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The Fu Foundation School of Engineering and Applied Science

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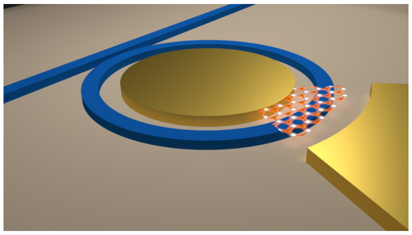
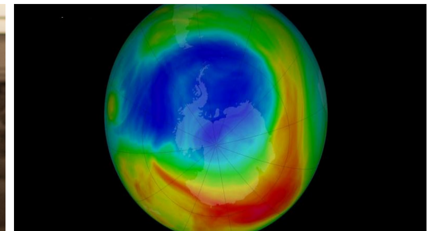
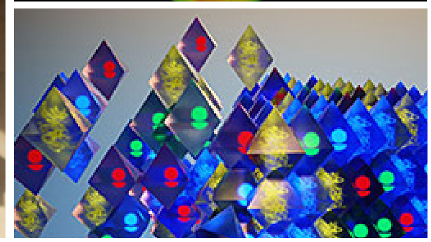
APAM NEWS

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



Dear APAM Family,

It has become usual to say that these are unusual times.

They are unusual because our campus life was disrupted in an unprecedented manner by the Covid-19 situation, as we brought in-person classes to the remote format and stopped on-campus research in a matter of a week or so. Due to the amazing efforts of our staff, faculty, students and administration, we did a superb job in making this transition. Particularly heartwarming to us in APAM, were our remote celebrations of our seniors and senior award winners, the winner of our Simon Prize for the top doctoral thesis (and of the life of the late Dr. Jane Faggen who helped establish this prize), and of all our graduates this past year!

They are unusual because we were again reminded that we must be inclusive, tolerant, respectful, and open to all types of people, and to help and nurture them all. This has been at the heart and soul of our great country. Though, of course, it has not been practiced perfectly and often not very well, these precepts and goals have been our great strengths, and hopefully these ideals and aspirations will continue to be our strengths, and be practiced better and better in our department, school, university, country, and world.

On a more upbeat note, the times are unusual because we just launched a new department website!

We now face the daunting task of beginning anew in a new academic year. We are resilient! We will survive and prosper!

Stay well,

Irving P. Herman
Chair, APAM

Images: (top left) New Way to Control the Phase of Light Using 2D Materials - Lipson Group, p.9; (bottom left) Beating the Heat in the Living Wings of Butterflies - Yu Group, p. 6; (center) Mateo Navarro Goldaraz, B.S. '20, p. 2; (top right) Successful Ozone Treaty Stops Jet Stream Drift in the Southern Hemisphere - Polvani Group, p. 7; (bottom right) Nano-objects of Desire: Assembling Ordered Nanostructures in 3-D - Gang Group, p. 12

Schechter '20 Named Valedictorian

Applied Mathematics major, **Emma Schechter**, is Columbia Engineering's Valedictorian for the undergraduate Class of 2020! She was awarded the Illig Medal and spoke at the Engineering Class Day on May 18. The following interview, by Jesse Adams, was originally published by *Columbia Engineering*.

Why Columbia Engineering?
I have always had a lot of interests, so the interdisciplinary focus at Columbia allowed me to not have to pick and choose what to focus on academically. I've always thought that interdisciplinary studies when studying STEM are incredibly important in helping one be a good person in addition to a good academic. I also knew that I wanted to be part of an arts community extracurricularly, so living in New York City was a dream.

Why Applied Math?
I was initially drawn to the flexibility of the program. Since I've always had many interests, I feel incredibly lucky to study something that is relevant in numerous disciplines. Applied Math can be relevant in technical and nontechnical studies, as we are in an age of prevalent computation, so I didn't have to commit to learning about one thing.

What was your favorite course and professor?
I truly cannot pick one course or professor. I loved *Introduction to Numerical Methods* with **Kyle Mandli**, *Uncertainty Quantification* with Kyle Mandli and **Michael Tippett**, *Modern Architecture in the World* with Anooradha Siddiqi, and *Computational Approaches to Human Vision* with Norma Graham. Professor Mandli has taught me so much and been especially formative in my intellectual growth, but again it's so hard to pick one!

What was the most meaningful project you worked on?
In *Modern Architecture in the World*, we had to design an exhibit, pick where to show that exhibit, and explain the intention behind our choices. My exhibit focused on dialogue between the female body and landscape. While this initially seemed insulated from my other studies, I really began to think about an engineer's role as a "builder," as what I was doing was similar to what an engineer does. It's so important to be aware of the inherent privilege of this role and the effect it has on people using the given device or environment.

How have you been spending your time away from Columbia?
I pride myself on being a hobbyist so I've actually been up to a lot! I'm currently in New York City and have been making jewelry, making videos, and learning animation. I am also the sound designer for "Disco Pigs," a play in the Senior Thesis Festival for directing students—since the festival is now virtual, I've been working on pre-recorded videos that will be integrated into the live performance.

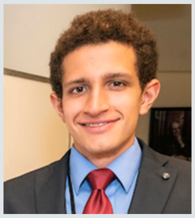
What are your plans for after graduation?
I plan on staying in New York. I do analog video projections at concerts in the city and want to keep doing so. I'm also continuing to work on projects that I have yet to publish, that combine arts and computation along with analog and digital media with the goal of creating accessible narrative works. In a few years, I believe I'll apply to graduate school for this sort of work existing at the intersection of art and computation. My dream job after graduate school would be writing and producing accessible narrative works involving sound art, analog video, and animation. Plus, I'd love to run an experimental art center that houses works involving some sort of creative computing.

Who are the most inspirational people in your life?
My grandfather who died when I was in high school was a huge role model for me, a hobbyist and one of the only people in my life interested in STEM and art. He worked in early computing and was a woodworker, actor, and writer. Norma Graham, the professor who teaches *Computational Approaches to Human Vision*, has also been incredibly inspirational to me—she studies mathematical modeling of vision, has been faculty at Columbia since 1970, and truly encourages interdisciplinary discussion in her course.

What was the most important thing Columbia Engineering taught you?
It taught me to be comfortable with not understanding something. You can't be an expert at everything, which is why asking for help is so important!

Undergraduate Award Winners

Three outstanding seniors were recognized at the 2020 Senior Celebration and Awards Ceremony for their excellent academic achievements.

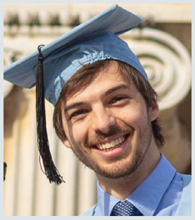


Marco Andrés Miller
Applied Physics Faculty Award Winner

Prof. Irving Herman stated, "Marco is an exceptional student. In addition to witnessing his extraordinary work in my classes, it has been a pleasure working with him this year as a grader. He has done exceptionally well in class, maintaining a 3.83 GPA, and has been heavily involved in research. At the 61^{st} Annual Meeting of the APS Division of Plasma Physics, he presented his summer research results in collaboration with the Princeton Plasma Physics Laboratory. His presentation, "A machine learning algorithm for the nonlinear Fokker-Planck-Landau collision operator in XGC," which showed how to use machine learning to create a fast and efficient computer simulation of plasma collisions for fusion experiments, was awarded the "Best Undergraduate Poster Award" at this major conference, a truly distinct honor. Andrés also spent a semester abroad working at the ITER experiment in France (the world's largest fusion experiment). Next year, he will enter the Ph.D. program in Nuclear Science & Engineering at MIT.

Emma Schechter
Applied Math Faculty Award Winner

Emma is outstanding in all ways, as exemplified by maintaining a 4.21 GPA, and valedictorian. Prof. Chris Wiggins, who taught the *Applied Math Senior Seminar*, stated that Emma's senior project was an incredible, reflective, and multidisciplinary look at gentrification and its impact on the census. She was unafraid to "swim outside" the conventional realm of applied math, into socio-economic and demographic matters that are often left to sociology. Her dream job would be to write and produce accessible narrative works involving sound, art, analog video, and animation. Emma plans on developing creative computing programs/multiple programs that combine coding and art, as well as electrical engineering and art, en route to graduate school.



Mateo Navarro Goldaraz
Materials Science Frances B.F. Rhodes Prize Winner

Mateo is a remarkable student who took on a series of challenging courses and new opportunities, all while maintaining a 3.78 GPA. Prof. Irving Herman commented, "Mateo did research in my group on small angle x-ray scattering of nanoparticles using the x-ray light source at Brookhaven National Lab, engaged in how different materials enable improvements in devices for electrochemical energy storage and conversion in the Marbella lab, and spent summers doing internships at Applied Materials." Mateo also engaged in outreach activities, such as teaching visiting students about nanomaterials, and, in his free time, enjoyed participating in the sailing club and excelling in soccer. In August, Mateo will join Applied Materials in Massachusetts full time.

Mandal Wins 2020 Simon Prize for Outstanding Dissertation

Learn more about the 2020 Simon Prize winner, Dr. Jyoti Mandal, in the Student Spotlight on page 3.

Dr. Jyotirmoy "Jyoti" Mandal is this year's recipient of the Robert Simon Memorial Prize for the most outstanding dissertation.

Jyoti received his Ph.D. from Columbia University in June 2019, where he was advised by **Prof. Yuan Yang**. His dissertation, titled "Spectrally Selective Designs for Optical and Thermal Management," focused on the creation of high-performance but low-cost solar heaters and radiative coolers, and designs that can switch between heating and cooling modes. Besides scientific novelty and performance, a guiding consideration for his designs was low-cost and simplicity of fabrication needed for use in developing countries.

Jyoti's research with Prof. Yang, in collaboration with colleagues from **Prof. Nanfang Yu**'s group, was published in several journals, including *Advanced Materials* (2017), *Science* (2018), *Joule* (2019), and *Science Advances* (2020).

Jyoti received his B.A. in Physics and Mathematics, with a minor in Materials Science, from Vanderbilt University in 2014. In 2019, he was selected as a Schmidt Science Fellow, and for his postdoctoral research under the fellowship, is designing optical components at the University of California, Los Angeles. Going forward, Jyoti hopes to continue his research on radiative energy transfer and optics, with the goal of controlling the behavior of light using disordered materials for optical designs.

History of the Prize: The Robert Simon Memorial Prize is awarded annually by the APAM Department to the graduate student who has completed the most outstanding dissertation. The Department chair in consultation with the Department faculty selects the awardee.

Robert Simon (December 25, 1919–February 11, 2001) received a B.A. degree *cum laude* in classics from the City College of New York in 1941, where he was elected to Phi Beta Kappa, and an M.A. in mathematics from Columbia University in 1949. Between 1941 and 1944, Mr. Simon was a lieutenant in the United States Armed Forces serving in England, France, and Italy. He participated in the D-Day operation as a navigator for a plane that dropped paratroopers in the vicinity of Omaha Beach. General Dwight Eisenhower personally shook his hand and wished him well the night before the D-Day assault.

Mr. Simon, who was born and lived in New York City, spent a lifetime making valuable contributions to the field of computer science. Starting in 1953, he worked for 15 years at Sperry's Univac Division in various capacities including marketing, planning, systems engineering, systems programming, and information services. He also spent a year working at the Fairchild Engine Division as director of the Engineering Computer Group. He personally directed the establishment of several company computer centers at sites throughout the United States. Between 1969 and 1973, he was a partner with American Science Associates, a venture capital firm. Mr. Simon was a founder and vice president of Intech Capital Corporation and served on its board from 1972 to 1981 and a founder and member of the board of Leasing Technologies International, Inc. from 1983 until his retirement in 1995.

The prize was established in 2001 by **Dr. Jane Faggen** with additional support from friends and relatives of Mr. Simon.

We mourn the loss of **Dr. Jane Faggen**, a dear friend of the APAM Department and close family friend of SEAS Dean and APAM Chair *Emeritus*, Robert Gross. She passed away on April 19, 2020.

Through her relationship with the Gross family, Jane learned about the APAM Department and became the generous donor of the Robert Simon Memorial Prize. For many years, she enthusiastically attended the ceremony in which this prize was awarded, always providing words of wisdom, including those about the burgeoning role of women in technology and other facets of life throughout her own career and life.

Jane earned her undergraduate degree at the University of Michigan, her M.S. from Cornell University, and her Ph.D. in Educational Psychology from the City University of New York (CUNY). She worked for Bell Labs and the Educational Testing Services; she was a programming librarian; and was a lecturer and a member of the research staff of the Computer Center of the CUNY Graduate Center. Jane was a pioneer in investigating the role of gender in education, which included the study she co-authored, *Women and Educational Testing: a Selective Review of the Research Literature*, in 1974 and the book she co-authored, *Sex Bias in the Schools: The Research Evidence*, in 1977. She was also an active volunteer worker for the Guidance Center of New Rochelle (a children's mental health clinic) and, being a great lover of both music and fine art, she became a docent at the Princeton Art Museum.

She was the mother of three children - Peggy, Patti, and Peter - and daughter, Peggy, attended this year's Simon Prize Award ceremony, which was conducted virtually, given the COVID-19 situation.

Martin Wins Best Student Oral Presentation AMS Award

Atmospheric science Ph.D. candidate, **Zane Martin**, from **Prof. Adam Sobel**'s group, won a "Best Student Oral Presentation" award at the 8th Symposium on the Madden-Julian Oscillation and Sub-Seasonal Monsoon Variability - a distinct conference within the American Meteorological Society's Annual Meeting. His award winning presentation was titled "Examining the MJO-QBO relationship in a GCM with a nudged stratosphere."

Student Spotlight: Jyotirmoy Mandal

Originally published by Columbia Engineering

Having spent his childhood in Bangladesh, **Jyotirmoy Mandal**, arrived at Columbia more than aware of the critical need for designs and devices that are accessible to people around the world, particularly in developing countries--where, for instance, innovative optical designs are often too expensive for widespread use. It's these sorts of challenges that fit Mandal's skillset, blending cutting-edge physics with very down-to-earth solutions any of us could implement.

A prime example can be found among one of his most recent projects, where working with his advisor **Yuan Yang**, associate professor of materials science and engineering, and their collaborator **Nanfang Yu**, associate professor of applied physics, he invented an exterior polymer coating, with nano-to-microscale air voids, that can radiate and lose heat into space, and can be fabricated, dyed, and applied like paint. This inexpensive, easy-to-apply coating can passively cool objects, and can lower the ambient temperature inside buildings without requiring any additional energy use.

Mandal's upbringing had a strong influence in his education and scientific motivations. He interest in science was sparked by his parents, who encouraged him to learn beyond textbooks by watching BBC and *National Geographic* documentaries, and by building toys and contraptions using tools from a young age. Mandal excelled in math and physics at secondary school, and went to Vanderbilt University in Nashville, TN, for college.

"Being part of a family of medical doctors, there was perhaps an implicit expectation from my family that I would go on to study medicine in college," says Mandal "But I was more interested in physics from a young age. I also liked hands-on research, as it leads to an understanding of fundamental theories grounded on real-world experience. During my senior year, I started to think about how science could be used to improve lives in developing countries such as mine, and that drew me towards applied physics."

Mandal earned his BA degree in physics and mathematics, with a minor in materials science and engineering, in 2014. He came to Columbia for his doctoral studies, and has been working with Yang, whose research is focused on developing next-generation batteries and thermal management. In collaboration with Yu, they have created an impressive variety of designs, including the paintable polymer coating that can passively cool buildings, selective solar absorbers that harvest heat from sunlight, and optically switchable designs that can change color to control light and heat. Mandal's work on the paintable polymer coating for passively cooling buildings was published last fall in *Science* to a good deal of interest, and his work on selective solar absorbers was published in *Advanced Materials*.

"Prof. Yang's openness to my exploring optical & thermal design when I joined his group, & his initiative while venturing into what was a new field for both of us, is a rare quality in an advisor. Being mentored by him has been an experience I will cherish."

- Jyotirmoy Mandal

In April 2019, Mandal was selected as a Schmidt Science Fellow, an innovative post-doctoral program focused on developing the "next generation of interdisciplinary science leaders to tackle the world's most significant problems and maximize scientific opportunities for society." **(Continued on page 14)**

Congratulations Graduates!

October 2019 Bachelor of Science
Sawal Acharya (AM), Abraham Oh (MSE)

October 2019 Master of Science
Jingwei Gao (MSE)

October 2019 Master of Philosophy
Lyuwen Fu (MSE), Jessica Oehrlein (AM-ATMOS), Long Yang (MSE)

October 2019 Doctor of Philosophy
Melanie Bieli (AM-ATMOS), Mark England (AM-ATMOS), Jyotirmoy Mandal (AP-SS)

February 2020 Bachelor of Science
Christian Cruz Godoy (AP), Kaiwen Liu (AM), Stephen Peng (AM)

February 2020 Master of Science
Rawan Al Aloula (AM), Kendra Bilardello (AM/CVN), Andrew Bishop (AP), Junming Cao (MSE), Wei Huan Chiang (MSE), Mathis Collier (AP-MP), Maria diMayorca (AP-MP), Jingnan Feng (MSE), Zhenxuan Fu (MSE), Shiqi Gao (MSE), Yuanchen Gao (MSE), Yuhan Gong (MSE), Tianyi Gu (MSE), Youcheng Hong (MSE), Hanpei Hu (AM), Ruiquan Huang (AM), Zhuting Jiang (AM), Shengchao Jiang (MSE), Aysha Khan (AM), Dawei Lan (MSE), Zachary Li (MSE), Boting Li (AP), Edison Lin (AP/CVN), Sirui Liu (MSE), Songwei Liu (MSE), Yulong Liu (MSE), Kevin Liu (AP-MP), Yu Luo (MSE), Mark Mathis (AP), Ivan Mitevski (AM), Siyu Pan (MSE), Michael Pieknik (AP/CVN), Junru Qian (MSE), Harish Ramesh (MSE), Pawas Shukla (AP-MP), Colton Smith (AM), Yankun Song (MSE), Juntao Wang (AM), Gale Wang (AP), Jiayang Wang (MSE), Peiyu Wang (MSE), Xiaotong Wang (AP-MP), Yuman Wu (AM), Wenjing Wu (MSE), Zirui Xu (AM),Xinlang Yue (AM), Yuan Zhang (AM), Hanrui Zhang (MSE), Yifan Zhang (MSE), Binchao Zhao (MSE), Weihang Zheng (AM), Yue Zhu (MSE)

February 2020 Master of Philosphy
Rachael Keller (AM), Aaron Michelson (MSE), Mehmet Hazar Seren (MSE)

February 2020 Doctor of Philosophy
Soham Banarjee (MSE), Adam Overvig (AP-SS), Sajan Shrestha (AP-SS), Christopher Wright (MSE)

May 2020 Bachelor of Science
Joseph Arlauckas (AM), Urvi Awasthi (AM/CC), Victor Borges (AM), James Borovilas (AP), Garrett Brown (AM), Sean Cahill (AM/GS), Jose Castillo (AM/GS), Thomas Chadrycki (AM), Arvind Chava (AM), Roland Chen (AM/GS), Chixuan Chen (MSE), Patrick Chi (AM), Monica Choi (AM), Olivia Contratto (AM), Boris DeArriz (AP), Unique Divine (AP), Xinhang Dong (AM), Miya Dubler (AM/CC), Chaim Eisenbach (AM), Justin Ernst (AM/GS), Kyelee Fitts (AM/CC), Dinko Franceschi (AM/GS), Felipe Fritsch (AM/CC), Zehui Gao (AM), Amelia Green (AM/CC), Garrett Gregor-Splaver (AM/GS), Alexander Herron (AP), Seongwoo Hong (AM), Ian Huang (AM/CC), Noah Igra (AM/GS), Joon Young Kang (AM), Arlo Kerman (AM/GS), Zicheng Liu (AP), John Lord (AM), Brigid Lynch (AM), Andrew Meador (AM/GS), Marco Andres Miller (AP), Miles Mitchell (AM/GS), Abram Moats (AM/CC), Natasha Mohan (MSE), Fernando Montes (AM), Daniel Moreno (AM), Mateo Navarro Goldaraz (MSE), Ninad Nirgudkar (AM/CC), Rohan Pandit (AM), Tommy Polanco (AM), Laurel Quinones (AM), William Randolph (MSE), Isaac Ruble (AP), Emma Schechter (AM/Valedictorian), Stevenson Shukman (AM), Erik Skalnes (AM), Joseph Terrigno (AM), Nancy Thomas (AM), Samuel Unger (AM), Nicholas Vallin (MSE), Esteban Vanegas (AM/CC), Sophia White (AM), Shen Xin (AM), Ziheng Xu (AM), Miguel Yepes (MSE), Hidy Yi (AM), Jaewon You (AM), Alec Zhang (AM/CC), Xuxin Zhang (AP), Yuhong Zhao (AM/GS), Aaron Zheng (AM), Xinyi Zhu (AM/CC)

May 2020 Master of Science
William Boyes (AP), Michael Chen (AM/CVN), Todd Elder (AP), Daithi Farley (MSE/CVN), Mia Fryer (AM), Dafina Georgievska (AM/CVN), Lyu Huang (AP-MP), Micheal Jones (AP), Micheal Christopher Jones (AP), Zhiyan Liu (MSE), Richard Milvenan (AP/CVN), Nathan Otero (AP-MP), Qiuyuan Peng (MSE), Kristofer Peterson (MSE/CVN), Yulun Tseng (AP-MP), Peter Wang (AM), Ziren Xia (MSE), Chenhui Yang (MSE),

May 2020 Master of Philosophy
Mel Abler (AP-PP), Alexander Battey (AP-PP), Michael Carter (MSE), Xiang Hua (AP-SS), Heqing Huang (AP-SS), Hwi Lee (AM),

May 2020 Doctor of Philosophy
Chia-Hao Liu (AP-SS)

Billinge Wins EPDIC Distinguished Powder Diffractionist Prize

The European Powder Diffraction Conference (EPDIC) commission awarded **Simon J.L. Billinge** the Distinguished Powder Diffractionist Prize for his "substantial contribution to the development of Total Scattering Techniques and PDF analysis". Billinge is a Professor of Applied Physics, Applied Mathematics, and Materials Science at Columbia University and a Scientist at Brookhaven National Laboratory. He is a fellow of the American Physical Society and the Neutron Scattering Society of America, a former Fulbright and Sloane fellow, and has earned a number of awards including being honored in 2011 for contributions to the nation as an immigrant by the Carnegie Corporation of New York and the 2010 Hanawalt Award of the International Center for Diffraction Data.

Lipson Elected Member of American Academy of Arts & Sciences

Michal Lipson, the Eugene Higgins Professor of Electrical Engineering and Professor of Applied Physics, is one of "12 Columbia professors who have been elected members of the American Academy of Arts and Sciences, joining some of the world's most accomplished leaders from academia, business, public affairs, the humanities and the arts in one of the nation's most prestigious honorary societies. Lipson, who is a member of the National Academy of Sciences, pioneered critical building blocks in the field of silicon photonics, which today is recognized as one of the most promising directions for solving the major bottlenecks in microelectronics." (by Eve Glasberg, *Columbia News*)

Mauel Named National Associate of the Academies

Michael Mauel, Professor of Applied Physics, was named a "National Associate of the Academies" by the National Academy of Sciences (NAS). Since 2001, "the NAS president designates individuals for this special lifetime honor under guidelines established by the Academies' Governing Board." The honor recognizes Prof. Mauel's service as co-chair of a NAS committee and as chair of the standing committee for plasma science.

Spiegelman Wins CEAA Distinguished Faculty Teaching Award

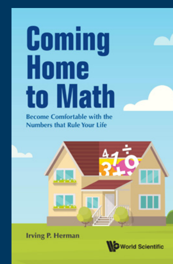
Marc Spiegelman is a recipient of the Columbia Engineering Alumni Association (CEAA) 2020 Distinguished Faculty Teaching Award. Spiegelman is the Arthur D. Storke Memorial Professor of Earth and Environmental Sciences and a Professor of Applied Physics and Applied Mathematics. Spiegelman was also the recipient of the 2004 Edward and Carol Kim Award for Faculty Involvement from Columbia Engineering.

Applied Mathematics Program Awarded $1.9M NSF Research Training Group Grant

The Program in Applied Mathematics in APAM was awarded a $1.9 million Research Training Group (RTG) grant from the National Science Foundation (NSF) to create a cutting-edge research and training program in modern applied mathematics. The theme of the project is physics- and data-based modeling, analysis, and computation. This RTG project is a joint effort of the APAM Department, the Department of Mathematics, and Columbia Engineering. Receiving this prestigious NSF award is a recognition of the prominence in applied mathematics research on Columbia's campus, centered around APAM. For more information, please see **https://bit.ly/2xcCUAQ**

Coming Home to Math

Prof. Irving Herman has just published *Coming Home to Math: Become Comfortable with the Numbers that Rule Your Life* with World Scientific.



We live in a world of numbers and mathematics, and so we need to work with numbers and some math in almost everything we do, to control our happiness and the direction of our lives. The purpose of *Coming Home to Math* is to make adults with little technical training more comfortable with math, in using it and enjoying it, and to allay their fears of math, enable their numerical thinking, and convince them that math is fun. A range of important math concepts are presented and explained in simple terms, mostly by using arithmetic, with frequent connections to the real world of personal financial matters, health, gambling, and popular culture.

***Coming Home to Math* is geared to making the general, non-specialist, adult public more comfortable with math, though not to formally train them for new careers or to teach those first learning math. It may also be helpful to liberal arts college students who need to tackle more technical subjects. The range of topics covered may also appeal to scholars who are more math savvy, though it may not challenge them.**

When asked about why he wrote *Coming Home to Math*, Herman noted: "A few years ago, I got tired of hearing time and time again in the popular media that people did not like math, were afraid of it, were not good at it, or new very little math. My response was to write this semi-popular, semi-trade book. Of course I love math and have always loved it, and at Columbia I am immersed among others like me. Though my research is not in any form of mathematics, it is applied physics, my math skills are pretty strong. My approach in writing *Coming Home to Math* was to look for connections between everyday people, and their lives, and some important and common areas of math, and to explore them - to help some start feeling comfortable with math, because it rules their lives (and it is loads of fun). I hope this approach will resonate with at least some of those in the intended audience. Because my background is not as strong as those whose careers center on math, this also meant that I needed to learn a bit more math and its everyday uses, and to seek advice from colleagues."

This is Herman's third book. He has also published the monograph *Optical Diagnostics for Thin Film Processing* (1996), which built upon his research on lasers and thin film processing, and *Physics of the Human Body* (2007, 2nd edition in 2016), which is a textbook he wrote for a course he developed, with the same name, for first-year SEAS students.

(Above) Thermal camera and visible photos of a hickory hairstreak (Satyrium caryaevorus) basking in the sun. Because of their small thermal capacity, the wings can overheat rapidly. (Below) Infrared photographs of butterflies, where brightness correlates with the capability of radiative cooling. Image credits: Nanfang Yu & Cheng-Chia Tsai

Beating the Heat in the Living Wings of Butterflies

By Holly Evarts, Originally published by Columbia Engineering

Columbia engineers and Harvard biologists discover that butterflies have specialized behaviors and wing scales to protect the living parts of their wings; nanostructures found in the wing scales could inspire the design of radiative-cooling materials to help manage excessive heat conditions; sensory network in the wings could inspire the design of advanced flying machines.

A new study from Columbia Engineering and Harvard University identified the critical physiological importance of suitable temperatures for butterfly wings to function properly, and discovered that the insects exquisitely regulate their wing temperatures through both structural and behavioral adaptations.

Contrary to common belief that butterfly wings consist primarily of lifeless membranes, the new study demonstrated that they contain a network of living cells whose function requires a constrained range of temperatures for optimal performance. Given their small thermal capacity, wings can overheat rapidly in the sun when butterflies cease flight, and they can cool down too much during flight in a cold environment. The study, published online by *Nature Communications*, is the first to explore the implications of temperature in shaping the wing structure and behavior of butterflies.

"Butterfly wings are essentially vector light-detecting panels by which butterflies can accurately determine the intensity and direction of sunlight, and do this swiftly without using their eyes," says **Nanfang Yu**, associate professor of applied physics at Columbia Engineering and co-PI of the study.

The team, which was co-led by Naomi E. Pierce, Hessel Professor of Biology in the department of organismic and evolutionary biology, and Curator of Lepidoptera at the Museum of Comparative Zoology, Harvard, used their expertise in biology and optics to make a number of significant discoveries. By carefully removing the wing scales to enable them to peer into the interior of the wings, and by staining the neurons found within the wing, they found that butterfly wings are loaded with a network of mechanical and temperature sensors. The living tissues in the wings are actively supplied by circulatory and tracheal systems throughout the adult lifetime—in the case of painted lady butterflies, for more than three weeks.

They also discovered a "wing heart" that beats a few dozen times per minute to facilitate the directional flow of insect blood, or hemolymph, through a "scent pad" or an androconial organ located on the wings of some species of butterflies.

"Most of the research on butterfly wings has focused on colors used in signaling between individuals," says Pierce. "This work shows that we should reconceptualize the butterfly wing as a dynamic, living structure rather than as a relatively inert membrane. Patterns observed on the wing may also be shaped in important ways by the need to modulate temperatures of living parts of the wing."

"This is an inspiration for designing the wings of flying machines: perhaps wing design should not be solely based on considerations of flight dynamics, and wings designed as an integrated sensory-mechanical system could enable flying machines to perform better in complex aerodynamic conditions."

- Prof. Nanfang Yu

Yu's lab designed a noninvasive technique based on infrared hyperspectral imaging, with each pixel of an image representing one infrared spectrum, that enabled them to make—for the first time—accurate measurements of the temperature distributions over butterfly wings. "This has been difficult to do until now," Pierce notes, "because of the thinness and delicacy of butterfly wings."

"This imaging technique enables us to examine physical adaptations that decouple the wing's visible appearance from its thermodynamic properties," Yu adds. "We discovered that diverse scale nanostructures and non-uniform cuticle thicknesses create a heterogeneous distribution of radiative cooling—heat dissipation through thermal radiation—that selectively reduces the temperature of living structures such as wing veins and scent pads."

The effect of this regional and selective enhancement of thermal radiation was amply demonstrated in the team's thermodynamic experiments on butterfly wings. Experimental conditions that mimic the butterflies' natural environment were created in Yu's lab, and allowed the researchers to quantify the relative contributions of several environmental factors to the wing temperature. These included the intensity of sunlight, the temperature of the terrestrial environment, and the "coldness" of the sky, which can serve as an efficient heat sink of thermal radiation from heated wings. The team found that in all simulated environmental conditions, despite diverse visible colors and patterns, the areas of butterfly wings that contain live cells (wing veins and scent pads) are always cooler than the "lifeless" regions of the wing due to enhanced radiative cooling.

"The nanostructures found in the wing scales could inspire the design of radiative-cooling materials to cope with excessive heat conditions," says **Cheng-Chia Tsai**, a PhD student in Yu's group and lead author of the study.

The researchers conducted a series of behavioral studies of living butterflies from six of the seven recognized butterfly families, to investigate responses to simulated sunlight applied to the wings. The team discovered that the insects use their wings to sense the direction and intensity of sunlight—the main source of warmth or overheating—and to respond with specialized behaviors to prevent overheating or overcooling of their wings. For example, all species studied exhibited a relatively constant "trigger" temperature of approximately 40°C (104°F), turning within a few seconds to avoid overheating of wings from a small light spot shone upon them. **(Continued on page 14)**

First Study to Relate Antarctic Sea Ice Melt to Weather Change in the Tropics

Originally published by Columbia Engineering, photo by Christopher Michel

Deteriorating sea ice translates to warmer ocean, more rain, and stronger trade winds

Arctic and Antarctic ice loss will account for about one-fourth of the warming that is projected to happen in the tropics, according to a new study published in *Nature Geoscience* led by **Mark England**, a polar climate scientist at Scripps Institution of Oceanography at the Univ. of California San Diego, and **Lorenzo Polvani**, the Maurice Ewing and J. Lamar Worzel Professor of Geophysics at Columbia.

While there is a growing body of research showing how the loss of Arctic sea ice affects other parts of the planet, this study is the first to also consider the long-range effect of Antarctic melt, the team said.

"We think this is a game-changer as it shows that ice loss at both poles is crucial to understand future tropical climate change," England said of the study funded by NASA and the National Science Foundation. "Our study will open a hitherto unexplored direction and motivate the science community to study the large effects that Antarctic sea ice loss will have on the climate system."

"Dozens of recent papers have studied how future Arctic sea ice melting will impact the climate system," noted Polvani, who was England's doctoral supervisor. "But the impact of the projected melting of Antarctic sea ice has been ignored. In our new paper, we show that its impact on tropical precipitations is even larger than the melting of Arctic ice."

The years 2017 and 2018 set records for minimum sea ice extent in Antarctica. England and colleagues from Columbia University's School of Engineering, Colorado State University, and the National Center for Atmospheric Research in Colorado, used computer simulations to see what scenarios play out near the equator if that decline continues through the end of the century. They found that ice loss combines with Arctic sea ice loss to create unusual wind patterns in the Pacific Ocean that will suppress the upward movement of deep cold ocean water. That will trigger surface ocean warming, especially in the eastern equatorial Pacific Ocean. Warming in that ocean region is a well-known hallmark of the El Niño climate pattern that often brings intense rains to North and South America among other places.

As that surface ocean water warms, it will also create more precipitation. Overall, the researchers believe the ice loss at both poles will translate to a warming of the surface ocean of 0.5^{o} (0.9^{o} F) at the equator and add more than 0.3 millimeters (0.01 inches) of rain per day in the same region.

"Our paper provides a beautiful example of how interconnected the climate system is," Polvani adds. "Who would have thought that a large fraction of changes in the tropics can actually be caused by changes by the polar regions?"

"Tropical climate responses to projected Arctic and Antarctic sea-ice loss", M.R. England, L.M. Polvani, L. Sun, et al. *Nat. Geosci.* 13, 275–281 (2020). DOI: 10.1038/s41561-020-0546-9

Successful Ozone Treaty Stops Jet Stream Drift in the Southern Hemisphere

Originally published by Columbia Engineering

By phasing out the use of ozone-depleting chemicals, the Montreal Protocol has halted trends in Southern Hemisphere climate system

More than ten years ago, **Prof. Lorenzo Polvani** and his then postdoctoral fellow **Seok-Woo Son** led a study that found, through the analysis of climate models used by the Intergovernmental Panel on Climate Change (IPCC), that the closing of the ozone hole—underway as a consequence of the 1987 Montreal Protocol—was going to halt the poleward drift of the jet stream in the Southern Hemisphere.

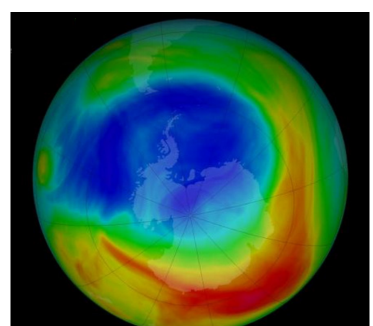
But Polvani's study, published in *Science* in 2008, was based on predictive modeling, not actual observations. Now, new research, led by his former postdoctoral fellow **Antara Banerjee**, demonstrates that the earlier study's prediction is actually happening: observations now show that, over the last 20 years, the jet stream in the Southern Hemisphere has indeed stopped drifting poleward, as the 2008 models had indicated. The new study, published March 25 by *Nature*, originated in Polvani's lab and was continued by Banerjee, now a CIRES Visiting Fellow in NOAA's Chemical Sciences Division.

"The position of the jet stream has implications for many aspects of the climate system in the Southern Hemisphere: it affects the weather all the way from into the subtropics, the ocean circulation, and more," said Polvani, Maurice Ewing and J. Lamar Worzel Professor of Geophysics in the APAM Department and co-author of the new paper. "The pause in the jet drift is a direct consequence of the Montreal Protocol, which was signed to protect the ozone layer. This result is an excellent example that shows the climate system can be altered with international treaties, something that climate skeptics often deny. The treaty works!"

Chemicals that deplete Earth's protective ozone layer have also been triggering changes in Southern Hemisphere atmospheric winds. Banerjee's new study finds that those changes have paused and might even be reversing because of the Montreal Protocol, the international treaty that successfully phased out use of ozone-depleting chemicals.

"This study adds to growing evidence showing the profound effectiveness of the Montreal Protocol. Not only has the treaty spurred healing of the ozone layer, it's also driving recent changes in Southern Hemisphere air circulation patterns," said Banerjee.

The ozone hole, discovered in 1985, has been forming every spring in the atmosphere high strengthening the winds of the polar vortex and affecting winds all the way down to the Earth's surface. Ultimately, ozone depletion has shifted the midlatitude jet stream and the dry regions at the edge of the tropics toward the South Pole.



(Above) The 2019 ozone hole reached a peak extent of 6.3 million square miles on Sept. 8, 2019, the lowest maximum observed in decades. This NASA visualization depicts ozone concentrations in Dobson Units, the standard measure for stratospheric ozone. (Image courtesy of NASA)

Previous studies have linked these circulation trends to weather changes in the Southern Hemisphere, especially rainfall over South America, East Africa, and Australia, and to changes in ocean currents and salinity. **(Continued on page 14)**

Engineering the Future of Cultural Preservation

Research projects from two MSE faculty members were featured in a *Columbia Engineering Magazine* web exclusive on cultural preservation.

Barmak: Pigment & Paper

It was a master's student continuing on from his undergraduate studies in the materials science and engineering program of the applied physics and applied math department who brought materials expert **Katayun Barmak** together with Alexis Hagadorn and Emily Lynch from Columbia University Libraries' Conservation Lab. In designing his master's research project, the student—Michael Berkson—had hoped to find a way to combine his research in materials science with his interest in art conservation, which had been sparked by a talk he heard about the work in Columbia's Ancient Ink Laboratory. This lab, of which Hagadorn was a member, at the time was an offshoot of the university's Nano Initiative run by electrical engineer James Yardley. Yardley's lab used nanotechnology to elucidate the material properties of inks painted millennia ago, many of which were composed of unknown ingredients. Using spectroscopic signatures—which register the way a material reflects light—the Ancient Inks group could also determine the age of a given manuscript.

Berkson's timing couldn't have been better. Hagadorn, current head of Columbia's conservation department, had identified the cause of a peculiar type of degradation manifesting in one of the library's rare 15th century encyclopedias. However, her research had raised further questions. Created at the dawn of the printing press, this volume contained a mix of mechanically produced text and hand painted blue and red initials. Oddly, only the latter were turning the paper beneath them brown before eating away at it. Hagadorn intuited that the blue ink involved—a common pigment derived from copper that pops up in everything from European illuminated manuscripts to Far Eastern scroll paintings—was somehow to blame. But since this ink is known for being extremely stable over long periods and varying conditions, a heretofore unknown cause must be at work. Having determined that a component in the blue ink was interacting with the original artist's surface preparation of the paper, a previously unrecorded phenomenon, she set out to determine what mechanisms were at fault.

"I thought, I'd love to explore that, but I definitely need a scientist to help me," she says. Luckily, at Columbia, where the arts and sciences are considered two sides of the same coin, such cross-disciplinary collaborations are easy to come by.

"Materials scientists are interested in conservation because they have a way of thinking they can bring to the problem," says Barmak from her art-filled office on the 11th floor of Mudd where she's gathered with Hagadorn and Lynch. This manuscript degradation, she says "would be equivalent to the corrosion of metals causing your car to rust. It's very much in the vein of materials science paradigm."

Once Barmak signed on, the project quickly became a master class in experimental design. Together with her students—since the project's inception, six in all have taken it up—she first had to craft a set of tests capable of narrowing down a multitude of parameters (such as ink recipes and base materials), all the while controlling for humidity, pH, temperature and a myriad of other factors. To do that, Barmak drew on her background in R&D at IBM to make use of a factorial design approach, in which multiple parameters are varied at a time to determine not only the most important parameters but also interactions between parameters. Barmak also drew on connections across the engineering school to access sophisticated microscopy and other state-of-the-art equipment. But in many cases, the group had to develop suitable protocols to ensure repeatability and minimize sample-to-sample variation. Being a small field, few tools are purpose-built for conservation and the team spent hours just brainstorming ways to ensure consistent application of the ink. "You're imitating something that really wasn't standardized," Hagadorn says. "So, for instance, how uniform the paint application was wasn't the concern of the creator. But it has to be one of ours." There, Lynch contributed a bit of inspired improvisation. "I found these plastic spatulas used in the cosmetics industry," she says. "They had the perfect width, so we just dragged them across in one swoop."

Thus far, their work identified exposure to elevated temperatures as one of the parameters, though not the only one. Ultimately, the group believes the degradation factors they're investigating, which they fully intend to publish, could have wide ramifications for the conservation field, considering how ubiquitous the ink they studied is.

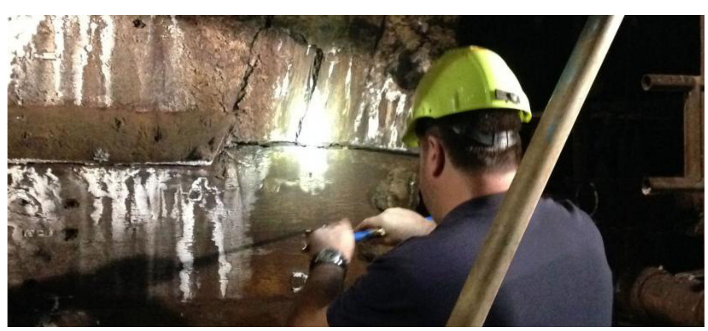
"I've worked on technologies that 30 years later have not yet hit the market," says Barmak. "But here, you're immediately connecting to the past and you're preserving it for the future. To have played even a small part in protecting these beautiful books is very satisfying."

Billinge: Physics & the Mary Rose

In 1545, Henry VIII's favorite warship—the Mary Rose—sank in the English Channel just off the coast of Portsmouth. In 1982, researchers located it, raised it and installed it in the eponymous museum where it's now been viewed by more than 60 million people. Hauling the brittle remains of a 600-ton Tudor era warship up from beneath four stories of seawater was just the first set of engineering challenges facing conservators at the Mary Rose Trust, however. In 2014, materials expert **Simon Billinge** worked with colleagues at the Trust to identify a mysterious deterioration process which had begun threatening to transform this 500-year-old shipwreck into dust.

Billinge, whose day job as a professor includes advancing the physics behind cleaner energy and better medicine, has pioneered techniques for parsing the atomic structure of different materials. Billinge's group cracked the Mary Rose case by imaging how x-rays scatter through sample cross sections at the smallest level—the researchers used that information to precisely characterize the nature of nano-scale materials hidden deep in the Tudor wood. Comparing the resulting images pixel by pixel allowed them to determine that over centuries the wood had become riddled with nanoparticles of zinc sulfide. Surfacing from the ocean floor's anaerobic environment kickstarted an oxidizing process that transmuted that sulfide into zinc sulfate—and ultimately sulfuric acid that ate away at the hull. How this zinc alloy built up inside the cellulous wasn't hard to deduce; it was clearly the byproduct of millions of microscopic sulfur-based organisms—bacteria poop in layman's terms.

This discovery led to a new conservation method: application of strontium carbonate, which holds the promise to not only preserve the ship itself, but also organic materials among the 19,000 artifacts salvaged along with the wreckage. But "this isn't just a big deal for conservators to understand," Billinge notes. "It's also a big deal for the study of bacteria ecology. These kinds of sulphur eating organisms are difficult to study and our map offers insights into how they self-organize in colonies and what they feed on."



(Above) Taking a core sample from the hull of the Mary Rose, a 16th century warship raised from the floor of the English Channel in 1982.

Columbia Team Discovers New Way to Control the Phase of Light Using 2D Materials

By Holly Evarts, Originally published by Columbia Engineering

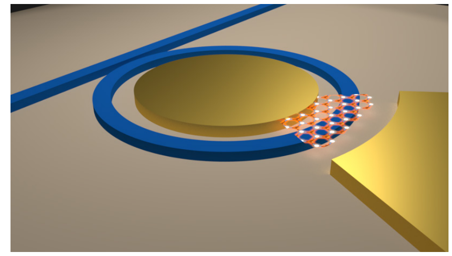
Researchers use atomically thin materials—1/100,000 the size of a human hair—to manipulate the phase of light without changing its amplitude, at extremely low power loss; could enable applications such as LIDAR, phased arrays, optical switching, and quantum and optical neural networks

Optical manipulation on the nano-scale, or nanophotonics, has become a critical research area, as researchers seek ways to meet the ever-increasing demand for information processing and communications. The ability to control and manipulate light on the nanometer scale will lead to numerous applications including data communication, imaging, ranging, sensing, spectroscopy, and quantum and neural circuits (think LIDAR—light detection and ranging—for self-driving cars and faster video-on-demand, for example).

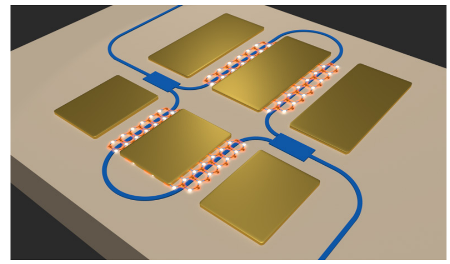
Today, silicon has become the preferred integrated photonics platform due to its transparency at telecommunication wavelengths, ability for electro-optic and thermo-optic modulation, and its compatibility with existing semiconductor fabrication techniques. But, while silicon nanophotonics has made great strides in the fields of optical data communications, phased arrays, LIDAR, and quantum and neural circuits, there are two major concerns for large-scale integration of photonics into these systems: their ever-expanding need for scaling optical bandwidth and their high electrical power consumption.

Existing bulk silicon phase modulators can change the phase of an optical signal, but this process comes at the expense of either high optical loss (electro-optic modulation) or high electrical power consumption (thermo-optic modulation). A Columbia University team, led by **Michal Lipson**, Eugene Higgins Professor of Electrical Engineering and professor of applied physics at Columbia Engineering, announced that they have discovered a new way to control the phase of light using 2D materials—atomically thin materials, ~ 0.8 nanometer, or 1/100,000 the size of a human hair—without changing its amplitude, at extremely low electrical power dissipation.

Illustration of an integrated optical interferometer with semiconductor monolayers such as TMDs on both the arms of the silicon nitride (SiN) interferometer. One can probe the electro-optic properties of the monolayer with high precision using these on-chip optical interferometers.



(Above) Illustration of an integrated micro-ring resonator based low loss optical cavity with semiconductor 2D material on top of the waveguide.



Above: Illustration of an integrated optical interferometer with semiconductor monolayers such as TMDs on both the arms of the silicon nitride (SiN) interferometer. One can probe the electro-optic properties of the monolayer with high precision using these on-chip optical interferometers. (Image credits: I. Datta & A. Mohanty, Lipson Nanophotonics Group)

In this new study, published by *Nature Photonics*, the researchers demonstrated that by simply placing the thin material on top of passive silicon waveguides, they could change the phase of light as strongly as existing silicon phase modulators, but with much lower optical loss and power consumption.

“Phase modulation in optical coherent communication has remained a challenge to scale, due to the high optical loss that was associated with phase change,” says Lipson. “Now we’ve found a material that can change the phase only, providing us another avenue to expand the bandwidth of optical technologies.”

The optical properties of semiconductor 2D materials such as transition metal dichalcogenides (TMDs) are known to change dramatically with free-carrier injection (doping) near their excitonic resonances (absorption peaks). However, very little is known about the effect of doping on the optical properties of TMDs at telecom wavelengths, far away from these excitonic resonances, where the material is transparent and therefore can be leveraged in photonic circuits.

The Columbia team, which included James Hone, Wang Fong-Jen Professor of Mechanical Engineering at Columbia Engineering, and Dimitri Basov, professor of physics at the University, probed the electro-optic response of the TMD by integrating the semiconductor monolayer on top of a low-loss silicon nitride optical cavity and doping the monolayer using an ionic liquid. They observed a large phase change with doping, while the optical loss changed minimally in the transmission response of the ring cavity. They showed that the doping-induced phase change relative to change in absorption for monolayer TMDs is approximately 125, which is significantly higher than that observed in materials commonly employed for silicon photonic modulators including Si and III-V on Si, while being simultaneously accompanied by negligible insertion loss.

“We are the first to observe strong electro-refractive change in these thin monolayers,” says the paper’s lead author Ipshita Datta, a PhD student with Lipson. “We showed pure optical phase modulation by utilizing a low loss silicon nitride (SiN)-TMD composite waveguide platform in which the optical mode of the waveguide interacts with the monolayer. So now, by simply placing these monolayers on silicon waveguides, we can change the phase by the same order of magnitude, but at 10,000 times lower electrical power dissipation. This is extremely encouraging for the scaling of photonic circuits and for low-power LIDAR.”

The researchers are continuing to probe and better understand the underlying physical mechanism for the strong electrorefractive effect. They are currently leveraging their low-loss and low-power phase modulators to replace traditional phase shifters, and therefore reduce the electrical power consumption in large-scale applications such as optical phased arrays, and neural and quantum circuits.

“Low-loss composite photonic platform based on 2D semiconductor monolayers,” I. Datta, S.-H. Chae, G.R. Bhatt, M.A. Tadayon, B. Li, Y. Yu, C. Park, J. Park, L. Cao, D.N. Basov, J. Hone & M. Lipson, *Nature Photonics*, Vol 14, pages 256–262 (2020). DOI: 10.1038/s41566-020-0590-4

Enabling New DNA-Based Therapy for Anti-Cancer Drug Delivery

Originally published by Brookhaven National Laboratory and Columbia Engineering

Scientists designed a tunable peptide-like molecular coating that enables 3-D DNA origami to maintain their structural integrity and functionality in different physiological environments relevant to drug delivery and other biomedical applications

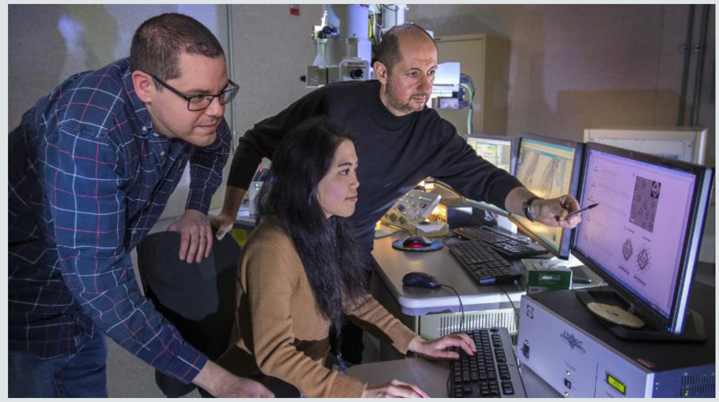
A collaborative team of researchers from Columbia Engineering and Brookhaven National Laboratory (BNL) has designed and synthesized molecule chains to efficiently protect 3-D DNA nanostructures from structural degradation under a variety of biomedically relevant conditions. They demonstrated how these "peptoid-coated DNA origami" have the potential for delivering anti-cancer drugs and proteins, imaging biological molecules, and targeting cell-surface receptors implicated in cancer. Their method for designing peptoids to stabilize DNA origami in physiological environments is described in a paper published in the March 9 online issue of the *Proceedings of the National Academy of Sciences*.

"DNA origami" is a term for the folding of long, flexible DNA chains into desired shapes at the nanoscale (billionths of a meter) by "stapling" different parts of the chain with complementary base pairs of short DNA strands. These programmable and precisely controlled nanoscale architectures could be beneficial for many biomedical applications, including the targeted delivery of drugs and genes to desired tissues or cells, imaging of biological processes inside the body, and biosensing for disease detection or health monitoring. However, to enable such applications DNA origami structures must retain their integrity while immersed in complex biological fluids and deploying new functions that are not inherent to DNA.

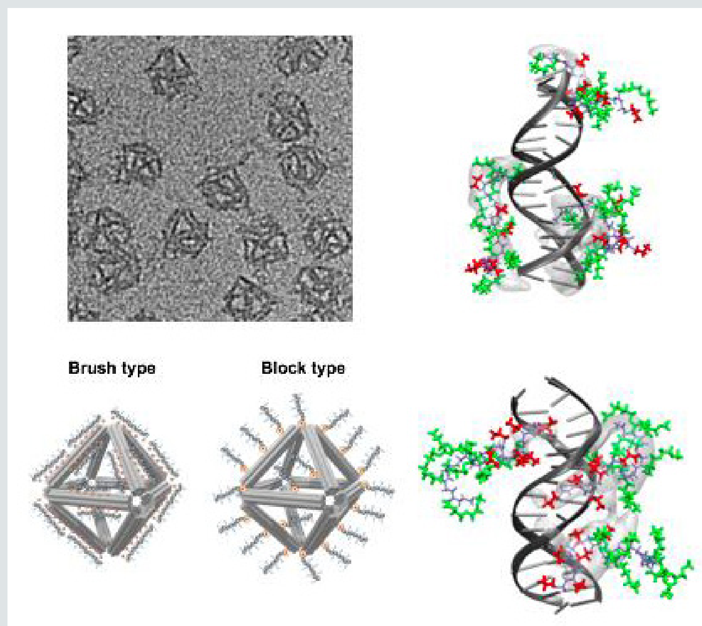
"Our goal was to make a minimalistic coating that would not add bulk to the origami but at the same time be efficient enough to offer protection, solubility, and compatibility with different biofunctions," said corresponding author **Oleg Gang**, professor of chemical engineering and of applied physics and materials science at Columbia Engineering and leader of the Center for Functional Nanomaterials (CFN) Soft and Bio Nanomaterials Group at BNL. "If the coated origami becomes bulky, its shape and how it interacts with and accommodates other biomolecules and origami would be affected, introducing a variety of complications."

One of the limiting factors in applying the structure and shape benefits of DNA origami to nanomedicine is that, once inside the human body, enzymes can digest unprotected DNA nanostructures, which are also easily degraded in response to changes in solution composition or pH level. The team devised a novel method for countering these forces.

"In this research, we synthesized biocompatible molecules called peptoids with a well-defined molecular sequence composition and length. We then coated octahedral-shaped DNA origami—which has high mechanical stability and a large open space for carrying nanoscale cargo such as small-molecule anti-cancer drugs—with these peptoids," explained first author Shih-Ting (Christine) Wang, a postdoc in the Soft and Bio Nanomaterials Group. "Our demonstrations showed that the peptoid coatings efficiently protected the DNA origami in various physiological conditions and supported the addition of different chemical functionalities for biomedical applications."



(Above - left to right) James Byrnes, Christine Wang, and Oleg Gang at Brookhaven Lab's Center for Functional Nanomaterials. Here, they used transmission electron microscopes to image 3-D DNA nanostructures (shown on the computer screen). Through these imaging studies and other experiments, they observed that the structure of these "DNA origami" remained intact after being coated with specifically designed molecules called peptoids and placed in various types of physiological conditions (e.g., solutions containing enzymes) relevant to biomedical applications. In follow-on demonstrations conducted in collaboration with Stanford University, they explored how their "peptoid-coated DNA origami" could be used for anti-cancer drug delivery.



(Top left) Structure of the octahedral-shaped DNA origami imaged with a transmission electron microscope (scale bar: 50 nanometers); the inset is a schematic of this structure. (Bottom left) Schematic of the two different types of peptoid architectures for the DNA origami coating: brush and block. (Right) Molecular dynamics simulations of the interactions between duplex DNA and peptoid architectures of the brush (top) and block (bottom) type (blue = peptoid backbone, red = DNA binding domain, blue = water-soluble domain).

Peptoids resemble peptides, or short chains of amino acids. However, in peptoids, the side chains (chemical groups attached to the main chain or backbone of the molecule) are attached to nitrogen rather than to carbon. Moreover, peptoids are more flexible, owing to the lack of hydrogen bonds in the backbone. This flexibility can be leveraged to control how the peptoids bind to the DNA origami.

Wang and Gang, assisted by a collaborator from Imperial College London, used facilities at Lawrence Berkeley National Laboratory's Molecular Foundry to synthesize two kinds of peptoid architectures for the protection of DNA origami: brush type and block type. **(Continued on page 11)**

Enabling New DNA-Based Therapy for Anti-Cancer Drug Delivery, continued

Both architectures have a DNA binding domain (positively charged part that binds to the negatively charged DNA) and a water-soluble domain (part that ensures DNA is surrounded by water molecules, which are required for stabilization). The brush-type architecture alternates between these two domains, while the block-type architecture clusters them to form distinct "blocks."

To determine which type was better at providing protection, the scientists studied the binding between 2-stranded (duplex) DNA and peptoids. Experiments with fluorescent dye (which binds to the DNA) showed that a specific brush-type architecture was most efficient at stabilizing duplex DNA coated with peptoids at high temperature. A collaborator at RMIT Univ. in Australia simulated the molecular-level DNA-peptoid interactions to understand why.

"We believe that the alternating structure achieves a balance, in that some pieces sit within the groove of the DNA double-helix structure to confer protection, while other pieces stick out to interact favorably with water," said Wang. "An optimal configuration is the brush type with 12 DNA-binding and 12 water-soluble groups."

Guided by these studies, the team investigated the structural stability of the peptoid-coated DNA origami in several types of physiologically relevant conditions: in a solution containing a low concentration of positively charged magnesium (Mg) ions, in a solution containing a DNA-specific nuclease (type of enzyme), and incubated in cell culture media (containing both nucleases and Mg ions at low concentration). Typically, a high Mg-ion concentration is required to stabilize DNA origami by reducing the repulsion of DNA-DNA negative charges, but physiological fluids contain much lower concentrations.

For their investigations, they used a combination of experimental techniques: agarose gel electrophoresis, a method for separating DNA fragments (or other macromolecules) on the basis of their charge and size; transmission electron microscopy imaging and dynamic light scattering at the CFN; and real-time small-angle x-ray scattering at the Life Science X-ray Scattering (LiX) beamline of Brookhaven's National Synchrotron Light Source II (NSLS-II). The results indicated that the structure of the origami had remained intact after it was coated with specifically designed peptoids and placed in the different physiological conditions.

Following these experiments, the scientists conducted a series of demonstrations in collaboration with the Bertozzi Group at Stanford University to explore how the peptoid-coated origami could be used in biomedical applications. For example, they loaded the chemotherapy drug doxorubicin into the coated origami. Doxorubicin is one of the commonly administered drugs to patients with HER2-positive breast cancer, in which an overexpression of the HER2 protein (a receptor on breast cells) causes cells to divide and grow uncontrollably. Over 48 hours, the coated origami released less of the doxorubicin than its noncoated counterpart, as measured through the intensity of the drug's intrinsic fluorescence.

"The ultimate goal is to be able to modulate the release rate during the drug delivery process to control biological and toxic effects," explained Wang.

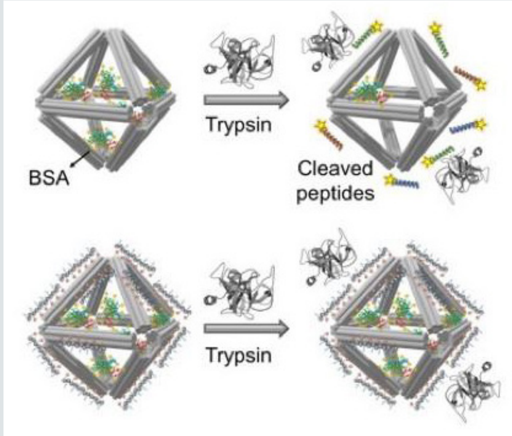
In a second nanocargo demonstration, they investigated whether proteins could be delivered in a similar way. They encapsulated a cow-derived protein (attached to fluorescent molecules for visualization) inside the coated origami in the presence of the protein-digesting enzyme trypsin. Digestion of this encapsulated protein by trypsin was reduced and slowed due to a combination of the DNA origami itself and the peptoid coating.

In a final demonstration, they functionalized the surface of the peptoid-coated DNA origami with trastuzumab. More commonly known by the brand name Herceptin, trastuzumab is an antibody that targets HER2 receptors. Upon binding to these receptors, trastuzumab blocks the cancer cells from receiving the chemical signals they need to grow. They achieved the surface functionalization by adding chemical groups to specific sites on the trastuzumab molecule and into the peptoid sequences. Through "click chemistry," these groups selectively react to form covalent bonds (akin to clicking a seatbelt buckle).

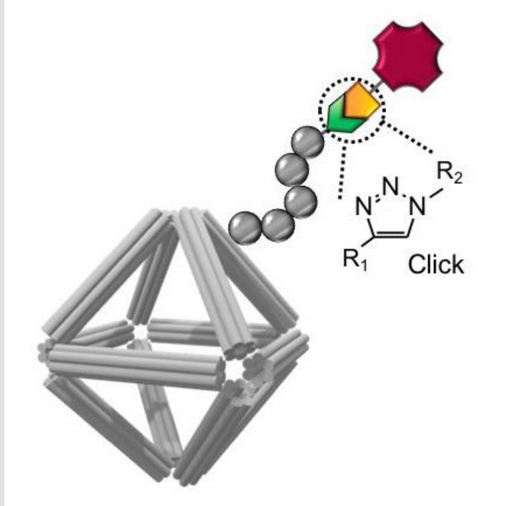
In follow-on experiments, Wang plans to explore the potential of combinatorial therapy, in which peptoid-coated DNA origami carrying doxorubicin and featuring a trastuzumab-functionalized surface targets HER2-positive breast cancer cells.

Wang was awarded funding through Brookhaven's Technology Maturation Program to further develop this technology on the basis of a pitch she developed as a participant in the second entrepreneurship training workshop hosted by Brookhaven's Office of Technology Transfer in April 2019. Brookhaven's Intellectual Property Legal Group recently submitted a provisional patent application for the peptoid design methodology to the U.S. Patent and Trademark Office.

"We are now moving into the translational stage, conducting experiments using cells and potentially whole organisms," said Gang.



(Above) An illustration showing that DNA origami with the protective peptoid coating reduces trypsin digestion of an encapsulated cow-derived protein (fluorophore-labeled bovine serum albumin, or BSA).



(Above) A schematic showing how "alkyne" reactive groups incorporated into peptoid sequences coating the DNA origami can conjugate with fluorophore-labeled nanocargo (such as trastuzumab) that have been modified with "azide" chemical groups (red shape). Through alkyne-azide click-chemistry reactions, the surface of peptoid-coated DNA origami can be functionalized.

Images courtsey of Brookhaven National Laboratory

"DNA origami protection and molecular interfacing through engineered sequence-defined peptoids," S.-T. Wang, M. A. Gray, S. Xuan, Y. Lin, J. Byrnes, A. I. Nguyen, N. Todorova, M. M. Stevens, C.R. Bertozzi, R. N. Zuckermann, O. Gang, *Proceedings of the National Academy of Sciences* Mar 2020, 117 (12) 6339-6348; DOI: 10.1073/pnas.1919749117

PhD student Yan Xiong, Prof. Sanat Kumar, Postdoc Jason Kahn, Prof. Oleg Gang, and PhD student Brian Minevich, all members of the Soft Matter Lab at Columbia Engineering. The group made and partially characterized various optical and enzymatic materials to demonstrate a new nanofabrication platform. The team—which also includes Brookhaven Lab scientists Ye Tian, Julien Lhermitte, Huolin Xin, Kevin Yager, Ruipeng Li, and Masafumi Fukuto—performed the other characterizations at Brookhaven's Center for Functional Nanomaterials and National Synchrotron Light Source II.

Nano-objects of Desire: Assembling Ordered Nanostructures in 3-D

Originally published by Brookhaven National Laboratory and Columbia Engineering

Scientists establish new nanofabrication platform for directing nanomaterial components of different natures into 3-D arrays with prescribed organizations; demonstrate new enhanced optical and catalytic functionalities

Scientists have developed a platform for assembling nanosized material components, or "nano-objects," of very different types—inorganic or organic—into desired 3-D structures. Though self-assembly (SA) has successfully been used to organize nanomaterials of several kinds, the process has been extremely system-specific, generating different structures based on the intrinsic properties of the materials. As reported in a paper published in *Nature Materials*, their new DNA-programmable nanofabrication platform can be applied to organize a variety of 3-D materials in the same prescribed ways at the nanoscale (billionths of a meter), where unique optical, chemical, and other properties emerge.

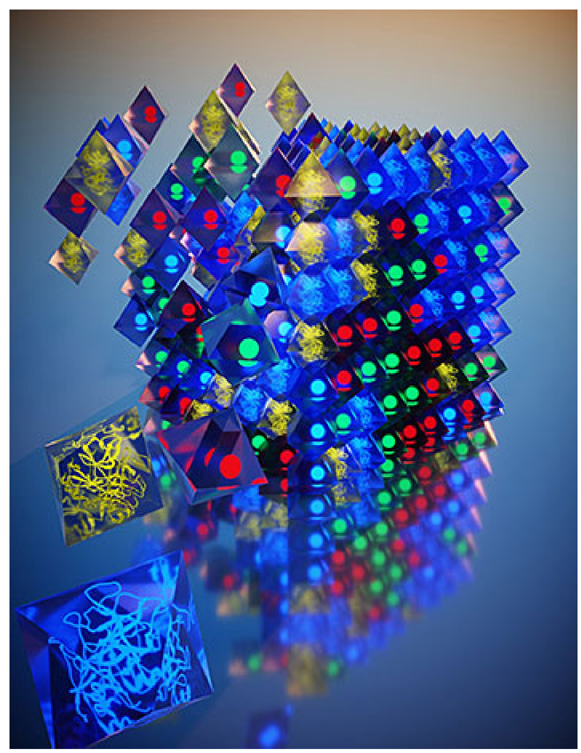
"One of the major reasons why SA is not a technique of choice for practical applications is that the same SA process cannot be applied across a broad range of materials to create identical 3-D ordered arrays from different nanocomponents," explained corresponding author **Oleg Gang**, leader of the Soft and Bio Nanomaterials Group at the Center for Functional Nanomaterials (CFN)—a U.S. Department of Energy (DOE) Office of Science User Facility at Brookhaven National Laboratory—and a professor of Chemical Engineering and of Applied Physics and Materials Science at Columbia Engineering. "Here, we decoupled the SA process from material properties by designing rigid polyhedral DNA frames that can encapsulate various inorganic or organic nano-objects, including metals, semiconductors, and even proteins and enzymes."

The scientists engineered synthetic DNA frames in the shape of a cube, octahedron, and tetrahedron. Inside the frames are DNA "arms" that only nano-objects with the complementary DNA sequence can bind to. These material voxels—the integration of the DNA frame and nano-object—are the building blocks from which macroscale 3-D structures can be made. The frames connect to each other regardless of what kind of nano-object is inside (or not) according to the complementary sequences they are encoded with at their vertices. Depending on their shape, frames have a different number of vertices and thus form entirely different structures. Any nano-objects hosted inside the frames take on that specific frame structure.

To demonstrate their assembly approach, the scientists selected metallic (gold) and semiconducting (cadmium selenide) nanoparticles and a bacterial protein (streptavidin) as the inorganic and organic nano-objects to be placed inside the DNA frames. First, they confirmed the integrity of the DNA frames and formation of material voxels by imaging with electron microscopes at the CFN Electron Microscopy Facility and the Van Andel Institute, which has a suite of instruments that operate at cryogenic temperatures for biological samples. They then probed the 3-D lattice structures at the Coherent Hard X-ray Scattering and Complex Materials Scattering beamlines of the National Synchrotron Light Source II (NSLS-II)—another DOE Office of Science User Facility at Brookhaven Lab. Columbia Engineering Bykhovsky Professor of Chemical Engineering Sanat Kumar and his group performed computational modeling revealing that the experimentally observed lattice structures (based on the x-ray scattering patterns) were the most thermodynamically stable ones that the material voxels could form.

"These material voxels allow us to begin to use ideas derived from atoms (and molecules) and the crystals that they form, and port this vast knowledge and database to systems of interest at the nanoscale," explained Kumar.

Gang's students at Columbia then demonstrated how the assembly platform could be used to drive the organization of two different kinds of materials with chemical and optical functions. In one case, they co-assembled two enzymes, creating 3-D arrays with a high packing density. Though the enzymes remained chemically unchanged, they showed about a fourfold increase in enzymatic activity. These "nanoreactors" could be used to manipulate cascade reactions and enable the fabrication of chemically active materials. For the optical material demonstration, they mixed two different colors of quantum dots—tiny nanocrystals that are being used to make television displays with high color saturation and brightness. Images captured with a fluorescence microscope showed that the formed lattice maintained color purity below the diffraction limit (wavelength) of light; this property could allow for significant resolution improvement in various display and optical communication technologies.
(Continued on page 14)



(Above) A schematic of the programmable assembly of 3-D ordered nanostructures from material voxels that can carry inorganic or organic nanoparticles with different functions, such as light emitters and absorbers, proteins, and enzymes with chemical activity. Material voxels are fabricated from DNA and nano-objects of different kinds, and their assembly is guided by the voxel design and DNA-programmable interactions.

Gold in Limbo Between Solid and Melted States

Originally published by Brookhaven National Laboratory

By capturing the laser-induced structural changes happening in polycrystalline gold thin films over time, scientists determined that melting does not occur uniformly—a finding that could have implications to laser micromachining of precision parts

If you heat a solid material enough, the thermal energy (latent heat) causes the material's molecules begin to break apart, forming a liquid. One of the most familiar examples of this phase transition from a well-ordered solid to less-ordered liquid state is ice turning into water.

Though melting is a fundamental process of matter, scientists have not been fully able to understand how it works at a microscopic level, owing to the lack of research capabilities with sufficient time resolution. However, the advent of x-ray free-electron lasers (XFELs) in the past decade is making the study of the mechanism of melting, as well as other ultrafast atomic-scale dynamics, possible. These instruments use free (unbound) electrons to generate femtosecond (one-quadrillionth of a second) pulses of light in the x-ray energy region. Compared with x-ray synchrotrons, XFELs have x-ray pulses of a much shorter duration and higher intensity.

Now, a team of international scientists has used one of these instruments—the Pohang Accelerator Laboratory XFEL (PAL-XFEL) in South Korea—to monitor the melting of nanometer-thick gold films made up of lots of very tiny crystals oriented in various directions. They used an ultrashort x-ray pulse ("probe") to monitor the structural changes following the excitation of these polycrystalline gold thin films by a femtosecond laser ("pump"), which induces melting. When the x-ray pulse strikes the gold, the x-ray beam gets diffracted in a pattern that is characteristic of the material's crystal structure. By collecting x-ray diffraction images at different pump-probe time delays on picosecond (one-trillionth of a second) scales, they were able to take "snapshots" as melting began and progressed in the gold thin films. Changes in the diffraction patterns over time revealed the dynamics of crystal disordering. The scientists selected gold for this study because it diffracts x-rays very strongly and has a well-defined solid-to-liquid transition.

The x-ray diffraction patterns revealed that melting is inhomogeneous (nonuniform). In a paper published online in the Jan. 17 issue of *Science Advances*, scientists proposed that this melting likely originates at the interfaces where crystals of different orientations meet (imperfections called grain boundaries) and then propagates into the small crystalline regions (grains). In other words, the grain boundaries start melting before the rest of the crystal.

"Scientists believed that melting in polycrystalline materials occurs preferentially at surfaces and interfaces, but before XFEL the progression of melting as a function of time was unknown," said co-corresponding author Ian Robinson, leader of the X-ray Scattering Group in the Condensed Matter Physics and Materials Science (CMPMS) Division at the U.S. DOE Brookhaven National Laboratory. "It was known that the laser generates "hot" (energetic) electrons, which cause melting when they transfer their energy to the crystal. The idea that this energy transfer process happens preferentially at grain boundaries and thus is not uniform has never been proposed until now."

"The mechanism of laser-induced melting is important to consider for micromachining of precision parts used in aerospace, automotive, and other industries," added first author Tadesse Assefa, a postdoc in Robinson's group. "The way the laser couples to the material is different depending on the pulse duration of the laser. For example, the ultrashort pulses of femtosecond lasers seem to be better than the longer pulses of nanosecond lasers for making clean cuts such as drilling holes."

(Above, left-right) Brookhaven Lab physicists Ian Robinson, Tadesse Assefa, Ming Lu, Emil Bozin, and Simon Billinge (BNL & Columbia University) at the Center for Functional Nanomaterials cleanroom, where they fabricated polycrystalline gold films of 50-, 100-, and 300-nanometer thickness. The team used time-resolved x-ray diffraction to understand the mechanism of melting in films excited by a laser that emits optical pulses with an extremely short duration. Their analysis of the x-ray diffraction images revealed that melting (induced by the laser) starts in one place and then moves into another location.

For their experiment, the scientists first fabricated thin films of varying thickness (50, 100, and 300 nanometers) at the Center for Functional Nanomaterials (CFN)—a DOE Office of Science User Facility at Brookhaven. Here, in the CFN Nanofabrication Facility, they performed electron-beam evaporation, a deposition technique that uses electrons to condense the desired material onto a substrate. The ultraclean environment of this facility enabled them to create gold films of uniform thickness over a large sample area.

At PAL-XFEL, they conducted time-resolved x-ray diffraction on these films over a range of laser power levels. Software developed by staff in Brookhaven Lab's Computational Science Initiative handled the high-throughput analysis of the terabytes of data generated as a detector collected the diffraction pattern images. The team then used software developed by scientists at Columbia Engineering to convert these images into linear graphs.

The plots revealed a double peak corresponding to a "hot" region undergoing melting (intermediate peak) and a relatively "cold" region (the rest of the crystal) which has yet to receive the latent heat of melting. Through electron coupling, heat goes to the grain boundaries and then conducts into the grains. This uptake of latent heat results in a band of melting material sandwiched between two moving melt fronts. Over time, this band becomes larger.

"One melt front is between a solid and melting region, and the other between a melting and liquid region," explained Robinson.

Next, the team plans to confirm their two-front model by reducing the size of the grains (thereby increasing the number of grain boundaries) so they can reach the end of the melting process. Because melting occurs as a wave traversing the crystal grains at a relatively slow speed (30 meters per second), it takes longer than the timing range of the instrument (500 picoseconds) to cross big grains.

They would also like to look at other metals, alloys (mixtures of several metals or a metal combined with other elements), and catalytically relevant materials, in which grain boundaries are involved in chemical reactions.

"This study represents the very beginning of how we build an understanding of the mechanism of melting," said Assefa. "By performing these experiments using different materials, we will be able to determine if our model is generalizable."

Other collaborating institutions: Univ College London, Sogang Univ, & Pohang Univ of Science & Technology. "Ultrafast x-ray diffraction study of melt-front dynamics in polycrystalline thin films," T.A. Assefa, Y. Cao, S. Banerjee, S. Kim, D. Kim, H. Lee, S. Kim, J.H. Lee, S.-Y. Park, I. Eom, J. Park, D. Nam, S. Kim, S.H. Chun, H. Hyun, K.-S. Kim, P. Juhas, E. Bozin, M. Lu, C. Song, H. Kim, S. Billinge, I. Robinson, Science Advances 17, Jan 2020 : Vol. 6, no. 3, eaax2445, DOI: 10.1126/sciadv.aax2445

Beating the Heat, continued from page 6

Yu and Pierce are now conducting a large-scale systematic optical study of the lepidopteran collections in Harvard's Museum of Comparative Zoology. These include thousands of individual specimens of hundreds of butterfly species across the entire phylogenetic tree, each specimen with full hyper-spectral imaging data taken from the ultraviolet to the mid-infrared.

In 1863, Henry Walter Bates, an English naturalist and explorer, wrote about butterfly wings in his book The Naturalist on the River Amazons, "On these expanded membranes Nature writes, as on a tablet, the story of the modifications of species …" Just like deciphering enigmatic symbols on a tablet, the team hopes to gain a comprehensive understanding of the wing coloration and pattern, which are the results of many (and often conflicting) biological and physical factors: sexual selection, warning coloration, mimicry, camouflage, and thermoregulation.

"Each wing of a butterfly is equipped with a few dozen mechanical sensors that provide real-time feedback to enable complex flying patterns," Yu says. "This is an inspiration for designing the wings of flying machines: perhaps wing design should not be solely based on considerations of flight dynamics, and wings designed as an integrated sensory-mechanical system could enable flying machines to perform better in complex aerodynamic conditions."

"Physical and behavioral adaptations to prevent overheating of the living wings of butterflies", Tsai, C., Childers, R.A., Nan Shi, N. et al. *Nat. Commun.* 11, 551 (2020). DOI: 10.1038/s41467-020-14408-8

Successful Ozone Treaty, continued from page 7

The Montreal Protocol of 1987 phased out production of ozone-destroying substances such as chlorofluorocarbons (CFCs). Beginning around 2000, concentrations of those chemicals in the stratosphere started to decline and the ozone hole began to recover. In this study, Banerjee and her co-authors have shown that around the year 2000, the circulation of the Southern Hemisphere also stopped expanding polewards—a pause or slight reversal of the earlier trends.

"The challenge in this study was proving our hypothesis that ozone recovery is in fact driving these atmospheric circulation changes and it isn't just a coincidence," Banerjee said.

To do that, the researchers used a two-step statistical technique called detection and attribution: detecting whether certain patterns of observed wind changes are unlikely to be due to natural variability alone and, if so, whether the changes can be attributed to human-caused factors, such as emissions of ozone-depleting chemicals and CO2.

Using computer simulations, the researchers first determined that the observed pause in circulation trends couldn't be explained by natural shifts in winds alone. Next, they isolated the effects of ozone and greenhouse gases separately. They showed that while rising CO2 emissions have continued expanding the near-surface circulation (including the jet stream) polewards, only the ozone changes could explain the pause in circulation trends. Prior to 2000, both ozone depletion and rising CO2 levels pushed the near-surface circulation poleward. Since 2000, CO2 has continued to push this circulation poleward, balancing the opposing effect of the ozone recovery.

"Identifying the ozone-driven pause in circulation trends in real-world observations confirms, for the first time, what the scientific ozone community has long predicted from theory," said John Fyfe, a scientist at Environment and Climate Change Canada and one of the paper's co-authors.

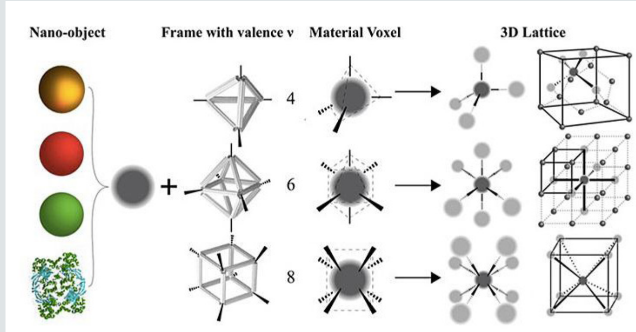
With ozone beginning to recover and CO2 levels continuing to climb, the future is less certain, including for those Southern Hemisphere regions whose weather is affected by the jet stream and those at the edge of the dry regions.

"We term this a 'pause' because the poleward circulation trends might resume, stay flat, or reverse," Banerjee said. "It's the tug of war between the opposing effects of ozone recovery and rising greenhouse gases that will determine future trends."

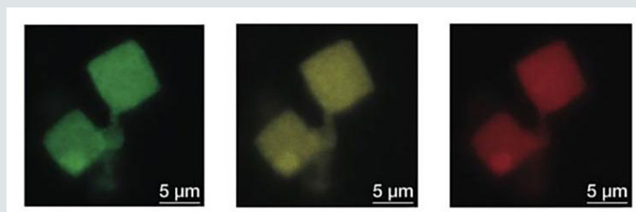
"A pause in Southern Hemisphere circulation trends due to the Montreal Protocol," A. Banerjee, J.C. Fyfe, L.M. Polvani, et al., *Nature* 579, 544–548 (2020). DOI: 10.1038/s41586-020-2120-4

Nano-objects of Desire, continued from page 12

"We need to rethink how materials can be formed and how they function," said Gang. "Material redesign may not be necessary; simply packaging "Material redesign may not be necessary; simply packaging existing materials in new ways could enhance their properties. Potentially, our platform could be an enabling technology 'beyond 3-D printing manufacturing' to control materials at much smaller scales and with greater material variety and designed compositions. Using the same approach to form 3-D lattices from desired nano-objects of different material classes, integrating those that would otherwise be considered incompatible, could revolutionize nanomanufacturing."



(Above) Schematic of the platform for assembling 3-D lattices from inorganic and organic nano-objects with DNA frames shaped as a tetrahedron (top row), octahedron (middle row), and cube (bottom row). The frame valence is determined by the vertices and corresponds to the number of connections (bonds) and how these connections are organized relative to one another. For example, the tetrahedral frame has a valence of four. The resulting 3-D lattices are based on the shape of the DNA frame—tetrahedral frames assemble into diamond structures, octahedral into simple cubic, and cubic into body-centered cubic—regardless of which nano-object (if any) is inside the frame.



(Above) Fluorescence microscope images of the lattice assembled from octahedron-shaped material voxels containing quantum dots of two different colors (fluorescence emissions of either 525 or 705 nanometers). The different colors correspond to different wavelengths. The uniform coloring in all images indicates a perfect mixing of quantum dots at subwavelength length scales.

"Ordered three-dimensional nanomaterials using DNA-prescribed and valence-controlled material voxels", Y. Tian, J.R. Lhermitte, L. Bai, et al., *Nat. Mater.* (2020). DOI: 10.1038/s41563-019-0550-x

Team Photo Credit: Columbia Engineering | Assembly Schematic Credit: Brookhaven National Laboratory | Platform Schematic and Fluorescence Images: Courtesy of the *Nature Materials* Paper | Video Credit: Jane Nisselson/Columbia Engineering

Faculty Research Videos

Oleg Gang's Soft Matter Lab: https://bit.ly/3euq94y

Nanfang Yu's Butterflies: https://bit.ly/363aNB0

Sobel on Climate & Coronavirus

Adam Sobel, Professor of Applied Physics and Applied Mathematics and of Earth and Environmental Sciences, was part of a panel who presented an online seminar on *Climate, Environment, and the Politics of Public Trust* on April 22nd, co-sponsored by the Center for Science & Society and the Center for the History & Ethics of Public Health at Columbia University's Mailman School of Public Health. The panelists discussed "how public trust relating to climate change and pollution has been constituted, eroded, and subverted by corporations and environmental agencies in the U.S., and what kinds of changes to our policies, politics, and communication may help to rebuild trust in our governmental agencies and institutions of science and medicine." **https://bit.ly/3euD9Hy**

Sobel was featured in *The New York Times'* article, "5 Hurricane Response Lessons that Apply to Coronavirus." At the close of the article Sobel states, "With this disaster, even more than with a hurricane, we will need to rely on each other, on a much larger scale and for a much longer time than any of us are accustomed to. We need young and healthy people to take all possible measures not to get the virus — even at possible cost to themselves, and even though their own risk of suffering serious harm from the virus is very low — in order to slow the spread for the benefit of those most at risk. And as economic activity declines with widespread social isolation, we need those whose livelihoods are not at risk to give some consideration to those whose are, and support them."

Sobel also recently contributed an article to Swiss Re's report, *Natural catastrophes: How can we be more resilient?* in which he cites the recent findings of Columbia researchers, Richard Seager and Mark Cane, and alumna, Amy Clement.

Tian '17 and Du Receive SIAM Review SIGEST Award


Xiaochuan Tian '17 & Qiang Du

A paper written by **Dr. Xiaochuan Tian** (Ph.D 2017, Applied Mathematics) and **Prof. Qiang Du**, "Asymptotically Compatible Schemes for Robust Discretization of Parametrized Problems with Applications to Nonlocal Models," originally published in the *SIAM Journal on Numerical Analysis (SINUM)*, was selected as a SIGEST paper and appeared in first issue of the 2020 *SIAM Review (SIREV)*.

SIREV is the flagship journal of SIAM (Society of Industrial and Applied Mathematics) and, arguably, the most impactful journal in applied math. The SIGEST section features an outstanding paper, previously published in one of SIAM's specialized research journals, that is of general interest to the 10,000+ readers of SIREV. SIAM considers this an award and a list of SIGEST papers and authors appears annually in *SIAM News*.

The introduction to Dr. Tian's and Prof. Du's paper be found at **https://epubs.siam.org/doi/10.1137/20N974963**

As noted by the editors, Dr. Tian previously won the "Best PhD dissertation award" in 2018 from the Association for Women in Mathematics (AWM), the largest professional organization to promote women in mathematics. Following her graduation from Columbia Engineering, Dr. Tian worked as a Bing Instructor at UT Austin. She will soon join UC San Diego as a tenure track faculty member in fall 2020.

DEEP CONVECTION

Prof. Adam Sobel, along with APAM alumna, **Dr. Melanie Bieli '19**, have started a new podcast, Deep Convection, which allows you to eavesdrop on conversations between climate scientists. "The goal is to capture what it is like to work in our field at this moment in history. We talk about our lives, how we came to do what we do, what the work means to us, and how that is changing, or isn't – and sometimes about science. Our top priority is to capture good conversations, but if some learning happens that's fine too." **https://deep-convection.org**

Career Events Featuring APAM Alumni


Kelley Litzner


Laurie Calvet

This spring the APAM Department welcomed back **Kelley Litzner** (MS '08, Applied Physics) from the Emerging Technologies Laboratory at Lockheed Martin to speak with undergraduate and graduate students about new opportunities within his group. **Laurie Calvet** (BS '95, Applied Physics) hosted a roundtable discussion where she provided insight on her experience as a head female researcher at the Centre National de la Recherche Scientifique (CNRS) in Paris, France.

Due to the evolving situation with COVID- 19, our Department hosted virtual career events to keep our students engaged. Our medical physics program had to pleasure of connecting with Christopher Smitherman, Chief Technical Officer and Director of Diagnostic Physics, at Petrone Associates. APAM students with an interest in technical consulting had the opportunity to engage with alumni from BCG, McKinsey, and Exponent. Undergraduate students with an interest in the pharmaceutical industry attended a panel discussion with alumni at Johnson & Johnson.

Given the current climate, some students are facing uncertainty regarding employment. If you have full-time, part-time, or summer internships available, feel free to reach out to the APAM Career Placement Officer, **Kristen Henlin**, at kah2247@columbia.edu.

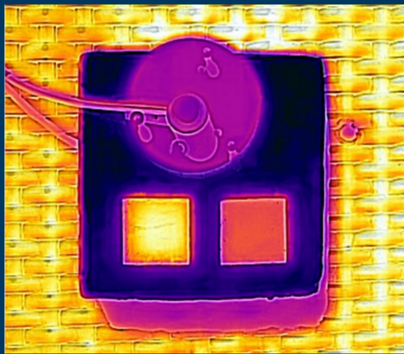
Student Spotlight, **continued from page 3**

He is one of 20 young researchers from 15 countries chosen for this program, now in its second year, which was founded by Eric and Wendy Schmidt in partnership with the Rhodes Trust. Each fellow is awarded a stipend of $100,000 and receives personalized mentoring from experienced and internationally accomplished scientists.

"As an applied physicist, I have sought to understand the interaction of light with materials, and create designs for controlling light using common materials and simple techniques, so that they can be used in developing countries," he says. "As I learn more about the fundamentals of optical design going forward, I hope to build low-cost optical components for next-generation cameras and imaging systems."

Mandal credits his journey from Bangladesh to Columbia to the support from his family. "I have been fortunate to have parents who have always encouraged me to pursue science since childhood and taken an active interest in my work. When I go back home now, they actually help me build setups and test my designs in the field. So in a sense, it is a full-circle, and I find that very fulfilling."

"I am very grateful to my advisor Professor Yang, and Professor Yu and his group for their patience and guidance," he adds. "Professor Yang's openness to my exploring optical and thermal design when I joined his group, and his initiative while venturing into what was a new field for both of us, is a rare quality in an advisor. So being mentored by him has been an experience I will cherish. Our works have also been guided by our involvement with the Yu group. We feed off each other's ideas, and I hope that our work together will continue to yield meaningful results."



APAM Publications:

Prof. Nanfang Yu, Prof. Yuan Yang, and colleagues were featured in *Nature,* "A rainbow of layered paints could help buildings to keep their cool," and in *NewScientist*, "Infrared-Reflecting Paint Can Cool Buildings Even When it is Black," which referenced their research in *Science Advances*. Reducing solar heating of building exteriors can substantially decrease electricity consumption and CO2 emission from buildings. White paint, or a mirror-like surface, is ideal to reflect sunlight and emit heat to the cold sky, which is called radiative cooling. However, white is not always suitable and color is often preferred for aesthetic reasons. In *Science Advances,* Vol. 6, eaaz5413, 2020, DOI: 10.1126/sciadv.aaz5413, Yuan Yang and Nanfang Yu developed a paintable bilayer coating that simultaneously achieves color and radiative cooling. The bilayer comprises a thin, visible-absorptive layer on top of a nonabsorptive, solar-scattering underlayer. The top layer absorbs appropriate visible wavelengths to exhibit target colors, while the underlayer maximizes the reflection of near-to-short wavelength infrared (NSWIR) light to reduce solar heating. Consequently, such a bilayer design shows higher NSWIR reflectance (by 0.1 to 0.51) compared with commercial paint monolayers of the same color and stays cooler by as much as 3.0° to 15.6°C under strong sunlight. Based on this strategy, high NSWIR reflectance of 0.89 is realized in the blue bilayer. The strategy can also be applied to textiles. This work shows that the bilayer paint design can achieve both color and efficient radiative cooling in a simple, inexpensive, and scalable manner. (Image above) Infrared camera image of a paint sample (right) atop a white underlayer stays cooler in the sunlight than a sample of the same paint on its own (left). Image Credit: Jyotirmoy Mandal

Research from Prof. Nanfang Yu and collaborators on butterfly wings, originally published in *Nature Communications*, was picked up by numerous media outlets including *Popular Science*, *The Economist*, *Scientific American*, *Buzzworthy*, *Science News*, *The Optical Society*, *Cosmos*, *UPI*, *ZME Science*, *Phys.org*, *Harvard Magazine*, and many others. https://bit.ly/2Aq6HYe

The Fall 2019 issue of *Columbia Engineering Magazine* featured Professors Simon Billinge, Oleg Gang, Michal Lipson, and Nanfang Yu in the article, "Engineered Structures and Properties." https://bit.ly/2Y3smxx

Research from Prof. Chris Wiggins and collaborators on "Multimodal transcriptional control of pattern formation in embryonic development" was published in the *Proceedings of the National Academy of Sciences* (*PNAS)*. This paper, which applies machine learning to understand transcriptional regulation, grew out of Wiggins' mentoring activities. The experimentalist senior author, Nicholas Lammers, was a student at a summer school Wiggins co-organized in 2007. The second author, Vahe Galstyan, began working on this topic in APMA E3900, an undergrad supervised research project, led by Wiggins. DOI: 10.1073/pnas.1912500117

Atmospheric science Ph.D. candidate, Zane Martin, from Prof. Adam Sobel's group, is a co-author on the paper, "Insignificant QBO-MJO prediction skill relationship in the SubX and S2S subseasonal reforecasts," which was selected as an EOS Editors' Highlight. (*Journal of Geophysical Research: Atmospheres*, 124, 12655– 12666, DOI: 10.1029/2019JD031416)

APAM @ Home: As inhabitants of NYC were instructed to shelter in place this past semester, many in the Columbia University community began working from home in early March. Classes, group meetings, seminars, social events, and a myriad of other activiies took place online, enabling us to stay connected and productive. We are so very proud of the APAM students, faculty, researchers, and staff members for rising to great levels of excellency in the face of tremendous challenge and change.

New APAM Website: The APAM Department website was recently redesigned to highlight our programs in Applied Physics, Applied Mathematics, Materials Science & Engineering, and Medical Physics. Stop by https://apam.columbia.edu to read more news and stay connected!

Contributing Authors

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Photos/Images

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