an ideal tool for this, but it is not a new invention. Obtaining information about distances in a structure is much easier than obtaining information about atomic positions. Distance information was used early on, as a first step towards determining structure by using X-ray diffraction data, and the foundation of what is now PDF was established by Debye, back in 1915.

A decisive contribution: However, there has been important development in recent years, for which Simon Billinge's work has been decisive. This is the realisation that high-resolution PDF requires using the weak signals obtained from high scattering angles, which have been hard to access using traditional X-ray sources. However, thanks to modern synchrotron light facilities (such as MAX IV in Lund, Sweden), this information can now be gathered, and with a high quality.

Through his own experiments and in collaboration with others, Simon Billinge has driven this technological development and clarified its potential for others. This has led to PDF becoming a standard tool for describing and understanding weakly ordered systems.

Studying growth: The development of nanomaterials has promoted the use of PDF as an analytical method, but PDF also permits the study of growth and transformation in crystalline systems. This is particularly important for our understanding of how the materials in a battery change as it charges and discharges, and how to optimise conditions for the synthesis of new materials.

Prize citation: "For a decisive contribution to making the pair distribution function a widely useful tool for structural and materials science."

About the laureate: Simon J. L. Billinge was born 1964 in London, UK. He received his PhD from the University of Pennsylvania in 1992 and has been Professor of Applied Physics, Mathematics and Materials Science at Columbia University, New York, US, since 2008.

About the Gregori Aminoff Prize: Every year, the Gregori Aminoff Prize in crystallography is awarded by the Royal Swedish Academy of Sciences. Crystallography is the study of atomic structures in solid materials and is used in chemistry, biology, medicine, geology and materials science. The Prize recognises a documented individual contribution to the field of crystallography and has been awarded to Swedish and foreign researchers since 1979. The prize money is 120,000 Swedish kronor.

Oleg Gang Named a 2024 Vannevar Bush Fellow

Department of Defense award will support Gang's project to explore a functional nanomaterial discovery and fabrication approach using a new concept of evolving materials.

By Holly Evarts, Originally published by Columbia Engineering

Oleg Gang

Columbia Engineering's Professor Oleg Gang has been named a 2024 Vannevar Bush Fellow, the Department of Defense's (DoD) most prestigious single-investigator award. The $3 million five-year fellowship will support Gang's project to establish a new strategy of evolving materials as a paradigm for creating, discovering, and enhancing functional nanomaterial fabrication. His goal is to push a frontier of self-assembly towards creating materials that can evolve based on the need to improve or enable new properties. Such novel nanomaterials will be applied for targeted functions, from optics to mechanics, from catalysis to signal processing.

Gang is one of 11 scientists and engineers to be given the 2024 Vannevar Bush Faculty Fellowship (VBFF), which is a highly competitive award that funds groundbreaking research with transformative potential. Named after Vannevar Bush, who played a large role in shaping the defense research enterprise as the director of the Office of Scientific Research and Development after World War II, the fellowship encourages high-risk, out-of-the-box ideas where researcher creativity intersects with the unknown.

Gang, a professor of chemical engineering and of applied physics and materials science at Columbia Engineering, directs the Soft and Bio Nanomaterials group at Columbia and the Center for Functional Nanomaterials at Brookhaven National Laboratory.He is particularly interested in advancing self-assembly as a design tool for creating complexly organized nanomaterials. Conventionally, the discovery and fabrication of materials are based on exploring large parameter spaces associated with material composition, structure, and processing conditions. Even for the desired material functions based on computed design, the practical realizations of targeted materials can be challenging due to the need to navigate in this large parameter space. The situation becomes even more difficult if theoretical models cannot predict the material design. In this respect, unlike abiotic materials, biological organisms solve the challenge of finding the "good enough" solution through the diversification of species, selection of best performers, and their mutation toward improvement through selection and adaptation.

Gang plans to apply this nature-developed approach to several classes of engineered material systems with optical, mechanical, and chemical functions. However, since there is no nature-created biological machinery for abiotic materials, he will establish in this project an evolution-based approach to create and perfect them according to the desired functionality. By leveraging self-assembly principles with architecture design and its performance, he will develop the foundations of a material evolution strategy and its practical implementation that can address challenges very difficult to solve using traditional fabrication.

A major challenge for self-assembly is the ability to arrange components of different types into rationally designed architectures, which is key to enabling many functions of nanosystems. Gang is working to establish experimental methods for creating designed nanomaterial systems using this approach with the goal of integrating nanoparticles, biomolecules, and polymers into unified systems to take advantage of their unique properties, and to exploit the emergent phenomena.

The new VBFF project will explore principles of material evolution in DNA-programmable systems, where DNA strands can direct the formation of materials from inorganic nanoparticles and proteins, aiming to create new mechanical and optical metamaterials and chemically active matrices. By developing methods for generating and selecting high-performing material species, Gang's team hopes to establish a guided evolution process for materials, akin to biological evolution

The VBFF funding will enable Gang to develop experimental platforms and algorithms for material evolution processes. The research aims to improve the performance of enzymatic nano-reactors, mechanical metamaterials, and nanomaterials for diverse optical applications.

Check out the video, "Nano-objects of Desire: Assembling Ordered Nanostructures in 3-D," at https://tinyurl.com/ceumb6jf

Paz-Soldan Chairs Decadal Plan Fusion Energy Sciences Advisory Sub-Committee

The Fusion Energy Sciences Advisory Committee (FESAC) has launched a Decadal Plan Sub-committee to "re-assess the [Fusion Energy Sciences] program elements and their alignment with the FESAC Long-Range Plan science drivers and the Bold Decadal Vision." As well as to "identify a scope that will address near-term scientific and technological gaps impacting the design and construction of a Fusion Pilot Plant on the pathway to commercialization".

Carlos Paz-Soldan, Associate Professor of Applied Physics and Applied Mathematics, has assumed the role of chair of this sub-committee as of July 1st, taking over from Prof. Troy Carter of UCLA. This FESAC sub-committee has an important role, after approval by the full FESAC, in providing advice to the Department of Energy.

Paz-Soldan said "It is a tremendous honor to be able to lead this group towards the completion of their goals. I am looking forward to working together with the committee to address these key issues facing our community".

Du Serves on 2024 SIAM Task Force on the Future of Computational Science

Qiang Du, the Fu Foundation Professor of Applied Mathematics, served on the 2024 SIAM Task Force on the Future of Computational Science. "The Task Force Report proposes a framework for the holistic discussion of emerging challenges and opportunities at the junction of traditional computational science, artificial intelligence (AI), and high-performance computing (HPC). Relevant challenges include the need for new hardware and software advances, as well as strategic investments to recruit and train diverse talent within the computational science workforce. The report also identifies three areas in which computational science can actively enhance both science and society: (i) Investments in software tools that bolster the impact of exascale computing, (ii) support for data science infrastructures that enable the scalable fusion of data from diverse sources, and (iii) improvements to the reliability and trustworthiness of AI that facilitate its integration with simulations and decision-making processes." (SIAM.org)

Read the report online at: https://shorturl.at/bFxip

Xscape Photonics Secures $44 Million to Transform AI Data Centers

A Columbia Engineering startup nabs $44M to tackle energy and scalability challenges with a new platform that significantly boosts AI data performance and efficiency

By Tina (Xintian) Wang, Originally published by Columbia Engineering

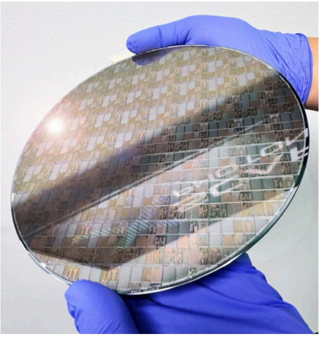
(Above) Xscape Photonics co-founders: Vivek Raghunathan, Alexander Gaeta, Michal Lipson, Keren Bergman, & Yoshi Okawachi

As AI workloads continue to rise — projections estimate over 20% of large-scale data centers' energy consumption will come from AI by 2025 — the urgency to innovate has never been greater. Xscape Photonics is stepping in with an innovative solution. Founded in 2022 out of research that started in Columbia Engineering's lab over a decade ago, the Santa Clara-based company, co-founded by three faculty members —**Keren Bergman, Michal Lipson,** and **Alexander Gaeta**, aims to address the performance bottleneck in AI training.

Multi-color photonics: a game changer: The company recently secured $44 million in Series A funding to accelerate the development of its novel multi-color photonics platform. The platform tackles the critical "escape bandwidth" problem, aiming to boost scalability, energy efficiency, and data performance in AI data centers. By using light to transmit terabytes of data, Xscape's technology minimizes energy consumption while enhancing data flow.

"With the explosion of AI applications, data centers are quickly becoming a major draw on our power grid," says Keren Bergman, Charles Batchelor Professor of Electrical Engineering at Columbia, co-founder of Xscape Photonics, and a leading researcher in photonic interconnected computing systems. "Our interconnect technology will propel AI system performance while essentially bending the energy curve, enabling future scalability."

Redefining AI infrastructure: AI workloads are placing unprecedented strain on data centers, with current technologies struggling to scale efficiently. At the heart of the problem lies the communication between GPUs and other chips within data centers, known as "interconnects." These interconnects have limited bandwidth, which restricts AI performance. A 2022 survey revealed that AI developers typically use only 25% of a GPU's capacity. Xscape has developed the ChromX platform, a multi-wavelength photonics approach designed to overcome data communications limitations. Typical interconnects are restricted to transmitting data over four colors on a single fiber, but ChromX can handle hundreds of colors. This innovation reduces power consumption tenfold while delivering an increase in performance—a significant leap forward for AI infrastructure.


Xscape Photonics ChromX Platform

A research collaboration born at Columbia: The origins of Xscape Photonics trace back to a collaborative research project at Columbia Engineering, where Bergman, Michal Lipson, and Alexander Gaeta are conducting pioneering work in photonics and AI data systems. Their combined expertise in silicon photonics, laser design, and data center architecture laid the foundation for the ChromX platform. With the addition of **Vivek Raghunathan**, CEO and co-founder, and **Yoshi Okawachi**, the team has expanded its capabilities in key areas of photonics and AI infrastructure.

Reflecting on the company's journey, Gaeta, co-founder and president at Xscape Photonics, a pioneer in in quantum and nonlinear photonics, and David M. Rickey Professor of Applied Physics and Materials Science and professor of electrical engineering notes, "It is gratifying to see that the research from this remarkable collaboration between Keren, Michal, and my group is being successfully commercialized. I believe it has the potential to have a broad impact on society by advancing AI and high-performance computing."

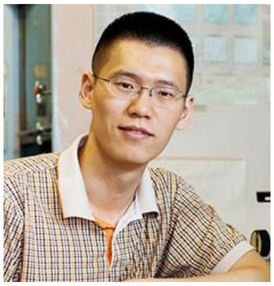
Backed by industrial giants: The latest round of funding, led by IAG Capital Partners, saw investment from industrial pioneers like Altair, Cisco Investments, Fathom Fund, Kyra Ventures, LifeX Ventures, NVIDIA, and OUP.

Greg Maskel, tech licensing officer at Columbia Technology Ventures, emphasized the significance of their work, stating, " Xscape's success is due to outstanding technology arriving at a timely moment, where the infrastructure needed to power AI computing needs technologies like Xscape's."

Scaling for the future: With the new funding, Xscape Photonics plans to scale the production of its ChromX platform to meet the growing demand from hyperscale AI customers—massive data centers operated by tech giants that require unprecedented processing power and data throughput to support large-scale AI applications.

Lipson, also a co-founder of Xscape Photonics, a pioneer in silicon photonics, and Higgins Professor of Electrical Engineering and professor of applied physics at Columbia, expressed her excitement for the future. She says, "It is wonderful to see how the field of silicon photonics has matured. My group has been working in this field for more than two decades, and it is highly rewarding that technologies developed with Professor Gaeta and Professor Bergman will revolutionize computing as we know it."

Lipson & Gaeta Join SCY-QNet NQVL Team: Professors **Michal Lipson** and **Alex Gaeta** are part of the newly formed SCY-QNet team. "In a landmark achievement for quantum science, Stony Brook University, in collaboration with Columbia University, Yale University and Brookhaven National Laboratory, has been chosen to lead a project in the competitive National Quantum Virtual Laboratory (NQVL) program. This initiative, funded by the U.S. National Science Foundation (U.S. NSF), marks a pivotal moment in advancing Quantum Information Science and Technology (QIST) in the United States. This ambitious project seeks to create a 10-node entanglement distribution quantum network linking laboratories across these renowned institutions" (stonybrook.edu). Learn more at: **https://shorturl.at/L3yCE**



Yuan Yang

New Battery Technology Could Boost Renewable Energy Storage

Columbia Engineers develop new powerful battery "fuel" - an electrolyte that not only lasts longer but is also cheaper to produce

By Holly Evarts, Originally published by Columbia Engineering

Renewable energy sources like wind and solar are critical to sustaining our planet, but they come with a big challenge: they don't always generate power when it's needed. To make the most of them, we need efficient and affordable ways to store the energy they produce, so we have power even when the wind isn't blowing or the sun isn't shining.

Columbia Engineering material scientists have been focused on developing new kinds of batteries to transform how we store renewable energy. In a new study published September 5 by *Nature Communications*, the team used K-Na/S batteries that combine inexpensive, readily-found elements -- potassium (K) and sodium (Na), together with sulfur (S) -- to create a low-cost, high-energy solution for long-duration energy storage.

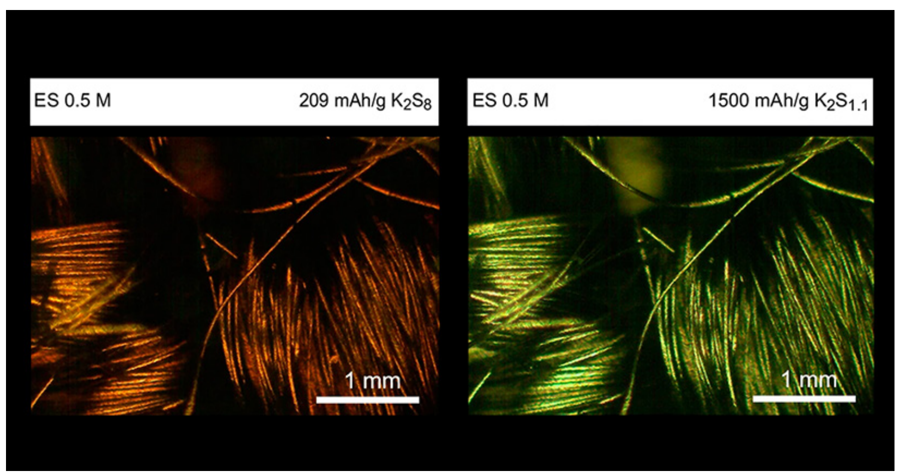
"It's important that we be able to extend the length of time these batteries can operate, and that we can manufacture them easily and cheaply," said the team's leader **Yuan Yang**, associate professor of materials science and engineering in the Department of Applied Physics and Mathematics at Columbia Engineering. "Making renewable energy more reliable will help stabilize our energy grids, reduce our dependence on fossil fuels, and support a more sustainable energy future for all of us."

New electrolyte helps K-Na/S batteries store and release energy more efficiently

There are two major challenges with K-Na/S batteries: they have a low capacity because the formation of inactive solid K2S2 and K2S blocks the diffusion process and their operation requires very high temperatures (>250 oC) that need complex thermal management, thus increasing the cost of the process. Previous studies have struggled with solid precipitates and low capacity and the search has been on for a new technique to improve these types of batteries.

Yang's group developed a new electrolyte, a solvent of acetamide and ε-caprolactam, to help the battery store and release energy. This electrolyte can dissolve K2S2 and K2S, enhancing the energy density and power density of intermediate-temperature K/S batteries. In addition, it enables the battery to operate at a much lower temperature (around 75°C) than previous designs, while still achieving almost the maximum possible energy storage capacity.

"Our approach achieves nearly theoretical discharge capacities and extended cycle life. This is very exciting in the field of intermediate-temperature K/S batteries," said the study's co-first author **Zhenghao Yang**, a PhD student with Yang.



(Above) Optical microscope imaging of catholyte at room temperature, showing that no solid is formed at the end of discharge (right figure). The coiled carbon fibers, which are the current collector (substrate) for the catholyte, are visible. The two images show the catholyte's color change during battery discharge. Image courtesy of Yuan Yang Lab.

Pathway to a sustainable energy future

Yang's group is affiliated with the Columbia Electrochemical Energy Center (CEEC), which takes a multiscale approach to discover groundbreaking technology and accelerate commercialization. CEEC joins together faculty and researchers from across the School of Engineering and Applied Science who study electrochemical energy with interests ranging from electrons to devices to systems. Its industry partnerships enable the realization of breakthroughs in electrochemical energy storage and conversion.

Planning to scale up

While the team is currently focused on small, coin-sized batteries, their goal is to eventually scale up this technology to store large amounts of energy. If they are successful, these new batteries could provide a stable and reliable power supply from renewable sources, even during times of low sun or wind. The team is now working on optimizing the electrolyte composition.

About the Study: *Tian, L., Yang, Z., Yuan, S. et al. Designing electrolytes with high solubility of sulfides/disulfides for high-energy-density and low-cost K-Na/S batteries. Nat Commun 15, 7771 (2024). https://doi.org/10.1038/s41467-024-51905-6*

The study was supported by Columbia University, the Air Force Office of Scientific Research (FA9550-22-1-0226) and the program of Interfacial Engineering and Electrochemical Systems at National Science Foundation (Award No. 2102592, 2341994, 23411995). Support from SEAS Interdisciplinary Research Seed (SIRS) and Climate School Seed Funding at Columbia University.

This study was highlighted by several media outlets, including Tech Explorist, Chem Europe, Mercom India, Wonderful Engineering, EurekAlert!, Interesting Engineering, AZoCleantech, The University Network, and Market Businss News.

Carlos Paz-Soldan

Fusion Energy: Powering a Solution for Climate Change

Collaboration between industry and academia can help accelerate breakthroughs in nuclear fusion in efforts to halt climate change

By Merri Kim, Originally published by Columbia Engineering

By far, the energy sector is the biggest contributor to greenhouse gas emissions, representing more than three-quarters of global emissions alone. To achieve net zero over the coming decades, as pledged by more than 140 countries, the global energy system will need a complete transformation. Rapidly weaning off fossil fuels will give the world a fighting chance to limit the worst effects of climate change.

Embracing established renewables like solar, wind, geothermal, and hydropower is key. And recent progress in fusion energy has drummed up excitement for the technology as an abundant, reliable, and emissions-free source of power that could effectively tackle the climate crisis.

"Now more than ever, there is a bigger pull for clean energy technologies due to the ever-greater need of addressing climate change," said **Carlos Paz-Soldan**, associate professor of applied physics and applied mathematics at Columbia Engineering. "We hope to deploy fusion technology on a timescale that can help with that problem."

Paz-Soldan, a faculty member of the Columbia Plasma Physics Lab, conducts both experimental and computational work related to magnetic "bottles" that confine plasma to produce fusion power, and plasma dynamics. "Fusion has a great many positive attributes, and so it's been called the holy grail of energy sources," Paz-Soldan said. "It doesn't produce the same level of toxic by-products associated with fission, has a relatively limitless fuel supply, and doesn't rely on the natural elements."

Nuclear fusion is the reaction that powers active stars, including our own sun. The center of stars is a place so incredibly hot and dense that hydrogen atoms combine to form helium atoms, releasing an immense amount of energy in the process. Recreating this reaction in a controlled laboratory environment on Earth is no small feat — which is why, for most of history, scientists have struggled to produce a fusion reaction that generates more energy than it consumes.

Fusion energy releases no greenhouse gasses, and a power plant could be built anywhere. The main fuel source, hydrogen, is readily found in seawater. In fact, the top inch of water off the Boston Harbor would provide enough hydrogen to power the entire city of Boston for 50 years.

In December 2022, a research team at Lawrence Livermore National Laboratory's National Ignition Facility (NIF) conducted the first-ever controlled fusion experiment to reach this milestone. A blast from 192 laser beams heated a tiny fuel pellet the size of a pencil eraser to over 300 million degrees Celsius (180 million Fahrenheit). The reaction released a yield of 3.15 megajoules from 2.05 megajoules of incident laser energy, an energy gain factor of 1.5.

Despite the technology's promise, fusion energy has a long, challenging road ahead before it becomes a practical option. The energy gain factor would need to be much higher, and the logistics and cost of building even a single power plant are significant hurdles. But the prospect of limitless, emissions-free energy is worth the risk — and the expanding private investment in the space suggests that the market agrees.

"There has been a real explosion of private fusion startups in the last several years, and they're really taking the baton to advance the technology towards commercialization," said Paz-Soldan. "The fusion ecosystem has traditionally been very dominated by the national laboratory complex, where things have been done in the public sector space, and now we have a lot more private sector actors that are able to go faster and take more risks."

About 45 companies are actively working on commercializing fusion energy, including Commonwealth Fusion Systems, Tokamak Energy, Realta Fusion, and Type One Energy. Paz-Soldan believes that universities like Columbia have an essential role to play in helping industry partners succeed by lending expertise and guiding research and development. Academic researchers can provide the foundational science needed to push fusion out of the laboratory and into the world, where it can meet humanity's growing demands for clean energy.

"In my opinion, the public has underrated the level of progress that's happened in this field," said Paz-Soldan. "There are certain technical gaps we know we need to close, but the more investment that we get now, the faster those gaps get closed."

New APAM Faculty Members

The APAM Department is pleased to announce the appointment of two two faculty members starting in January 2025.

Michele Simoncelli

Michele Simoncelli is a new tenure-track assistant professor in Materials Science and Engineering. Prof. Simoncelli and his group develop the theoretical and computational framework to understand, quantitatively describe, and control quantum transport phenomena in solids and liquids involving, e.g., charge, heat, light and spin, their possible synergies or conflicts, and related macroscopic signatures. The ambition is twofold: first, to evolve current materials for storage and management of information or energy, and second, to innovate on existing applications or even conceive new ones, in collaboration with experimentalists and industry.

Prior to joining the Columbia faculty, he received a master's degree in Physics of Complex Systems from Politecnico di Torino (Italy) and his PhD from EPFL (Switzerland) in May 2021. From fall 2021 to 2024, he held the Crone Research Fellowship in the Physics Department at the University of Cambridge. Learn more about Prof. Simoncelli at **https://shorturl.at/AxS2p**

Xueyue Zhang

Xueyue (Sherry) Zhang is a new tenure-track assistant professor in Applied Physics. Prof. Zhang and her lab leverage the unique advantages of qubit-photon interactions to advance the frontiers of quantum science and technology. They focus on introducing new capabilities, such as high levels of connectivity, into superconducting circuits and solid-state spin platforms by integrating these qubits with microwave waveguides and silicon photonics. This foundation enables the Zhang lab to explore novel possibilities in basic science, such as many-body quantum simulation and quantum topological photonics, as well as pushing the boundaries of quantum computing and networking technologies.

Prior to joining the Columbia faculty, she earned her Backelor's with honors in Microelectronics Engineering from Tsinghua University in 2017 and a PhD in Applied Physics from Caltech in 2023. She then joined UC Berkeley as a Miller Postdoctoral Fellow in Electrical Engineering and Computer Sciences and Physics. Learn more about Prof. Zhang at **https://shorturl.at/nFt4B**

Columbia Engineers Knit a "Blanket" of Sophisticated Radio-Frequency Antennas

Researchers are the first to use traditional flat-knitting techniques to fabricate flexible, lightweight metasurfaces--large-aperture antennas--that can easily be stowed and deployed for long-range communications

By Holly Evarts, Originally published by Columbia Engineering

Imagine taking the radio frequency properties of the dish antennas you see on rooftops and knitting them into a wearable garment -- a sweater or a blanket that is ultralight, portable, easy to fold up and stow away. Not having to use heavy, bulky satellite antennas would make communications much easier for those who live or travel in remote locations -- a lightweight, flexible antenna that can send information over long distances would be a useful tool for both the public and private sectors.

A Columbia Engineering team reports that they have used their expertise in metasurfaces -- ultra-thin optical components that can control the propagation of light -- and a low-cost, highly scalable flat-knitting platform to create radio-frequency (RF) communications antennas that are easy to carry and deploy. The study, led by Nanfang Yu, associate professor of applied physics and applied mathematics, was published in *Advanced Materials*.

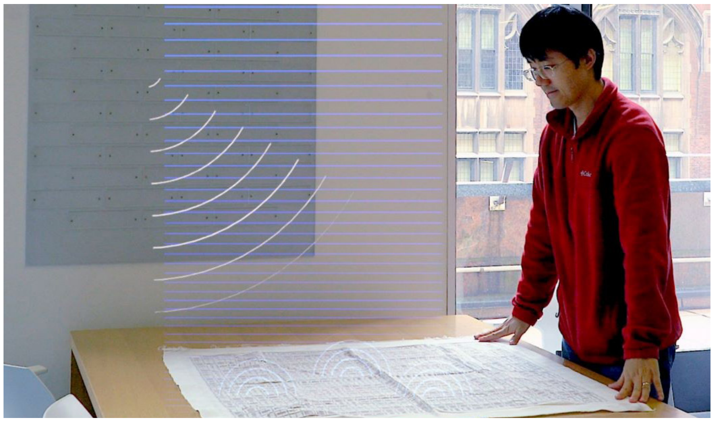
Why knitting? Most RF antennas, particularly highly directional array antennas like reflectarrays are planar, rigid devices. While these devices will likely always remain state-of-the-art in terms of pure performance metrics, they are often large, heavy, and unwieldy and can be expensive to manufacture. Researchers have been investigating ways to produce smaller, more flexible antennas, including inkjet printing or screen-printing directly on textiles, and embroidery. But these techniques are quasi-additive approaches in which a conductive material is added to an existing textile instead of being integrated into the textile during the fabrication process of the textile itself, introducing problems such as delamination, slip, or cracking of the metallic region, as well as issues of production scalability.

Yu's group realized that what they needed to create was a high-throughput, inexpensive technique that directly integrates flat array antennas onto textiles. So they decided to study knitting and weaving, which, while being the most common approaches for fabricating patterned textiles, have not been explored as a way to produce complex array antennas with engineered electromagnetic responses.

A Fair Isle approach: The researchers took a novel approach to fabricating flexible, lightweight centimeter-wavelength metasurfaces. They leveraged an old-school colorwork knitting technique called float-jacquard knitting (think Fair Isle sweaters) and used commercially available metallic and dielectric yarns with existing knitting machinery to produce two prototype reflectarray devices, a metasurface lens (metalens) and a vortex-beam generating device. In the float-jacquard knitting technique, two or more types of yarn are used to produce a pattern: a yarn is floated loose beneath the fabric when not used and transferred back to the frontside as needed to create the desired pattern.

By integrating the textile fabrication and antenna patterning into a single process, the team streamlined the fabrication process and alleviated common defects in fabric-based antennas. The group is the first to adapt flat-knitting techniques to incorporate antennas directly during the fabric production procedure – integrated fabrication – and able to do it at low cost and high yield on an industrial scale. For example, each of the prototype metasurfaces with a footprint of approximately one square meter was knit within 45 minutes. In addition, the flat-knit fabric devices withstood repeated washing and stretching on a frame.

"The float-jacquard knitting technique used for making our textile metasurfaces is exactly the same technique that my mother used to make sweaters for me. I still remember a purple sweater I wore as a kid that had a row of white cats across the chest; I remember that when I inspected the inner side of the sweater, I saw white parallel yarns – the floats," said Yu, a pioneer in researching nanophotonic devices like metasurfaces.



(Above) Prof. Yu with the metalens prototype, which shapes a divergent wavefront into a planar one, increasing the directionality of the outgoing radio-frequency electromagnetic wave.

He noted that these complex RF antennas can be readily produced by existing infrastructure: "We can leverage the very old and very well-established knitting industry to fulfill some of the needs of modern telecommunications. The facile and scalable nature of the fabrication approach means these devices could be inexpensive, ultra-lightweight, flexible variants of sophisticated radio-frequency communications antennas."

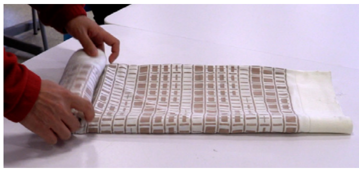
The results: The researchers showed experimentally that when the metalens operates as a receiving antenna, it focuses an incident centimeter-wave into a tight (diffraction-limited) focal spot, and that when it operates as a transmitting antenna, it converts the divergent emission from a horn antenna (a common RF source) into a wave with planar wavefront – a highly directional beam.

They also demonstrated that more complex wavefront shaping tasks can be accomplished: the vortex-beam generating metasurface produces a vortex beam – a beam with a corkscrew-shaped wavefront. Because of the peculiar wavefront, the vortex beam can carry an independent channel of information, thus a vortex beam and a beam with planar wavefront used together can make a communications channel twice as efficient.

Next steps: In future efforts, the researchers will explore modern knitting techniques – there are at least a dozen varieties – and knitting machines to realize more complex multi-functional designs – fabrics with combined designer electromagnetic, electronic, and mechanical responses. This could be used to engineer hinge points or folds, and electronic circuits into a fabric, which could be actuated to further facilitate stowage and deployment or even switch between different electromagnetic functionalities.

The scalability of flat knitting ranks highly among all techniques used to produce flexible or rigid RF metasurfaces and reflectarrays: commercial flat-knitting machines are capable of producing textiles up to two meters in width and with no limitation in the length direction. The researchers will explore this advantage to create high-gain antennas with apertures several meters in diameter yet lightweight and stowable to be carried by satellites to communicate across vast distances.

"It's important to stress that these devices were fabricated using commercially available off-the-shelf yarns and leveraging established fabrication techniques," Yu said. "I am almost certain that communities of knitters can come up with ingenious ways to integrate aesthetics and functionality into a sweater – a sweater that can double as a WiFi signal booster."



Yu's Portable Knitted Antennas Video:

https://tinyurl.com/5henb9ek

The Art of AI

In the new course AI in Context, faculty from across the University teach AI through the lens of philosophy, music, literature, and other domains

Originally published by Columbia Engineering

(Above) Columbia Engineering faculty members teaching the AI in Context course, Lydia Chilton, Adam Cannon, Vishal Misra, & Chris Wiggins

The use of generative AI by students in higher education is fraught with controversy. With a bit of prompting, programs like ChatGPT can write code, conduct research, and even produce entire essays. An anonymous survey of more than 6,300 college students found that almost two-thirds of them use or have used AI as part of their studies.*

Critics have cited the threat of cheating, as well as weakened critical thinking, as reasons why ChatGPT and similar tools should be banned from schools. But others, like Columbia Engineering's Adam Cannon, believe students need to be educated about the technology so they can make better decisions about its use.

"The genie is out of the bottle, so we need to learn how to accommodate generative AI into our classes and into education more broadly," says Cannon, senior lecturer in the Department of Computer Science. "If we can educate them about not just the technology but also the societal impacts of the technology, then they will not only be better and more innovative users but also more responsible users."

An interdisciplinary course designed to be accessible to all majors

This fall, Cannon and faculty from Engineering and Arts and Sciences launched AI in Context, a course that covers the history, development, applications, and societal impacts of AI. The course consists of five modules, each taught by a faculty member from a different part of the University. It offers students an opportunity to explore the potential of the technology in different contexts.

"No matter what our students major in, they'll need the analytical tools to ask what AI is and how we should relate to it," says Katja Vogt, professor of philosophy at Columbia and co-founder of the ValuesLab. "These questions require collaboration between fields, including philosophy."

Eight years ago, Cannon started an interdisciplinary course, Computing in Context, that has proved immensely popular with students. The course explores elementary computing concepts, along with use of computing in disciplines like the social sciences, economics and finance, and digital humanities.

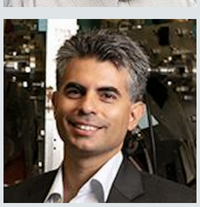
Similarly, AI in Context starts with the history of intelligence beginning in the 1900s and the advent of AI in the 1950s, taught by **Chris Wiggins**, associate professor of applied mathematics at Columbia. Vishal Misra, professor of computer science, then describes the evolution of neural networks and large language models. Vogt covers philosophy of AI, with topics such as fairness, alignment, and biases.

"As a philosopher, I'm interested in values, language, and the mind. Applied to AI, this means I'm interested in what it would mean for AI to be aligned with values and whether this is possible," she explains. "In class, we discuss this with regard to a range of values — some ethical or moral, some concerned with language and thought: fairness, truth, accuracy, understanding, interpretability, and more."

Students also work on a semester-long generative AI project led by Lydia Chilton, assistant professor of computer science. Seth Cluett, a lecturer in music, will close out the course with faculty members Kirkwood Adams and Maria Baker from Columbia's Writing Center. These modules will delve into the use of AI in creative fields.

The course is designed to be accessible to all majors, in the hope that students outside of Engineering will attend. Cannon foresees AI in Context becoming a mainstay course at Columbia that will evolve as the technology continues to rapidly advance.

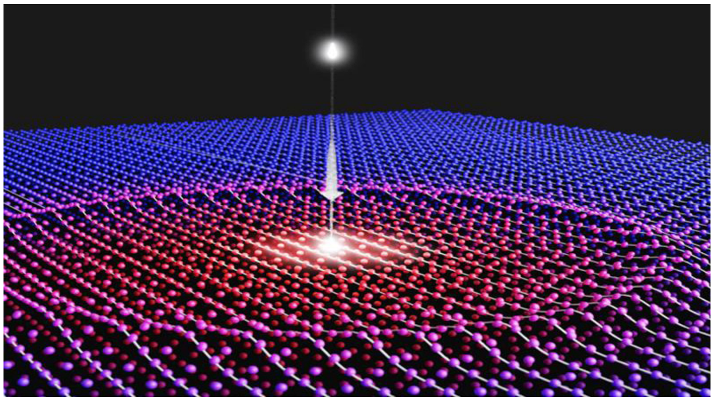
"We're going to learn a lot from [the first cohort] while they learn from us. It's going to be as much an education for the faculty involved as the students," he says. "We think that this is a technology that's going to grow in its importance and impact on our culture and society, and so it needs to be incorporated into a 21st century education."



Plasma Faculty Weigh in on the Future of Fusion Energy

Prof. Gerald Navratil (top photo) was quoted in T*he New York Times* article, "Inside the Quest to Make Fusion Energy a Reality: Start-ups say we're closer than ever to near-limitless, zero-carbon energy from fusion. When will we get there?" by Raymond Zhong (https://shorturl.at/mTo18). Navratil was also quoted in the *CNN Climate* article, "A nuclear fusion startup just reached a milestone in its bid to commercialize unlimited clean energy," by Laura Paddison (https://shorturl.at/FjvHG).

Prof. Carlos Paz-Soldan (bottom photo) was featured in the *Nature* news article, "ITER delay: what it means for nuclear fusion," by Elizabeth Gibney. After ITER (the International Thermonuclear Experimental Reactor - a global scientific project to demonstrate the feasibility of fusion energy as a large-scale, carbon-free energy source) announced a 4-year delay to its major experiments, many speculate that they may not be the first to reach their goals. "If a private company achieved a sustained burning plasma at a fraction of ITER's size, cost and complexity, that could change funders' dedication to ITER," says Paz-Soldan. "I do think the value proposition for ITER would require re-evaluation if this were to occur," he says. "But I do not think now is the appropriate time to have this conversation." https://shorturl.at/7BQZM



Atomic 'GPS' Elucidates Movement During Ultrafast Material Transitions

Simon Billinge & collaborators at Brookhaven demonstrated that a materials characterization technique can be successful at a new type of facility, and they used it to discover a hidden materials phase

Originally published by Brookhavenn National Lab

Scientists from the U.S. Department of Energy's (DOE) Brookhaven National Laboratory and Columbia Engineering have created the first-ever atomic movies showing how atoms rearrange locally within a quantum material as it transitions from an insulator to a metal. With the help of these movies, the researchers discovered a new material phase that settles a years long scientific debate and could facilitate the design of new transitioning materials with commercial applications.

This research, published in *Nature Materials*, marks a methodological achievement; the researchers demonstrated that a materials characterization technique called atomic pair distribution function (PDF) analysis is feasible — and successful — at X-ray free-electron laser (XFEL) facilities. PDF is typically employed for synchrotron light source experiments, during which samples are bombarded with pulses of X-rays. By studying how X-ray diffraction patterns change after interacting with materials, scientists can better understand the properties of those materials. But these experiments are restricted by the shortest X-ray pulses that can be generated.

"It's like a camera's shutter speed," explained Jack Griffiths, co-lead author of the paper. "If you are taking a photo of something changing faster than your camera's shutter speed, your photo will be blurry. Like a quick shutter speed, shorter X-ray pulses help us view quickly changing materials in more detail." Griffiths was a postdoctoral researcher in the X-ray Scattering Group within Brookhaven's Condensed Matter Physics & Materials Science (CMPMS) Department when the research was conducted and is now a postdoctoral researcher at the National Synchrotron Light Source II (NSLS-II), a DOE Office of Science user facility at Brookhaven Lab.

Synchrotron light sources are excellent for characterizing materials that aren't changing or materials that change over minutes to hours, like batteries as they charge and discharge. But this group of scientists wanted to observe material changes on picosecond time scales.

"It's hard to imagine how fast a picosecond really is," Griffiths said. In one second, light can travel around the Earth seven and a half times. But in one picosecond, light can only travel one third of a millimeter. "The time scales are almost incomparable."

(Above) The research team used their new ultrafast pair distribution function (uf-PDF) technique to explore the transition of a quantum material to a previously undiscovered material phase The schematic shows how the absorption of a laser photon initiates a small change that propagates through the material over time, rather than instantaneously changing the whole material. Credit: Jack Griffiths/Brookhaven National Laboratory

So, the scientists brought the PDF technique to an XFEL called the Linac Coherent Light Source (LCLS), a DOE Office of Science user facility at DOE's SLAC National Accelerator Laboratory that generates incredibly bright and short pulses of X-rays.

"When you are doing something for the first time, there is always this aspect of unknown. It can be nerve-racking but also very exciting," said Emil Bozin, the other co-lead author and a physicist in the CMPMS X-ray Scattering Group. "We knew the core limitations of bringing PDF to an XFEL, but we didn't really know what to expect."

With the fast "shutter speed" of LCLS, the scientists were able to create movies elucidating atomic movement, like that which occurs when their quantum material sample transitioned between a metal and an insulator.

"I was simply blown away by how well it worked," said **Simon Billinge**, professor of materials science and of applied physics and applied mathematics at Columbia Engineering and a physicist in Brookhaven's X-ray Scattering Group.

Simon Billinge

"It's similar to needing a navigation app," Billinge added. "You know where you are now and what your destination is, but you need the app to give you a route or a few route options. Ultrafast PDF was our navigation app."

Understanding these atomic routes is an important first step for designing transitioning materials with a myriad of applications in computing, chemistry, and energy storage. Once scientists understand how the materials transition, they can then manipulate the atomic routes and design materials optimized for commercial applications. Computer memory materials, for example, transition to a different phase when a file is saved. In this case, it is important to have materials that don't require a lot of energy to switch phases. But they also have to be resistant to unwanted phase switching and data corruption over long periods of time.

"Getting PDF working with an XFEL was the result of a huge organizational effort," said Ian Robinson, the X-ray Scattering Group leader at Brookhaven Lab and a professor at the London Centre for Nanotechnology at University College London (UCL). For example, Robinson noted, "we closely coordinated with Sébastien Boutet and Vincent Esposito from LCLS to determine that the Macromolecular Femtosecond Crystallography (MFX) beamlines were the most promising for the PDF technique."

The team also included physicists from Columbia University; University of Wisconsin, Madison; DOE's Argonne National Laboratory; and the United Kingdom's Science and Technology Facilities Council.

With their successful proof-of-principle experiments, the researchers were eager to look into another phase transition of the quantum material, which scientists study as a "model" for other useful materials. And the excitation of the material with a laser pulse led to an exciting discovery.

Uncovering a new material phase

Like the insulator to metal transition of this quantum material, some material transitions are driven by changes in temperature, pressure, or magnetic field. But because these environmental changes can occur naturally or unintentionally, they can be unreliable for some applications. When it comes to computing, it is important that the materials responsible for storing files don't switch phases just because a room became too hot or cold.

So, the researchers looked into "non-equilibrium" transitions, a change in material state induced by a reliable and controlled trigger. In this case, they zapped the quantum material with a laser pulse.

Even though the laser light perturbed just a few atoms, those atoms' neighbors responded to the change. And then the neighbors' neighbors felt the impact, until the local change had propagated throughout the entire quantum material. **(Continued on page 13)**

Atomic 'GPS' Elucidates Movement During Ultrafast Material Transitions

(continued from page 12)

"It was just like how an earthquake on the ocean floor can disrupt a little bit of water and create a wave that eventually reaches the edge of the ocean," added Billinge.

Using ultrafast PDF, the researchers closely observed atomic movement as the sample was bombarded with laser pulses. And for the first time, they directly observed the quantum material transitioning to a new state that had not yet been identified.

"This was like discovering a new, hidden phase of matter that is inaccessible during equilibrium transitions," said Bozin.

The scientists' discovery contributed to a years long debate about what really happens when certain quantum materials are excited by a laser; it is not just like heating the material, but rather the generation of a transient "metastable" intermediate state.

Interestingly, the material was disordered for tens of picoseconds, "even though it started and ended in an ordered state," Griffiths said.

Robinson added, "The discovery of a transient state represents a new phase of the material, which lives for just a short time. This is a vital sign that an undiscovered, fully stable material may be lying at a nearby composition."

Scientists are eager to uncover these "hidden" materials. But they also want to unlock the full potential of the new ultrafast PDF technique.

"There are several forms of complex phase switches that occur in quantum materials, and we plan to explore them with ultrafast PDF," said Bozin. "Understanding these phase transitions can facilitate the development of commercial materials. But the scientific community can also use the technique to answer fundamental physics questions, explore ultrafast phenomena, and build better superconductors."

He added, "Though we answered questions about material transition pathways, it seems as if we have opened a door rather than closing one."

Like this project, future ones will not be successful without multidisciplinary collaboration.

"We didn't just use the LCLS facilities at SLAC," Billinge explained. "The people there were also integral to making ultrafast PDF a success."

The Brookhaven team is ready to optimize the ultrafast PDF technique, especially as LCLS is upgraded to LCLS-II-HE, which will enable even higher resolution molecular movies.

"There is international interest in making this a routine and successful technique," said Bozin. "And we are looking forward to being a part of it."

Sample preparation was done at the Center for Functional Nanomaterials, a DOE Office of Science user facility at Brookhaven Lab. Additional measurements were taken at the Advanced Photon Source, a DOE Office of Science user facility at Argonne. This work was mainly supported by the DOE Office of Science.

How Does the Information Ecosystem Influence Politics?

A new course combines data and political science to understand some of the most vital phenomena of our time

Chris Wiggins & Eunji Kim

By Grant Currin, Originally published by Columbia Engineering

Eunji Kim caught **Chris Wiggins'** attention when she started talking about memes at an event on AI and democracy. "A string of fellow technologists — including myself — got up and made various technical claims about how technology is useful for understanding the information ecosystem," says Wiggins, an associate professor of applied mathematics at Columbia Engineering. "Then Prof. Kim got up and said, in academic terms, none of you has any idea how Americans actually interact with information."

Now, the professors are teaching "Persuasion at Scale: Causal Inference, Machine Learning, and Evidence-Based Understanding of the Information Environment", a new course at the intersection of data and political science. Both are members of the Columbia University Data Science Institute (DSI).

"It's very common for researchers in computational social science to use big data to draw conclusions about society," says Kim, an assistant professor in political science who uses quantitative methods to study political communication and public opinion in American politics. "But if you don't consider political context and meaning that influences your data, the analysis will be incomplete and your conclusions could be wrong."

In their new course, Kim and Wiggins aim to give students the tools necessary to rigorously analyze the impact of political communication—from campaigns and advertisements to partisan media and social media. "Persuasion is happening at scale on information platforms," Wiggins says, "so we now have the chance to understand this question statistically."

Machine learning — a branch of AI — will be a pillar of the course. Students will learn how this technology underlies the content recommendation and moderation systems that drive information platforms. They will also use machine learning techniques to interpret datasets.

Equipping students to challenge conventional wisdom: Persuasion at Scale pairs an examination of the research literature on political persuasion with a survey of the statistical methods necessary to make sense of complex datasets. Students will use real-world data to quantify the effects of partisan media, social media, advertising, and political campaigns while taking a historical view on the development of persuasion architectures.

"When we actually bring data to these questions and look at them objectively, we sometimes find that conventional wisdom isn't supported — or that it's wrong," Kim says. For example, op-eds, blog posts, and cable news monologues often assume that Americans are living in partisan echo chambers, with half the country watching Fox News and the rest watching MSNBC.

"If you look at actual behavior-level data, the extent to which echo chambers exist is very limited because most people do not consume news to begin with," Kim says. "Consumption of news content is very low relative to other media, like sports or entertainment."

Another counterintuitive finding is that political campaigns — even those that spend hundreds of millions of dollars — often don't have a substantial impact on voter choices. "There's a lot of discrepancy between what people believe versus what empirical social science has been discovering," Kim says.

Students will learn to employ causal inference techniques to distinguish between correlation and causation in real-world datasets.

An opportunity for interdisciplinary collaboration: The course, which is offered under the Provost's Cross-Disciplinary Frontiers Initiative, is open to undergraduates across the University. The professors hope to offer roughly 70 students from diverse backgrounds the chance to collaborate and learn from each other.

"Engineering students don't often take classes in political science, and our own social science students do not often take many math classes," Kim says. "These types of classes are critical for them to learn how to fix the many complex problems facing our society."

For Wiggins, the course is an opportunity for students to bring quantitative rigor to a domain that's often understood through conventional wisdom and unjustified assumptions. "I think it's useful to zoom out and see how persuasion — whether it's political persuasion or marketing — has some universal aspects that we can understand using mathematics," he says. "By combining that context with the language of probability, we hope to enable students to look past inflammatory anecdotes in order to think methodologically and historically."

David Keyes

Keyes Wins Second Gordon Bell Prize

David Keyes, Adjunct Professor in the APAM Department and Professor of Applied Mathematics and Computational Science and the Director of the Extreme Computing Research Center at the King Abdullah University of Science and Technology (KAUST), has received the Gordon Bell Prize for the second time. The Gordon Bell Prize for Climate Modelling recognizes the contributions of climate scientists and software engineers. The 2024 ACM Gordon Bell Prize for Climate Modelling was awarded to a 12-member team for their project "Boosting Earth System Model Outputs and Saving PetaBytes in Their Storage Using Exascale Climate Emulators." The award recognizes innovative parallel computing contributions toward solving the global climate crisis. The members of the team are: Sameh Abdulah, Marc G. Genton, David E. Keyes, Zubair Khalid, Hatem Ltaief, Yan Song, Georgiy L. Stenchikov and Ying Sun (all of King Abdullah University of Science and Technology, Saudi Arabia); Allison H. Baker (NSF National Center for Atmospheric Research, USA); George Bosilca, (NVIDIA, USA); Qinglei Cao (St. Louis University, USA); and Stefano Castruccio (University of Notre Dame, USA). Prof. Keyes' first Gordon Bell Prize prize was awarded 25 years ago in cooperation with NASA for an aerodynamics application. This is also Prof. Keyes' fourth Gordon Bell nomination in the past three years.

World's Largest Fusion Energy Tokamak Device Endorses Sabbagh Research Group Solution Enabling Sustained Fusion Production

The tokamak magnetic confinement concept was chosen for the International Tokamak Experimental Reactor (ITER) device, the world's largest fusion energy device of its kind, now being constructed in the south of France. A key goal of the device is to generate 500 MW of fusion power in its plasma for long pulses, representing an anticipated ten-fold return on the input heating power, paving the way toward bringing virtually limitless, carbon-free, and environmentally-benign power to humanity in a next-step fusion energy pilot plant.

Figure 1 (left): Dr. Veronika Zamkovska, Mr. Matt Tobin, Prof. Steven A. Sabbagh, Dr. Guillermo Bustos-Ramirez, and Dr. Hankyu Lee in the ITER Council Chamber, and (right) in the ITER Assembly Hall adjacent to the ITER Tokamak Building.

A long-standing grand challenge problem in tokamak fusion energy research and development is the prediction and avoidance of plasma disruptions which stop plasma operation in the device, and create transient electromagnetic and thermal forces that may damage the device. An applied research approach named disruption event characterization and forecasting (DECAF), pioneered by APAM senior research scientist and adjunct professor **Steven A. Sabbagh**, is a leading solution to this critical applied plasma physics issue producing high accuracy disruption prediction in both large database analysis and real-time application [S.A. Sabbagh, et al., *Physics of Plasmas* 30 (2023) 032506]. The unique DECAF approach has U.S. and international patents pending.

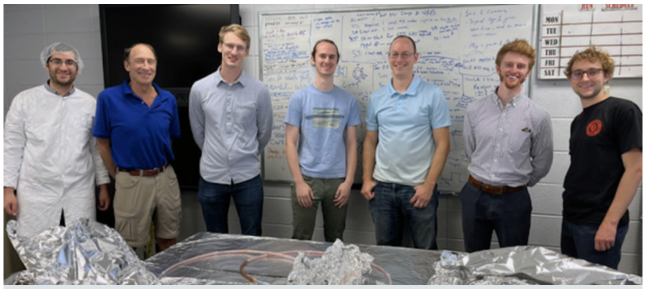
Recently, plasma control management of the $22 billion dollar ITER Project, led by Dr. Peter de Vries, has endorsed the implementation and use of DECAF for real-time disruption prediction and avoidance in ITER, along with associated physics analysis. Dr. Sabbagh leads U.S. Department of Energy (DOE) multi-institutional grants supporting DECAF research through an international effort comprised of four U.S. institutions (Columbia University, the Princeton Plasma Physics Laboratory (PPPL), Nova Photonics, SapientAI) and international collaborations with the Korea Institute of Fusion Energy (KFE) and the UK Atomic Energy Authority.

Steven A. Sabbagh

Prof. Sabbagh's present Columbia research group includes APAM associate research scientist Dr. Veronika Zamkovska, postdoctoral researchers Dr. Guillermo Bustos-Ramirez, Dr. Joseph Jepson, Dr. Hankyu Lee, and students Mr. Juan Riquezes, Mr. Matt Tobin, Mr. Frederick Sheehan, and Mr. Grant Tillinghast. More than half of the group visited ITER Headquarters during the summer to attend and make presentations at the 3rd IAEA Technical Meeting on Plasma Disruptions and their Mitigation, visit the ITER experimental site, and meet with the ITER control group (Figure 1).

Prof. Sabbagh and the visiting Columbia research team met extensively with the leadership and members of the three main branches of the ITER Plasma Control Team to discuss details of DECAF and how to best implement it on ITER and use it for analysis (Figure 2). These meetings, spanning several days, were the first in-person meetings between DECAF Group members and the ITER Plasma Control Team on DECAF research and implementation on ITER. Initial remote discussions have been conducted remotely over many preceding months.

DECAF research presents a new paradigm in the pursuit of a high accuracy solution to tokamak plasma disruption prediction and avoidance, which is required to meet the lofty goal of greater than 98% accuracy in the predictive performance of the underlying physics models over the entire databases of large auxiliary-heated tokamaks located around the world (e.g. the Korea Superconducting Tokamak Advanced Research (KSTAR) at KFE in South Korea, the Mega-Ampere Spherical Tokamak (MAST) and it's upgrade MAST-U in the UK, the National Spherical Torus Experiment at PPPL, and the DIII-D National Fusion Facility at General Atomics in San Diego). Access to 9 such databases presently exists, with others continuing to be added, representing a petabyte-scale data store – a modern-day "big data" problem. Addressing such a problem requires full automation of all steps, so that physics models can be repeatedly validated against entire device databases. Validation of physics models at that scale is transformative in the field of magnetic confinement fusion, and required to reach the high accuracy goals disruption prediction and avoidance, with the required physical understanding of the analysis to provide confident extrapolation to future devices. DECAF research also expanded to real-time implementation on the KSTAR device with dedicated experiments producing 100% accuracy of magnetohydrodynamic (MHD)-induced plasma disruptions, published at the IAEA Fusion Energy Conference in 2023. At present, DECAF physics models are broadening in depth and scope at a rapid rate, with the analysis itself now having sufficient "intelligence" to point out problems in present models, or the need for new physical models (part of the "DECAF workflow"). Such topics include tokamak plasma density limits produced by loss of energy balance, microturbulence, and other reasons, fast magnetic field reconnection dynamics and related physics, resistive MHD mode stability and triggering, and MHD mode coupling and locking. A manifestation of this rapid physics model expansion is the record number of presentations (14) shown by the DECAF group at the 2024 American Physical Society Division of Plasma Physics Meeting in Atlanta, GA. DECAF research will continue to introduce new topical physics areas as needed in the pursuit of producing a solution for the tokamak plasma disruption prediction and avoidance challenge.



Columbia's Relativistic Electron Mitigation Coil Invites Attention

Visitors from MIT and Commonwealth Fusion Systems (CFS) toured the HBT-EP tokamak research facility to learn more about the installation of the world's first Relativistic Electron Mitigation Coil (REMC) and to present lectures on the relativistic electron mitigation in the SPARC fusion energy device under construction by CFS.

In 2011, **Prof. Allen Boozer** first proposed the idea of installing an optimally shaped 3D conducting element inside of the vacuum vessel that is driven by the disruption voltage to provide a "fail-safe" prevention of high-energy runaway electrons. Tokamak disruptions are among the most serious events to cause potential harm to first wall of a fusion energy device. Preventing disruptions and controlling instabilities that may lead to disruptions have been a key research focus of Columbia University. Prof Boozer's concept has also driven plans for installation of similar systems on the National DIII-D Tokamak operated by General Atomics in San Diego, and the TCV Tokamak Operated by the Ecole Polytechnique de Lausanne in Switzerland.

Dr. Jeffrey Levesque, lead scientist on the HBT-EP experiment, described details of the nearly completed REMC installation. Drs. Robert Granetz (MIT), Alex Tinguely (MIT), and John Boguski (CFS) were shown the many components installed inside the HBT-EP vacuum vessel that will be used to test the REMC concept. The flexibility of the HBT-EP device simplifies installation and enables extensive model validation. Levesque and the HBT-EP team are installing two REMC coils to investigate the role of plasma coupling. Operation of the new REMC will explore perfomance of the passive coil system, measurements of disruption forces, and the role of halo currents flowing from the plasma into the first wall.

After the day's tour of the HBT-EP facility, Drs. Tinguely and Boguski presented a seminar describing plans for disruption mitigation at the SPARC fusion energy demonstration facility and noted the importance of upcoming HBT-EP results.

(above) Members of the REMC coil installation crew with visitors from MIT/CFS. Noah Notis (APAM), Robert Granetz (MIT), John Boguski (CFS), Nigel DaSilva (APAM), Jeff Levesque (APAM), Alex Tinguely (MIT), & Anson Braun (APAM)

Columbia Plasma Physicists at the 2024 APS Annual Meeting

Dr. Alex Battey

Dr. Boting Li

Haley Wilson

Columbia University students, scientists, and faculty descended in Atlanta, GA to present their research results and interact with colleagues at the 66th Annual Meeting of the American Physical Society (APS) Division of Plasma Physics. Columbia plasma physicists presented over 125 presentations during the five day meeting to an international audience of more than 2,000 participants.

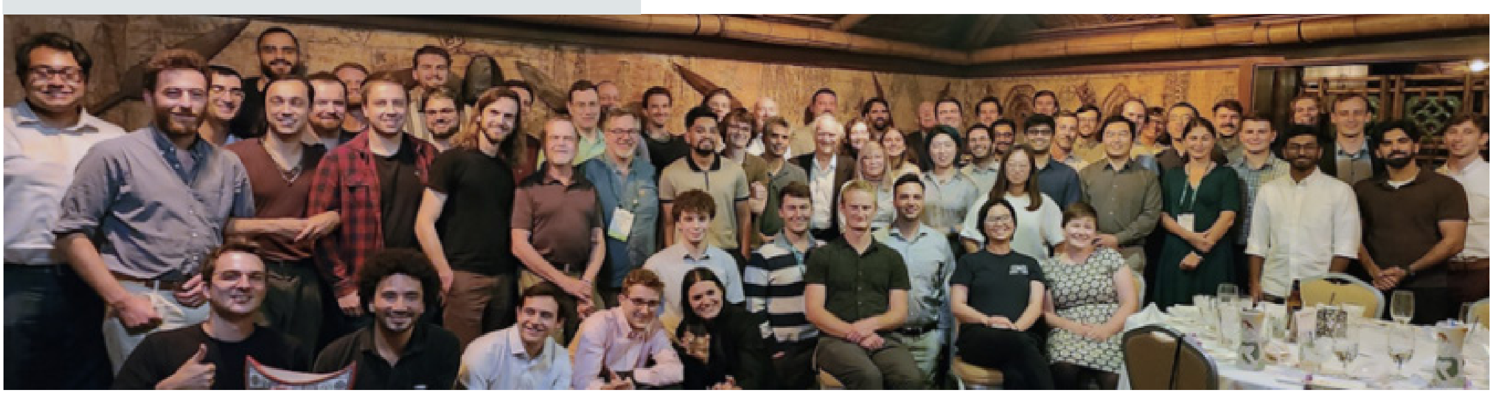
Presentations are either contributed by participants or invited by the APS Program Committee. Less than 110 scientists are invited to present their results. Invited presentations represent the most exciting results achieved during the past year or present important messages for the plasma physics community.

This year three early career Columbia students were among those invited. Leading off the meeting on Monday morning, was **Boting Li** (PhD 2024) who presented her doctoral research conducted at Columbia's HBT-EP tokamak in her presentation titled "Sawtooth Suppression by Flux Pumping on HBT-EP." **Alex Battey** (PhD 2024), Associate Research Scientist at Columbia, presented his research conducted at the DIII-D National Tokamak Facility in San Diego, CA titled "The Effect of Externally Applied and Self-Excited Waves on Relativistic Electrons." And current applied physics graduate student **Haley Wilson** presented the results from the joint Columbia University-MIT MANTA Collaboration titled "Using integrated modeling to optimize fusion performance in MANTA, a negative triangularity fusion pilot plant concept."

Several Columbia alumni also were invited to present their latest results. **Dr. Mel Abler** (PhD 2020) now at the Space Science Research reported the "First Laboratory Observations of Residual Energy Generation in Strong Alfvén Wave Interactions," based on detailed measurements conducted at UCLA. **Dr. Seth Davidovits** (BS 2010) now at the Lawrence Livermore National Laboratory presented work on inertially confined fusion titled "Assessing explanations for unexpected fuel-ablator mixing measurements in HDC implosions at the NIF." **Captain Dr. Royce W. James**, who conducted his doctoral research at Columbia's HBT-EP tokamak and who now professor of physics at the US Coast Guard Academy, engaged the plasma physics community in the "Healthy to Innovative Framework" as a framework to maximize innovation and drive the culture of discovery in science. Dr. James presentation was titled "How do you work this "HTI" thing anyway; Leveraging the Merger of Healthy to Innovative (HTI) Workspaces and a Focus on People to Boost Outcomes and Discovery."

An important part of the Annual Meeting is to meet with colleagues and share ideas, progress, and methods. At the Conference Awards Banquet, the APS formally Awarded **Professor Carlos Paz-Soldan** with Fellowship. Another especially noteworthy event is the Columbia University Plasma Physics Group Reunion Dinner. Nearly 70 students, scientists, and alumni celebrated the many contributions and progress of Columbia University Plasma Physics.

(Below) 2024 Columbia University Plasma Physics Group Reunion Dinner



Accelerating Commercial Fusion: the role of Industry and Academia

Bringing together experts from Fusion Industry and Academia, Columbia University's School of Engineering and Applied Science recently hosted a panel discussion entitled "Accelerating Commercial Fusion: the role of Industry and Academia." The panel included Prof. Alexis Abramson, incoming Dean of the Columbia Climate School, Prof. Cary Forest, Professor of Physics at the University of Wisconsin-Madison and Co-Founder and CSO of Realta Fusion, Charlie Baynes-Reid, the CFO and General Counsel of Type One Energy, Dr. Michael Ginsberg, President, Tokamak Energy LLC, Michael Segal, Senior Director of Open Innovation at Commonwealth Fusion Systems, and Sam Wurzel, Founder of Fusion Energy Base and former DOE Employee. A vibrant discussion was executed exploring these questions:

Is fusion energy just around the corner? Recent years have seen several dramatic advances in this field: fusion ignition by lasers at the National Ignition Facility, 59 megajoules of fusion energy by the magnetic approach in the United Kingdom, and most importantly the emergence of a vibrant fusion private sector backed by $7 billion of venture capital funding.

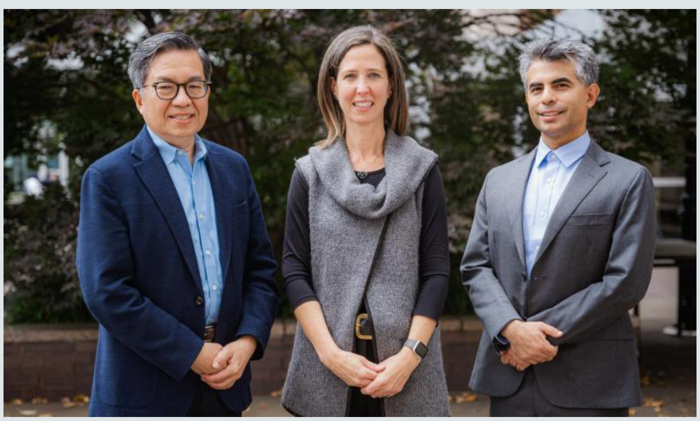
How can progress in fusion be accelerated? This panel explored the progress and plans in the private sector, discuss the ambitious timelines of leading fusion startup companies, and identify the challenges facing the sector.

What is academia's role? The panel discussed the essential role of university programs in performing early-stage R&D, developing new concepts, and building the fusion workforce of tomorrow.

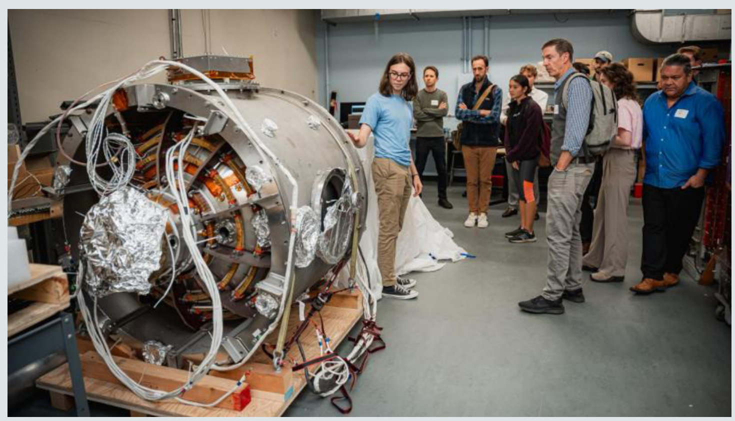
Beyond the panel, the event also included a tour of the Columbia Plasma Physics Laboratory, one of the premier academic laboratories in the field, and concluded with a reception. A video of the event is available at: **https://shorturl.at/EOAal**

(Above) Sam Wurzel, Charlie Baynes-Reid, Michael Ginsberg, Cary Forest, Carlos Paz-Soldan, Alexis Abramson, & Michael Segal

(Above) Panelists and host, Prof. Carlos Paz-Soldan, at the event during Columbia Engineering Climate Week 2024



(Above) Columbia Engineering Dean Shih-Fu Chang, Dean of the Columbia Climate School Alexis Abramson, & Prof. Carlos Paz-Soldan



(Above) APAM graduate students led a tour of the Columbia Plasma Physics Laboratory

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