Research Report

Imaging and Analysis Center

PMI

PRINCETON UNIVERSITY

2025

iac.princeton.edu

A MESSAGE FROM THE DIRECTORS

Dear Friends of the Imaging and Analysis Center,

The Imaging and Analysis Center (IAC) in the Princeton Materials Institute (PMI) offers high-end, state-of-the-art instrumentation and expertise for characterization of hard, soft, and biological materials to stimulate research and education at Princeton University and beyond. The IAC houses and operates a full range of instruments employing visible photons, electrons, ions, X-rays, and scanning probe microscopy for the physical examination and analysis of complex materials. With ~30 years of continuous support from Princeton University, as well as the National Science Foundation, the Air Force Office of Scientific Research, the Office of Naval Research, the State of New Jersey, industrial companies, etc., the IAC has become the largest central facility at Princeton and a world leader in advanced materials characterization.

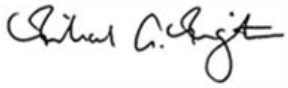
A central mission of the IAC is the education, research, and training of students at Princeton University. The IAC supports more than ten regular courses annually. The award-winning course, MSE505-Characterization of Materials is conducted at the IAC for both graduate and undergraduate students. The IAC also offers a full range of training courses, which involve direct experimental demonstrations and hands-on instruction ranging from basic sample preparation, to the operation of high-end electron microscopes. The IAC's short courses have drawn over 4,500 student enrollments. Additionally, over 700 industrial scientists from more than 140 companies and 40 institutions have utilized instruments in the IAC. Our efforts have helped build bridges between Princeton and Industry that have fostered many innovations and new product developments.

Recent IAC internal users include over 350 students and researchers from more than 90 research groups. The IAC supports ~240 current research contracts worth a total of ~$450M. In the IAC, undergraduate students are provided with the opportunity to operate various electron microscopes during class and later utilize these instruments in research for their senior thesis. The research experience provided by the IAC has helped students win many national awards including the Fannie and John Hertz Foundation Fellowship, Rhodes Scholarship, Barry M. Goldwater National Scholarship, Fulbright Scholarship, National Science Foundation Graduate Research Fellowship, etc.

In this report, we highlight many recent research projects conducted by our internal users, which were enabled by the IAC's facilities and expertise. These topics cover a wide range of scientific disciplines, reflecting the great diversity in research conducted at Princeton. We hope this report will encourage learning from our students and stimulate research and education in the years to come.

Thank you for your continued support and please enjoy learning about the IAC and the exciting research being carried out here at Princeton University.

Nan Yao, Director, Imaging and Analysis Center



Richard A. Register, Director, Princeton Materials Institute

Imaging and Analysis Center

Recent IAC users include over 300 students and researchers from 18 departments and centers on campus. Undergraduates, graduate students, and postdocs are each provided with a unique opportunity to conduct research using the IAC's state-of-the-art instrumentation. Their research covers a diverse spectrum of topics including: improving photovoltaics, batteries, circuit-design, and cements; elucidating biochemical pathways, understanding the structures of biomolecular machines; and characterizing samples from aerodynamic wing models, pharmaceutical drug crystals, catalytic nanoparticles, and biofilms.

Nanomaterials
topological 2D materials, cathode coating for battery cells, lead free solder, catalysts etc.

Biomaterials
biofilms, hydrogel, dental implants, contact lenses, surgical mesh, etc.

Electronic Materials
light-emitting diodes, transistors, solar cells, etc.

Ceramics and Glasses
cement, rock, anti-corrosion coating, display panel, anti-reflection coating, etc.

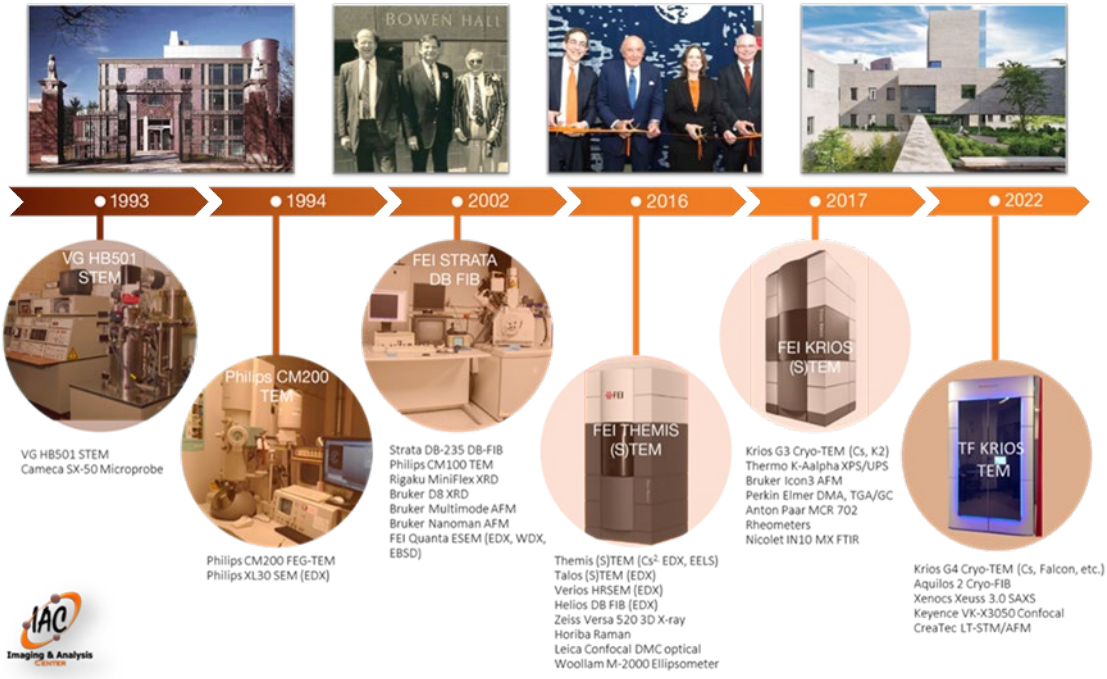
Polymers
bolck copolymer, food wrap, adhesives, paints, etc.

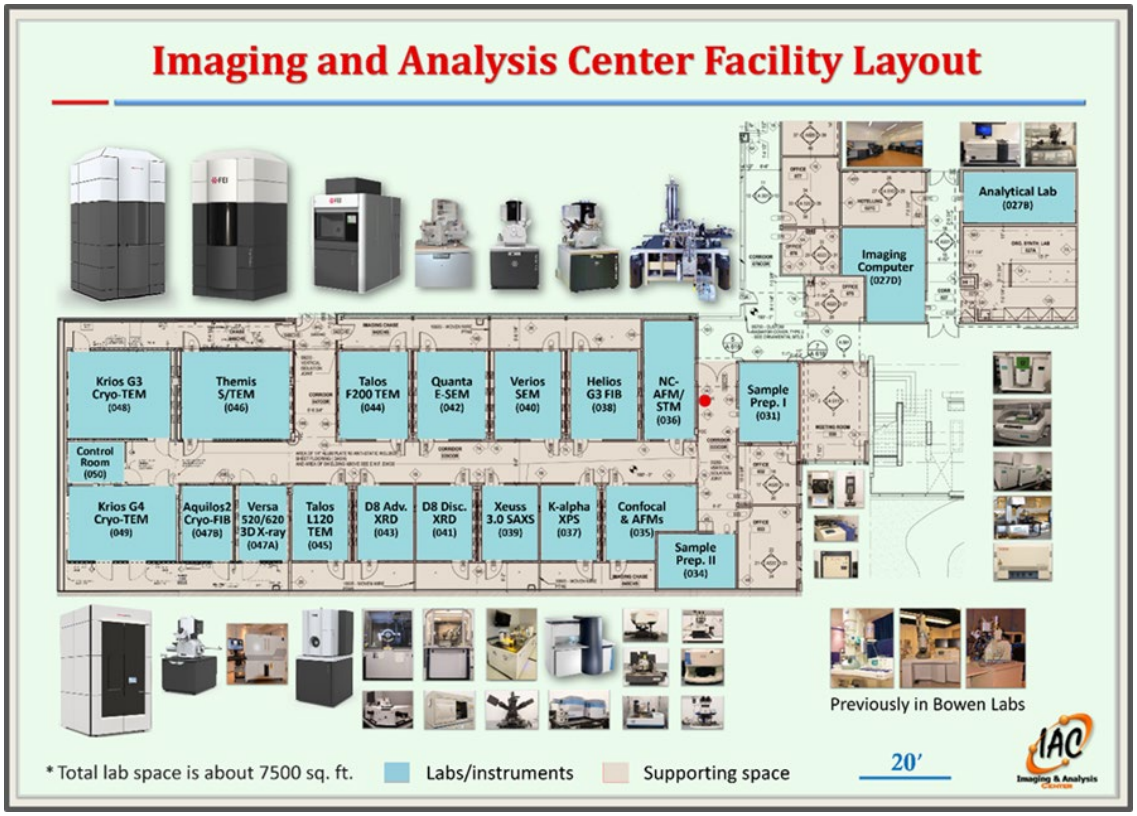
Metal Alloys
corrosion resistance supports, turbine blades, automobile chassis, etc.

Pharmaceutical Materials
drug coating, toothpaste, molecular crystals, etc.

Imaging and Analysis Center (IAC)

IAC Background: It started in 1993 with one person and one microscope, and today, it has grown to eight staff members and has become a world-leading materials characterization center for the physical and life sciences.





IAC team members

Nan Yao John Schreiber Paul Shao Denis Potapenko Dan McNesby Kevin Lamb Gary Cheng Will Chiusano

IAC faculty users from Princeton in 2025

Architecture
Forrest Meggers

Civil & Environmental Eng.
Catherine Peters
Claire White
Glaucio H. Paulino
Ian Bourg
Jason Ren
Joshua Atkinson
Jyotirmoy Mandal
Peter Jaffe
Reza Moini
Ryan Kingsbury

Ecology and Evolutionary Biology
Mary Stoddard
Tiago R. Simoes

Materials Institute
Loren Pfeiffer
Nan Yao

Mechanical and Aerospace Eng.
Aditya Sood
Aimy Wissa
Craig Arnold
Daniel Cohen
Edgar Choueiri
Egemen Kolemen
Howard Stone
Julia Mikhailova
Kelsey Hatzell
Yiguang Ju

Chemical & Biological Eng.
Bruce Koel
Charles Schroeder
David Graves
Emily Davidson
Lynn Loo
Marcella Lusardi
Michele L. Sarazen
PT Brun
Rick Register
Rodney Priestley
Sujit Datta

Electrical & Computer Eng.
Andrew Houck
Antoine Kahn
Barry Rand
Claire Gmachl
Gerard Wysocki
Iain McCulloch
James Sturm
Jeff Thompson
Kaushik Sengupta
Mansour Shayegan
Nathalie De Leon
Saien Xie
Steve Lyon
Tian-ming Fu

Neuroscience
Brad Dickerson
David Tank
Sebastian Seung
Ellen Zhong

Plasma Physics
Robert Goldston
Yevgeny Raitses

Chemistry
Alice Kunin
Andrew Bocarsly
Bob Cava
Erin Stache
Greg Scholes
Haw Yang
Leslie M. Schoop
Lilia Xie
Marissa Weichman
Mircea Dinca

Geosciences
Adam Maloof
Blair Schoene
Christopher Griffin
John Higgins
Satish Myneni
Thomas Duffy

Molecular Biology
Fred Hughson
George Ghanim
John Jimah
Jonathan Bouvette
Kai Mesa
Martin Jonikas
Nieng Yan
Sabine Petry

Physics
Ali Yazdani
Jamie Rankin
Peter Schiffer
Phuan Ong
Sanfeng Wu
Aviram Uri

IAC users from the industry and other universities in recent years

Industrial and government seminar speakers

Some recent highlights related to the IAC

Yao named Fellow of the Materials Research Society

IAC director, Nan Yao, has been elected to the 2026 class of Materials Research Society Fellows in recognition of his distinguished research achievements and global impact on materials characterization. As founding director of Princeton's Imaging and Analysis Center, he has enabled major advances—from the co-discovery of the first natural quasicrystal to atomic-scale studies shaping modern materials science—and has led extensive educational and outreach efforts. His fellowship will be formally recognized at the MRS Spring 2026 Meeting in Hawaii.

IAC-Based Materials Science Courses Receive SEAS Outstanding Teaching Awards

Both PMI's core Materials Science and Engineering courses, taught in the IAC – MSE302: Laboratory Techniques and MSE505: Characterization of Materials, have been honored with 2025 Outstanding Teaching Awards from Princeton's School of Engineering and Applied Science (SEAS). These awards recognize the courses' innovative use of IAC's state-of-the-art instrumentation, hands-on experimental curriculum, and dedication to training the next generation of materials scientists. Through direct engagement with electron microscopy, X-ray analysis, scanning probe methods, and advanced spectroscopy, students gain first-hand experience with techniques at the forefront of modern materials research.

Cryo-Tomography and Cryo-FIB Training Program for Eli Lilly Scientists

From November 10 to 12, 2025, IAC offered extensive educational opportunities for Eli Lilly scientists to learn the latest technology in cryo-tomography and cryo-FIB for pharmaceutical applications. Four Eli Lilly researchers participated in intensive hands-on training, instrument demonstrations, and data-analysis sessions focused on visualizing drug formulations and biological interfaces at nanoscale resolution. The program strengthened IAC's industry partnerships and highlighted the Center's role in advancing next-generation characterization tools for pharmaceutical research.

IAC contributed to a major step toward the realization of quantum computers, published in the Journal *Nature*

IAC scientists Gary Cheng and Nan Yao are partnering with researchers from Electrical and Computer Engineering and Chemistry. Supported in part by the Princeton Quantum Initiative, the team has built a superconducting qubit that lasts three times longer than today's best versions. This represents a significant step toward realizing quantum computers.

IAC Hosts "Seeing is Achieving" Workshop Showcasing Advanced Microscopy

The September 2025 "Seeing is Achieving" workshop in the IAC featured live demos and expert talks on cutting-edge microscopy and spectroscopy techniques. Hosted by the IAC and Oxford Instruments, the event highlighted innovations in materials and biological sciences, offering hands-on instrument sessions, real-time data analysis, and insights from leading researchers. More than 40 participants from 13 academia and industry engaged in technical discussions, explored emerging applications, and fostered new collaborations.

Princeton-Bruker Atomic Force Microscopy workshop

IAC, in partnership with Bruker Nano GmbH, hosted an atomic force microscopy workshop on March 18–19, 2025. About 50 attendees from eight universities and 11 companies enjoyed lectures, hands-on demonstrations, technical tutorials, and discussions on advanced AFM methods. Participants learned new imaging and nanomechanical analysis techniques while networking with colleagues from academia and industry.

National Science Foundation Recognizes IAC as a World Leader in Advanced Imaging and Material Analysis

The Imaging and Analysis Center (IAC) provides cutting-edge instrumentation and expertise for the characterization of hard and soft materials, including biological specimens. The center is crucial in advancing research and education at Princeton University and beyond. The IAC is closely associated with the Princeton Center for Complex Materials [a Materials Research Science and Engineering Center (MRSEC), a prominent research hub funded by the National Science Foundation (NSF)]. In a recent NSF-MRSEC review, the committee highly praised the IAC, stating that "**it is among the best in the world for advanced imaging and analysis of materials.**"

The Princeton University website cover story highlights that IAC and other microscopy efforts are making a giant impact on the minuscule

The Imaging and Analysis Center (IAC) at the Princeton Materials Institute provides advanced instrumentation and expertise for characterizing hard and soft materials, including biological specimens. This center is essential for advancing research, education, and innovation at Princeton University and beyond. The IAC's impressive technological capabilities are supported by federal research grants, donor contributions, and the University endowment, enabling the acquisition of top-tier equipment for cutting-edge research to support the University's mission to advance learning through scholarship, research, and teaching of unsurpassed quality. The IAC is a resource hub offering state-of-the-art instrumentation and expertise to Princeton and external researchers alike.

IAC researchers contributed to the discovery of an exotic quantum interference effect in a topological insulator device

This work, published in a recent issue of Nature Physics, highlights more than 15 years of research at Princeton. Scientists developed a bismuth bromide (α-Bi_4Br_4) topological insulator just a few nanometers thick to explore quantum coherence. They observed long-range quantum coherence effects from Aharonov-Bohm interference, opening new possibilities for topological quantum physics and engineering. This could also advance spin-based electronics, improving energy efficiency and opening new avenues in quantum information science.

A collection of Micrometeorites. Micrometeorites are microscopic extraterrestrial particles from asteroids and comets that continuously fall to Earth. Preserving primitive solar-system materials and extreme-condition phases, they provide a unique record of early planet formation, space–atmosphere interactions, and the ongoing exchange of matter between Earth and space. Photo credit: IAC international collaborators from Oslo, Norway: Jan Braly Kihle & Jon Larsen.

Acknowledgment:

The Imaging and Analysis Center acknowledges partial support from the National Science Foundation through the Princeton University Materials Research Science and Engineering Center (PCCM), DMR-2011750.

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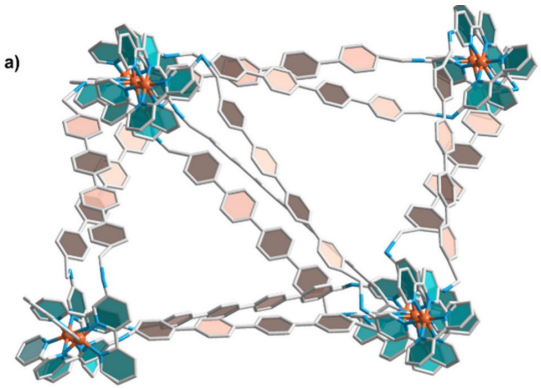
Andlinger Center for Energy and the Environment

Cobalt-Embedded Metal−Covalent Organic Frameworks for CO_2 Photoreduction

Wanpeng Lu,[1] Claudia E. Tait,[2] Gokay Avci,[3] Xian'e Li,[1,4] Agamemnon E. Crumpton,[1] Paul Shao,[5] Catherine M. Aitchison,[4] Fabien Ceugniet,[1] Yuyun Yao,[1] Mark D. Frogley,[6] Donato Decarolis,[6] Nan Yao,[5] Kim E. Jelfs,[3] and Iain McCulloch[1,7]

[1]Chemistry Research Laboratory, University of Oxford, Oxford OX1 3TA, U.K.: [2]Department of Chemistry, University of Oxford, Oxford OX1 3QZ, U.K.; [3]Department of Chemistry, Molecular Sciences Research Hub, Imperial College London, London W12 0BZ, U.K.; [4]Laboratory of Organic Electronics, Department of Science and Technology (ITN), Linköping University Norrköping, Norrköping SE-60174, Sweden; [5]Princeton Materials Institute, Princeton University, Princeton, New Jersey 08540, United States; [6]Diamond Light Source, Oxfordshire OX11 0DE, U.K.; [7]Andlinger Center for Energy and the Environment and Department of Electrical and Computer Engineering, Princeton University, Princeton, New Jersey 08544, United State.



With the pressing urgency to reduce carbon footprint, photocatalytic carbon dioxide reduction has attracted growing attention as a sustainable mitigating option. Considering the important role of catalytic active sites (CASs) in the catalytic processes, control and design of the density and environment of CASs could enhance the catalyst performance. Herein, we report a novel metal−covalent organic framework (MCOF), MCOF-Co-315, featuring earth-abundant Co cocatalysts and conjugation through a covalently bonded backbone. MCOF-Co-315 showed a CO production rate of 1616 μmol g^{-1} h^{-1} utilizing $Ru(bpy)_3Cl_2$ as photosensitizer and triethanolamine (TEOA) as sacrificial electron donor with a 1.5 AM filter, vis mirror module (390−740 nm), and irradiation intensity adjusted to 1 sun and an especially outstanding apparent quantum yield (AQY) of 9.13% at 450 nm. The photocatalytic reaction was studied with electron paramagnetic resonance (EPR) spectroscopy, X-ray absorption near-edge structure (XANES), and in situ synchrotron Fourier Transform Infrared (FT-IR) spectroscopy, and an underlying mechanism is proposed.

Status: published work in J. Am. Chem. Soc. 2025, **147**, 9056

Filament-Induced Failure in Lithium- Reservoir-Free Solid-State Batteries

Se Hwan Park,[1] Abhinand Ayyaswamy,[2] Jonathan Gjerde,[3] W. Beck Andrews,[4] Bairav S. Vishnugopi,[2] Michael Drakopoulos,[5] Nghia T. Vo,[5] Zhong Zhong,[5] Katsuyo Thornton,[4] Partha P. Mukherjee,[2] and Kelsey B. Hatzell[1,6]

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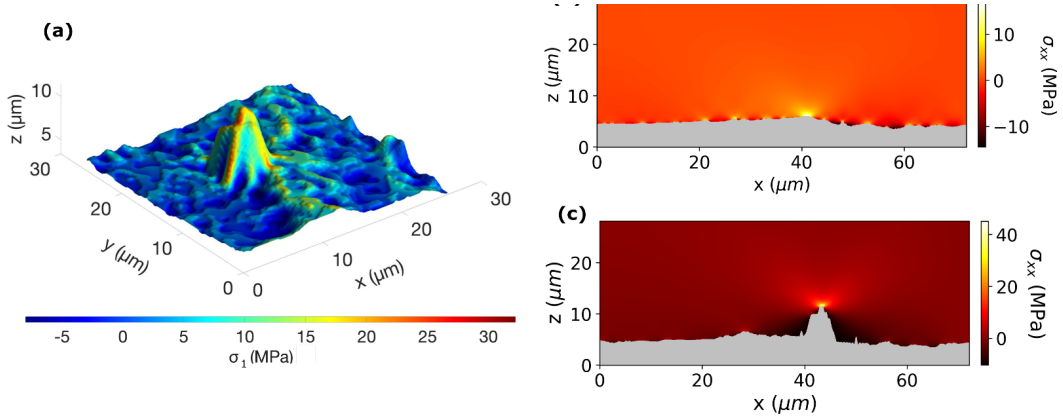

Lithium-reservoir-free solid-state batteries can fail due to electrical shorting as a result of fracture and lithium metal filament formation. Mechanical stress at the solid electrolyte surface can induce fractures, which promote lithium filament growth. This stress arises from both electrochemical sources, due to lithium electrodeposition, and mechanical sources, such as external stack pressure. Solid electrolyte surface roughness and the applied stack pressure together affect stress development. This study combines electrochemical experiments, 3D synchrotron imaging, and mesoscale modeling to explore how stack pressure influences failure mechanisms in lithium free solid-state batteries. At low stack pressure, irregular lithium plating and the resulting high local current density drive failure. At higher stack pressure, uniform lithium plating is favored; however, notch-like features in the surface of the solid electrolyte experience high tensile stress, leading to fractures that cause premature short-circuiting.

Status: published work in ACS Energy Letters 2025, **10**, 1174

Chemo-mechanical limitations of liquid alloy anodes for sodium solid-state batteries

Daren Wu,[1] and Kelsey B. Hatzell[1,2,3]

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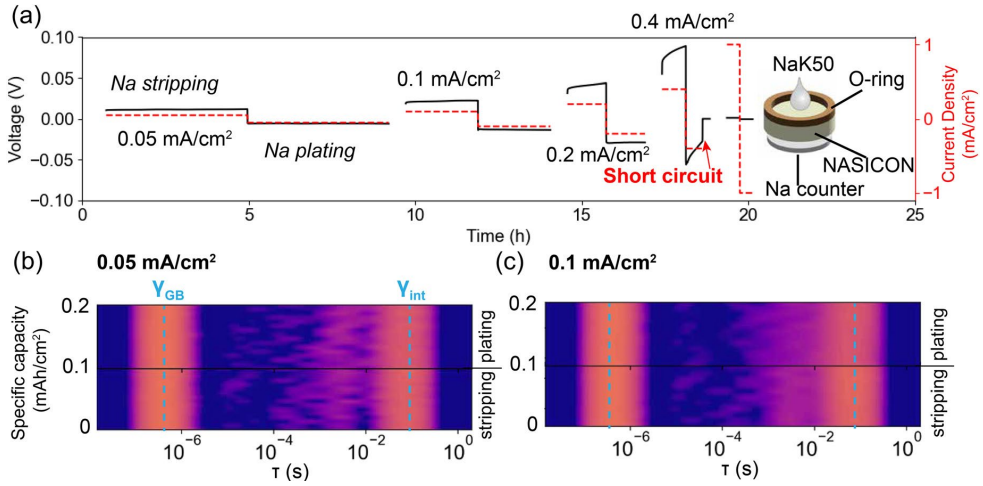

Sodium–potassium (NaK) liquid metal anodes address interfacial challenges in sodium solid-state batteries by eliminating solid–solid contact issues of solid Na anodes. Operando galvanostatic electrochemical impedance spectroscopy and *in situ* synchrotron X-ray computed tomography experiments reveals that interfacial Na depletion upon electrodissolution results in void formation and K metal precipitation. Conversely, Na plating upon electrodeposition results in local Na accumulation at the interface. Long-term deposition results in Na filament growth and short-circuit failure. These degradation processes arise from poor wetting due to the high surface tension of NaK and its limited Na diffusivity. Strategies which reduce the tendency for segregation are necessary for long-term cycling.

Status: published work in EES Batteries 2025, 1, 1682

Phase separation dynamics in sodium solid-state batteries with Na–K liquid anodes

Daren Wu,[1] Zhuo Li,[1] Michael Drakopoulos,[2] Nghia T. Vo,[2] Zhong Zhong,[2] and Kelsey B. Hatzell[1,3,4]

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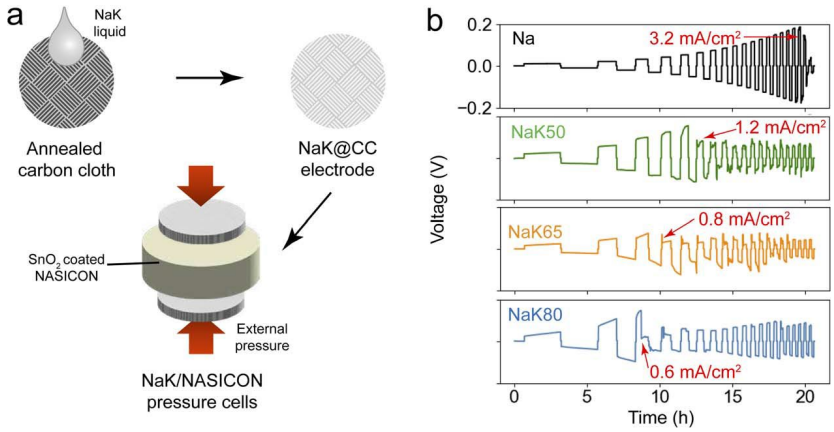


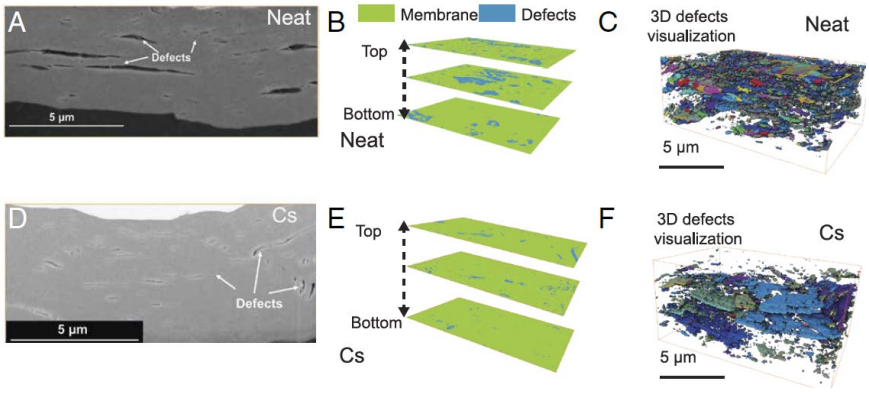
Alkali metal anodes hold great promise for high-energy-density batteries for grid-scale applications. However, challenges such as void formation at the solid electrolyte interface during electrodissolution and dendrite or filament growth during plating hinder their high-rate and high-capacity performance. Contact between an alkali anode can be improved either via increasing external stack-pressure or via introducing materials that are flexible, compliant, and conformable. Herein, we investigate a conformable sodium-potassium (NaK) liquid alloy anodes with a sodium solid electrolyte. Our results reveal that the liquid–solid phase separation in NaK anodes affects their long-term stability and performance. Critical stripping capacity is correlated with the liquid to solid phase transition upon sodium depletion upon during electrodissolution. Using a combination of electrochemical characterization and synchrotron 3D X-ray CT, it is shown that the interaction between the NaK liquid alloy and its carbon substrate plays a crucial role in anode behavior. This effect is particularly pronounced at higher potassium concentrations, where decreases in viscosity and surface tension further restrict liquid mobility. These findings highlight the potential of NaK anodes for improving the durability of solid-state batteries while emphasizing the need to optimize interfacial dynamics and mitigate phase separation for reversible operation.

Status: published work in Journal of Materials Chemistry A 2025, **13**, 22074

Water content modulation enables selective ion transport in 2D MXene membranes

Yaguang Zhua,[1] Qinsi Xiongb,[2] Woo Cheo Jeon,[2] Monika Blum,[3,4] Fernando Caminoe,[5] George C. Schatz,[2] and Kelsey B. Hatzell[1,6]

[1]Andlinger Center for Energy and Environment, Princeton University, Princeton, NJ 08540; [2]Department of Chemistry, Northwestern University, Evanston, IL; [3]Advanced Light Source, Lawrence Berkeley National Laboratory, Berkeley, CA; [4]Chemical Sciences Division, Lawrence Berkeley National Laboratory, Berkeley, CA; [5]Center for Functional Nanomaterials, Brookhaven National Laboratory, Upton, NY; [6]Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, NJ, USA



Separation membranes are critical for a range of processes, including but not limited to water desalination, chemical and fuel production, and recycling and recovery applications. Fundamentally, there are intrinsic trade-offs between permeability and selectivity. Local water organization and content can impact membrane structure in laminar transition metal carbide (MXene) membranes and impact selective ion permeation. Intercalation of chaotropic cesium (Cs^+) ions within the layers reduces the water content in the membrane and at the surface which cannot be found in the intercalation of other ions. Additionally, 3D imaging using focused ion beam scanning electron microscopy showed fewer defects in the Cs-MXene membrane, due to reduced local water content, leading to more efficient ion sieving. Xray diffraction and density functional theory calculations on the nanochannel structure demonstrated that the chaotropic ion results in the smallest nanochannel size and induces a stronger resistance to water-induced nanochannel swelling. With a narrower nanochannel, the Cs-MXene membrane limits ion transport pathways. Our findings highlight the potential for controlling the structural organization of 2D MXene membranes to enable on-demand transport of ions for diverse applications.

Status: published work in Proc. Nat. Acad. Sci. 2025, **122**, e2501017122

School of Architecture

Beaded metamaterials

Lauren Dreier,[1] Trevor J. Jones,[2,3] Abigail Plummer,[4,5] Andrej Košmrlj,[4,6] and P.-T. Brun[2,7]
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Beading transforms flexible fiber networks into load-bearing structures by incorporating rigid, discrete elements in programmable weave patterns. Beaded assemblies function as mechanical metamaterials, where emergent mechanical behaviors arise from the interplay between geometry and material properties. Here, we investigate how this interplay governs the global mechanics of bead-thread networks. Using a combination of experiment and simple modeling, we identify conditions under which beaded structures undergo superjamming — a mechanically locked state that dramatically enhances load capacity. Our results show how potentially limiting factors such as gravity and friction can be leveraged to extend the domain of soft materials design into applications that demand rigidity.

Status: published work in Nature Communications 2025, **16**, 7899

Department of Astrophysical Sciences

Net lithium deposition and dominant self-sputtering in lithium tokamak experiment-β with a liquid lithium wall

E. Jung,[1,2] S. Abe,[2] A. Maan,[2] J. Garcia,[2] Z. Lin,[3] D.P. Boyle,[2] R. Majeski,[2] B.E. Koel[3]
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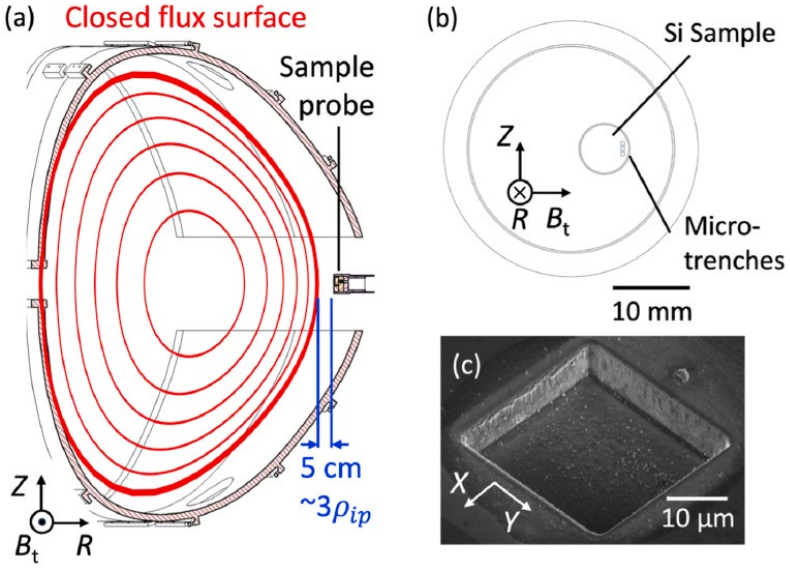

We observed enhanced net lithium deposition and lithium erosion, possibly dominated by physical sputtering of lithium by lithium-ion bombardment, on the outer plasma-facing surface in the Lithium Tokamak eXperiment-β (LTX-β) during liquid lithium wall operations. Silicon crystal samples with micro-trenches (30 μm × 30 μm × 2–7 μm deep) were exposed to hydrogen plasmas in LTX-β for solid and liquid lithium wall operations. Postmortem analysis using X-ray photoelectron spectroscopy combined with argon ion sputtering measured net lithium deposition of 8.2 or 21 nm on the silicon crystal surface exposed for ~ 50 repeated shots of ~ 50-ms hydrogen plasma discharges during the liquid lithium wall operations at a temperature of 475 K. Energy dispersive X-ray spectroscopy measured oxygen concentration patterns on the micro-trench floors, which were due to oxidized lithium deposition. Using the inhomogeneous oxygen concentration pattern caused by an ion-shadowing effect associated with the micro-trench's geometric structure, we determined a polar incident ion direction of 68.4 ± 1.6◦ referenced to the surface normal. This observation was well-explained by the hypothesis that self-sputtering of Li was a dominant lithium erosion source in addition to lithium sputtering by hydrogen bombardment.

Status: published work in Nuclear Materials and Energy 2025, **42**, 101839

Department of Chemical and Biological Engineering

Can a Simple Two-Letter Model Predict Complex Solution Phase Behavior of Block−Random Copolymers?

Amala Akkiraju,[1] Lauren W. Taylor,[2] Richard A. Register,[1] and Athanassios Z. Panagiotopoulos[1]

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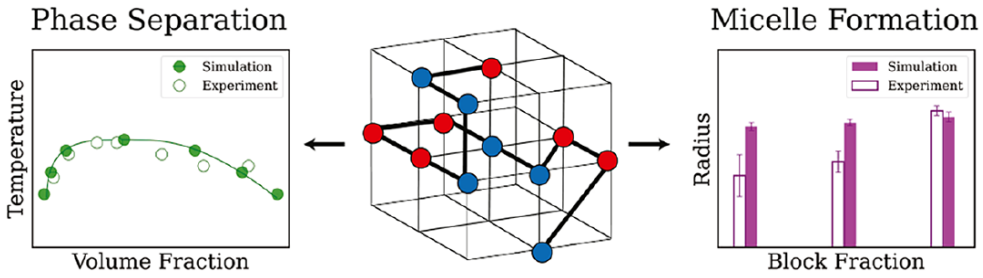

Control of synthetic polymer solution phase behavior is crucial for soft materials engineering. Recent experiments on styrene-isoprene block−random copolymers revealed various sequence-dependent phase behavior outcomes. This work aims to provide a quantitative description of those experimental findings using a simple two-letter lattice model with grand canonical Monte Carlo simulations. The results demonstrate that this can be achieved using a single solvent selectivity parameter and appropriate temperature scaling. Predictions of critical temperatures, phase diagrams, and certain micelle radii agree well with the corresponding experimental results. However, the model cannot reproduce large experimental crew-cut micelles, instead predicting large hollow-cored aggregates that disassemble into smaller micelles, raising questions about the equilibrium nature of the remarkably large experimental micelles. The model's ability to quantitatively describe phase and aggregation behavior demonstrated in this work would be valuable for designing synthetic polymers with desirable properties.

Status: published work in Macromolecules 2025, **58**, 4488

Synthesis and Tunable Properties of Chemically Recyclable Multiblock Copolymers via Tandem Olefin Metathesis Polymerizations

William R. Archer,[1] Cherish Nie,[2] Shawn M. Maguire,[1] Sahana V. Sundar,[1] Rodney D. Priestley,[1,3] Emily C. Davidson,[1,3] Paul J. Chirik,[2] and Richard A. Register[1,3]

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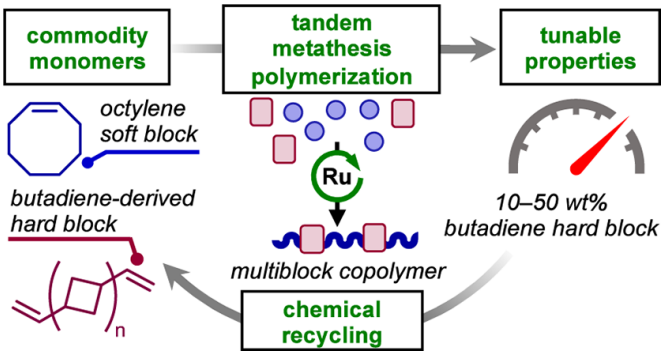

Chemical recycling, in which materials are depolymerized to monomer, enables access to repeated, closed-loop recycling. However, current routes to chemically recyclable polymers typically rely on synthesizing monomers with cleavable heteroatomic linkages or tailored ring strains. In this work, we report the synthesis of all-hydrocarbon chemically recyclable multiblock copolymers containing (1,n′-divinyl)-oligocyclobutane (DVOCB-(n)). DVOCB(n) is synthesized from the Fe-catalyzed reversible [2+2]-cycloaddition of butadiene, a commodity monomer, and is semicrystalline. Using commercially available all-hydrocarbon monomers, we developed a tandem ring-opening metathesis polymerization-acyclic diene metathesis approach which enabled the synthesis of materials with octylene soft segments and systematic variations in DVOCB(n) hard-segment length and content (10−50 wt % DVOCB(n)). We characterized the thermo-mechanical properties of the resulting multiblock copolymers using differential scanning calorimetry (DSC), dynamic mechanical analysis (DMA), and wide-angle X-ray scattering. By tuning the DVOCB segment length and content, DSC and DMA analysis revealed a broad spectrum of tunable melting temperatures (45−120 °C) and rubbery plateau moduli. Finally, ethenolysis of these copolymers was demonstrated and pristine DVOCB(n) recovered, thus offering potential end-of-life circularity for these materials.

Status: published work in Macromolecules 2025, **58**, 4272

Coordinated Cation Transport in $Ti_3C_2T_x$ MXene Membranes

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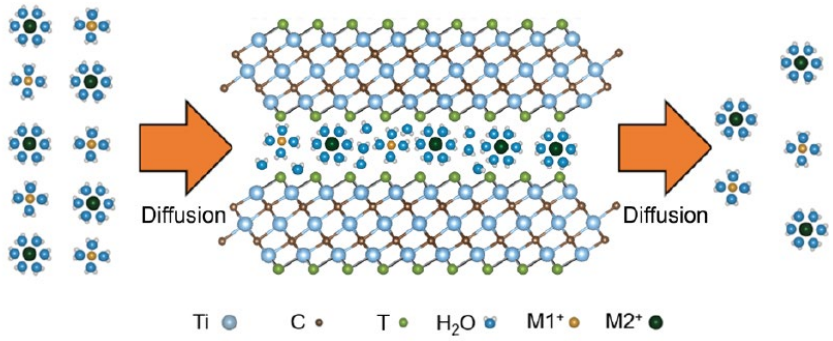

Membrane nanofiltration is an attractive strategy for the selective recovery of high-demand metals from wastewater and brine. Effective sieving of ions in aqueous environments will require precise control over membranes' nanochannel size and chemistry. $Ti_3C_2T_x$ MXene is an environmentally stable 2D material that can be processed into laminar membranes containing nanoscale interlayer spaces. The MXene interlayer environment depends on the ion species and amount of water intercalated between MXene sheets, and it is the major factor governing permeation and selectivity through MXene membranes. Coordinated ion−ion and ion-interlayer dynamics in the presence of complex mixtures can impact ion permeability and selectivity. Herein, we observe strong competitive effects between different cations (Li^+, Na^+, and Ca^{2+}) in binary mixtures, resulting in reduced selectivity when compared with single-salt permeability ratios. X-ray diffraction, molecular dynamics, and density functional theory simulations support the conclusion that cations with stronger attraction to MXene flakes can preferentially occupy the MXene nanochannels and hinder other ions via charge or size exclusion. Elucidation of ion transport behavior in MXene under complex conditions will allow for more rational design of efficient ion-sieving membranes.

Status: published work in ACS Appl. Mater. Interfaces 2025, **17**, 38062

Supramolecular bending and twisting in the hierarchical self-assembly of monodisperse mesogenic oligomers

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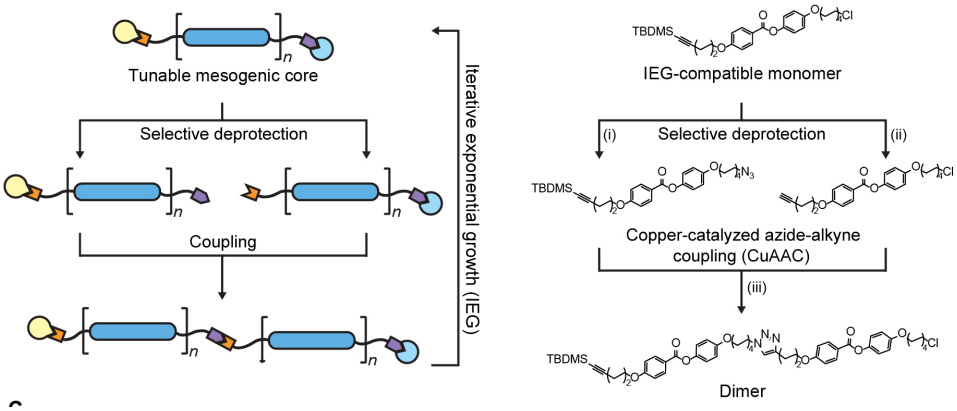

Understanding how different forms of supramolecular curvature arise during assembly is crucial to designing and tuning the microstructure of hierarchically self-assembled materials. Here, we show that in crystalline phases of mesogenic oligomers, the oligomer length is a critical parameter that determines the type of curvature (Gaussian or cylindrical) exhibited by the self-assembled structures. We use iterative exponential growth to synthesize monodisperse mesogenic oligomers ranging from dimer to octamer. By analyzing their phase behavior and microstructure, we elucidate how length-dependent thermodynamic and kinetic effects tune their hierarchical degree of ordering. The oligomers' length-dependent crystalline order drives the formation of scrolled sheets in shorter oligomers and twisted ribbons in longer oligomers. These studies highlight how oligomer length interplays with mesogen geometry and crystalline packing to drive self-assembly, introducing oligomer length as a powerful design parameter toward tailored applications of mesogenic systems.

Status: published work in Science Advances 2025, **11**, eadw5327

Influence of fluid rheology on multistability in the unstable flow of polymer solutions through pore constriction arrays

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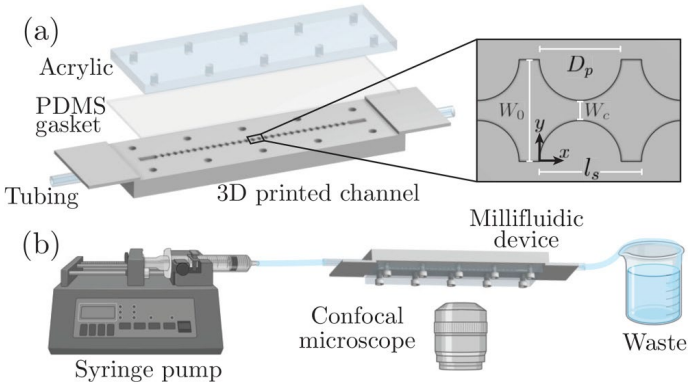

Diverse chemical, energy, environmental, and industrial processes involve the flow of polymer solutions in porous media. The accumulation and dissipation of elastic stresses as the polymers are transported through the tortuous, confined pore space can lead to the development of an elastic flow instability above a threshold flow rate, producing a transition from steady to unsteady flow characterized by strong spatiotemporal fluctuations, despite the low Reynolds number (Re « 1). Furthermore, in 1D ordered arrays of pore constrictions, this unsteady flow can undergo a second transition to multistability, where distinct pores simultaneously exhibit distinct unsteady flow states. Here, we examine how this transition to multistability is influenced by fluid rheology. Through experiments using diverse polymer solutions having systematic variations in fluid shear-thinning or elasticity, in pore constriction arrays of varying geometries, we show that the onset of multistability can be described using a single dimensionless parameter, given sufficient fluid elasticity. This parameter, the streamwise Deborah number, compares the stress relaxation time of the polymer solution to the time required for the fluid to be advected between pore constrictions. Our work thus helps to deepen understanding of the influence of fluid rheology on elastic instabilities, helping to establish guidelines for the rational design of polymeric fluids with desirable flow behaviors.

Status: published work in Journal of Rheology 2025, **69**, 235

Elastic instability of wormlike micelle solution flow in serpentine channels

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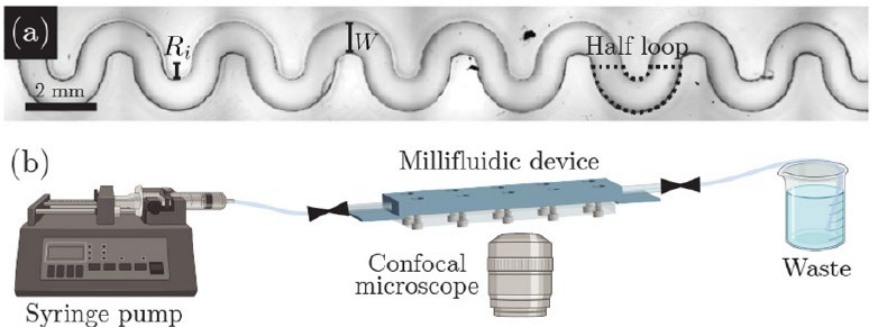

Wormlike micelle (WLM) solutions are abundant in energy, environmental, and industrial applications, which often rely on their flow through tortuous channels. How does the interplay between fluid rheology and channel geometry influence the flow behavior? Here, we address this question by experimentally visualizing and quantifying the flow of a semi-dilute WLM solution in millifluidic serpentine channels. At low flow rates, the base flow is steady and laminar, with strong asymmetry and wall slip. When the flow rate exceeds a critical threshold, the flow exhibits an elastic instability, producing spatially-heterogeneous, unsteady three-dimensional (3D) flow characterized by two notable features: (i) the formation and persistence of stagnant but strongly-fluctuating and multistable "dead zones" in channel bends, and (ii) intermittent 3D "twists" throughout the bulk flow. The geometry of these dead zones and twisting events can be rationalized by considering the minimization of local streamline curvature to reduce flow generated elastic stresses. Altogether, our results shed new light into how the interplay between solution rheology and tortuous boundary geometry influences WLM flow behavior, with implications for predicting and controlling WLM flows in a broad range of complex environments.

Status: published work in Soft Matter 2025, **21**, 5045

Role of Crystal Thickness on the Critical Tie Molecule Fraction in Semicrystalline Polymers

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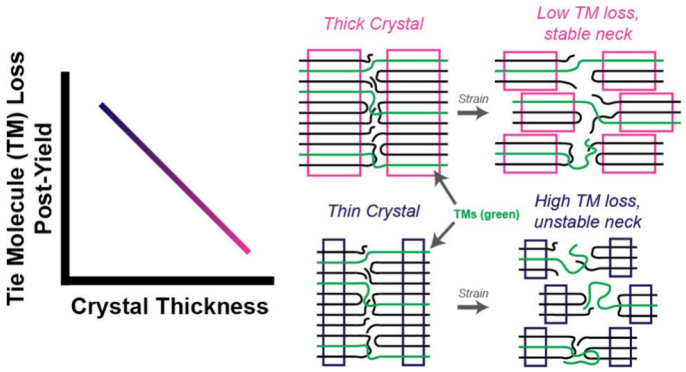

In semicrystalline polymers, polymer chains which connect two adjacent crystallites (known as tie molecules, or TMs) provide toughness, with the fraction of chains forming TMs (P) expected to increase with molecular weight. However, the factors controlling the minimum TM fraction required to impart ductility (P_{BDT}) remain elusive. In the present work, random copolymers of norbornene and hexylnorbornene (hPNrH) were synthesized, hydrogenated, and characterized to relate solid-state structure to P_{BDT}. Both domain spacing and crystallinity were varied by adjusting the hexylnorbornene mole fraction across four series of copolymers (0, 1, 3, and 5 mol %), with each series spanning a range of molecular weights that include the brittle−ductile transition (BDT). A strong inverse relationship between P_{BDT} and crystal thickness (L_c) was observed, indicating that ductility depends on both P and morphology. Compared to polyethylene (PE), hPNrH was found to require three times fewer TMs for ductility at a given L_c, principally due to the lower yield stress of hPNrH compared to PE. To rationalize the dependence of P_{BDT} on Lc, partial TM loss beyond the yield point is proposed, where polymers with thinner initial L_c lose a larger fraction of TMs. This idea is supported by measurements of the postyield strain hardening modulus $\langle G_p \rangle$, where polymers with comparable initial P show a progressive reduction in $\langle G_p \rangle$ as the initial L_c decreases.

Status: published work in Macromolecules 2025, **58**, 10800

Spatial self-organization of confined bacterial suspensions

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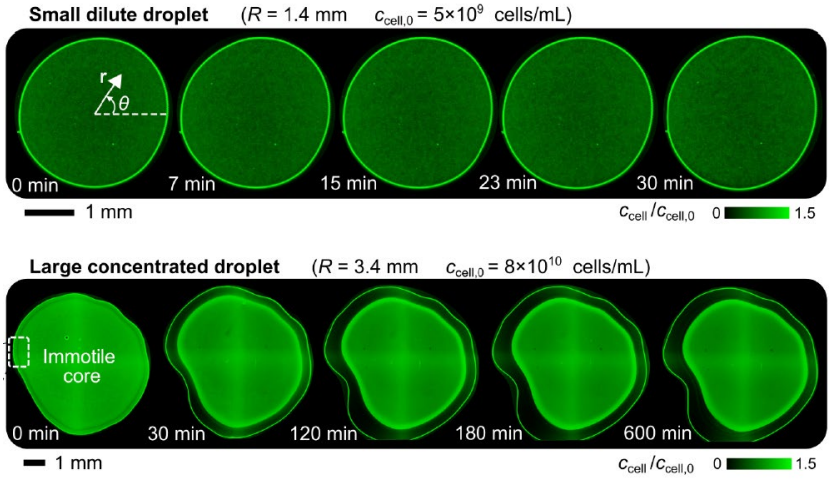

Lab studies of bacteria usually focus on cells in spatially extended, nutrient-replete settings, such as in liquid cultures and on agar surfaces. By contrast, many biological and environmental settings—ranging from mucus in the body to ocean sediments and the soil beneath our feet—feature multicellular bacterial populations that are confined to tight spots where essential metabolic substrates (e.g., oxygen) are scarce. What influence does such confinement have on a bacterial population? Here, we address this question by studying suspensions of motile Escherichia coli confined to quasi two-dimensional (2D) droplets. We find that when the droplet size and cell concentration are both large enough, the initially uniform suspension spatially self-organizes into a concentrated, immotile inner "core" that coexists with a more dilute, highly motile surrounding "shell." By simultaneously measuring cell concentration, oxygen concentration, and motility-generated fluid flow, we show that this behavior arises from the interplay between oxygen transport through the droplet from its boundary, uptake by the cells, and corresponding changes in their motility in response to oxygen variations. Furthermore, we use biophysical theory and simulations to quantitatively describe this interplay. Our work thus sheds light on the rich collective behaviors that emerge for bacterial populations in confined environments.

Status: published work in Proc. Nat. Acad. Sci. 2025, **122**, e2503983122

Mapping the polymorphic phase transformations of $CsPbI_3$ perovskite thin films

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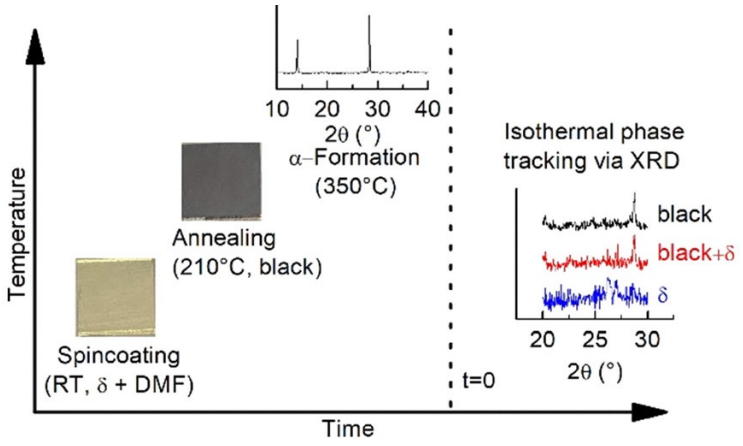

Inorganic perovskite $CsPbI_3$ has a bandgap of 1.7 eV, making it an ideal complementary absorber to Si for integration into tandem solar cells. However, the black, photoactive $CsPbI_3$ phases are metastable and readily transform into a yellow non-perovskite δ-$CsPbI_3$ phase at room temperature, posing a significant challenge to long-term device stability. In this study, we investigate the temperature-dependent dynamics of these phase transitions in $CsPbI_3$ thin films using a combination of in situ X-ray diffraction and time-resolved optical microscopy. We find the transformation rate to be highly temperature-dependent, with the fastest conversion occurring at 225 °C, where 50% of the film transformed to δ-$CsPbI_3$ within 17 minutes. To identify processing temperatures with longer phase-stability windows, we used the time- and temperature-dependent phase dynamics data to generate a time-temperature-transformation diagram for thin film $CsPbI_3$. Processing near the peak conversion temperature must be completed within two minutes to retain black-phase purity, while processing above 280 °C or below 150 °C provides a much wider processing window with <1% conversion to δ-$CsPbI_3$ occurring after 10 minutes. Conversely, it may be useful to hold $CsPbI_3$ solar cells or thin films with phase-stabilizing modifications near 225 °C to accelerate potential phase transitions and maximally stress their stability.

Status: published work in Journal of Materials Chemistry C 2025, **13**, 19654

Insights into Liquid-Phase Titration of Palladium Surfaces

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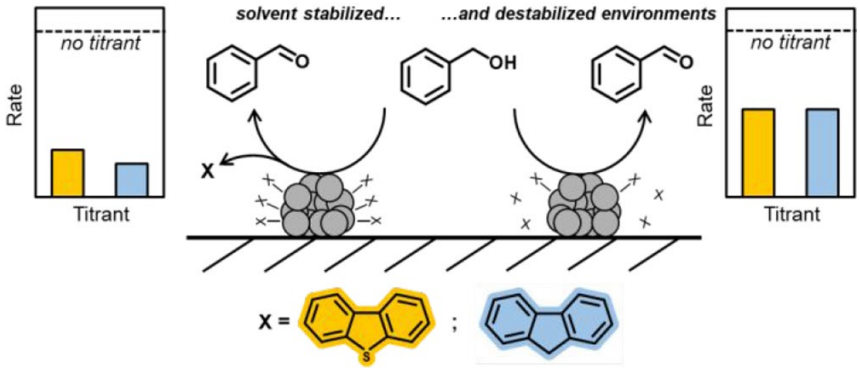

Chemisorption of strongly bound adsorbents to catalyst surfaces has been utilized extensively for site titration in the gas phase; however, extension of these molecular surface interactions to the liquid phase is not straightforward. Here, metal surface titration by solvated aromatic organothiols and hydrocarbons was studied on silica-supported Pd nanoparticle catalysts (Pd/SiO2) during batch benzyl alcohol (BA) oxidation reactions. Competitive effects of reversible titrant adsorption, titrant stabilization in varying environments, and reactant accessibility to titrated surfaces are evaluated to determine the primary drivers of benzaldehyde formation rates (rBzH) under varying titrant concentrations, solvents, and Pd oxidation states. In neat BA solvent, rBzH remains nonzero even at dibenzothiophene (DBT) and fluorene (DBT analogue without sulfur) loadings that exceed total metal atoms by a factor of 6, thus suggesting reversible titrant adsorption−desorption that is corroborated by Fourier transform infrared spectroscopy. Further depression of rBzH at titrant/Pdtot = 100:1 is consistent with titrant adsorption−desorption that is quasi-equilibrated, as well as titrant binding energies and selective site titration that influence apparent activation barriers. Effects of titrant stabilization by solvent molecules are further realized in BA oxidation reactions in n-decane, yielding more favorable titrant adsorption efficiency. Overall, titration efficiency in the liquid phase is found to be the net result of titrant adsorption configuration, binding energy, and stabilization by solvent molecules in the bulk that influence the relative favorability of adsorption and desorption.

Status: published work in Industrial and Engineering Chemistry Research 2025, **64**, 1101

Getting out of a tight spot: Cooperative unclogging of hydrogel particles in disordered porous media

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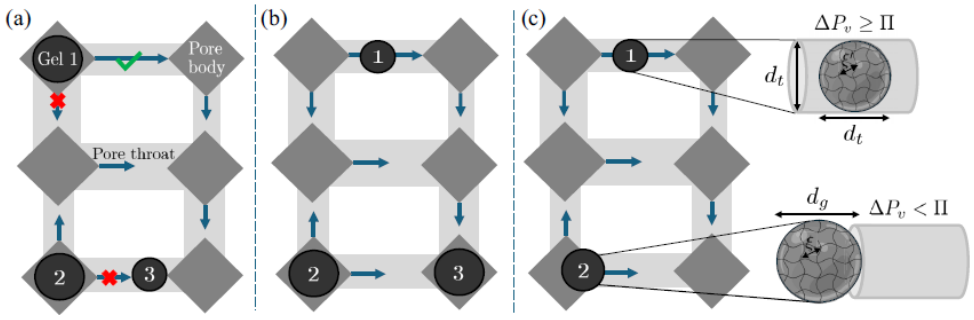

We use event-driven pore network modeling to study the transport of hydrogel particles through disordered porous media—a process that underlies diverse applications. By simulating particle advection, deformation, and clogging at the pore scale, we identify a dimensionless "squeezing parameter" that quantitatively predicts the depth to which particles penetrate into a given medium across diverse conditions. Our simulations also uncover a surprising cooperative effect: Adding more particles enables them to penetrate deeper into the medium. This phenomenon arises because individual particles redirect fluid to adjacent throats, forcing nearby particles through tight pores that they would otherwise clog. Altogether, these results help to establish a quantitative framework that connects microscopic particle mechanics to macroscopic transport behavior.

Status: published work in Physical Review Research 2025, **7**, L032013

Characterization of K-MER and 13X zeolites for humid direct air capture of CO_2 under equilibrium and cycling conditions

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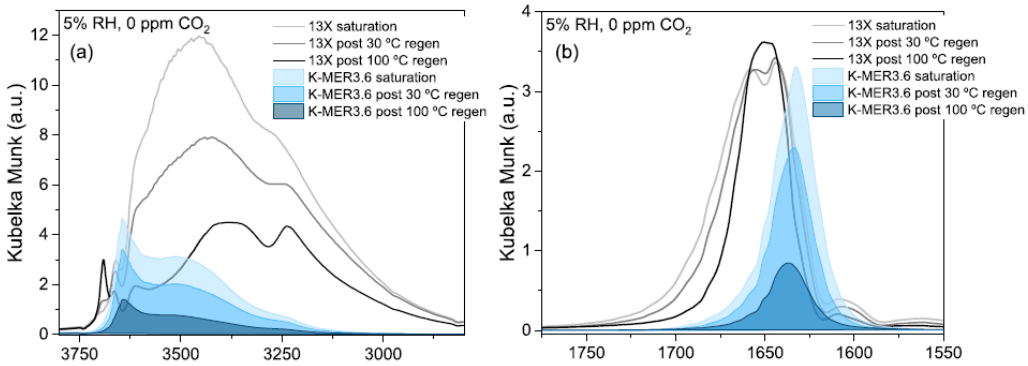

The deleterious effects of moisture on uptake capacity and regeneration energy requirements remain a major challenge for zeolite adsorbents in carbon capture applications. This motivates the need to design CO_2-selective and/or more hydrophobic zeolites even at the low Si/Al needed for practical binding site densities, particularly for the dilute CO_2 concentrations (~400 ppm) involved in direct air capture (DAC) processes. Herein, we present the dry and humid DAC performance of commercial 13X and for the first time, potassium-exchanged merlinoite (K-MER, Si/Al = 3.6). We show that the CO_2 selectivity observed in K-MER for concentrated, humidified CO_2 does not persist at 400 ppm CO_2 and the same humidity (2095 ppm H_2O) at equilibrium. Despite this, we demonstrate that under non-equilibrium cycling conditions using mild regeneration at 100 ◦C, K-MER retains 73% of its dry uptake capacity over 5 humid DAC cycles, in contrast to 47% measured over 13X. A combination of adsorption isotherm and competitive adsorption/desorption studies in a dynamic column breakthrough (DCB) system, coupled with insights from steady-state and time-resolved diffuse reflectance infrared spectroscopy (DRIFTS), reveals that the more robust humid performance of K-MER compared to 13X can be attributed to more facile regeneration of CO_2 binding sites due to more weakly-bound H_2O and CO_2 species. These results underscore how the nature and strength of adsorbed species in binary CO_2 and H_2O mixtures are greatly influenced by the combination of framework topology and Si/Al (even for Si/Al < 5).

Status: published work in Chemical Engineering Journal 2025, **524**, 168648.

Modulating Poly(oligocyclobutane) Properties Through Backbone Modifications

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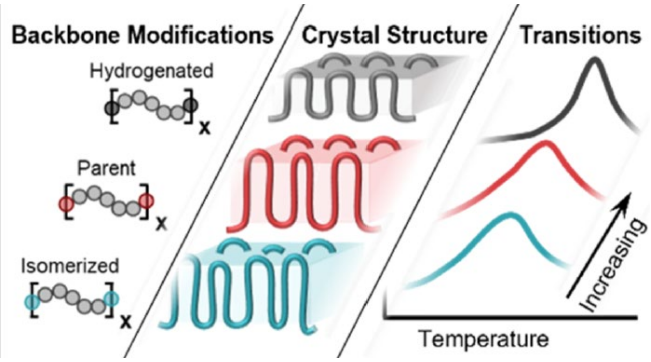

Poly(1,n′-divinyl)oligocyclobutane (pDVOCB) has emerged as a class of poly(cycloolefin) that is amenable to chemical recycling and demonstrates promising thermomechanical properties. However, their high melting temperatures coupled with insolubility makes melt processing challenging due to thermo-oxidation of internal alkenes. To address these issues, we describe a series of polymers incorporating modifications to the pDVOCB backbone and analyze the effects on material stability and processability. Intentional migration of the internal 1,2-disubstituted alkenes to an exocyclic trisubstituted position yields isomerized pDVOCB (IpDVOCB) which exhibits a depression of thermal transitions by up to 50 °C. Conversely, elimination of stereo-irregularity between enchained DVOCB oligomers through alkene saturation yields hydrogenated pDVOCB (HpDVOCB), resulting in elevated thermal transitions by up to 30 °C. These shifts are attributed to changes in crystal defect density which is strongly influenced by chain stereoregularity. Understanding these behaviors guides future polymer design and expands the control and use of this new class of recyclable poly(cycloolefin)s.

Status: published work in Macromolecules 2025, **58**, 9469

Interfacial Morphodynamics of Proliferating Microbial Communities

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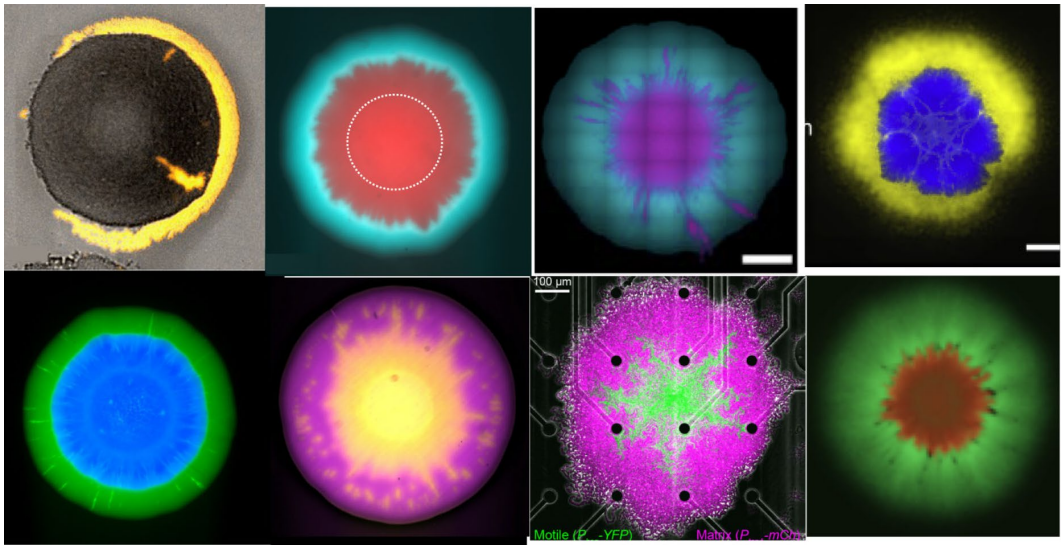

In microbial communities, various cell types often coexist by occupying distinct spatial domains. What determines the shape of the interface between such domains—which, in turn, influences the interactions between cells and overall community function? Here, we address this question by developing a continuum model of a 2D spatially structured microbial community with two distinct cell types. We find that, depending on the balance of the different cell proliferation rates and substrate friction coefficients, the interface between domains is either stable and smooth or unstable and develops fingerlike protrusions. We establish quantitative principles describing when these different interfacial behaviors arise and find good agreement with both the results of previous experimental reports as well as new experiments performed here. Our work, thus, helps to provide a biophysical basis for understanding the interfacial morphodynamics of proliferating microbial communities as well as a broader range of proliferating active systems.

Status: published work in Physical Review X 2025, **15**, 011016

Influence of Pd speciation and support interactions for Suzuki reactions

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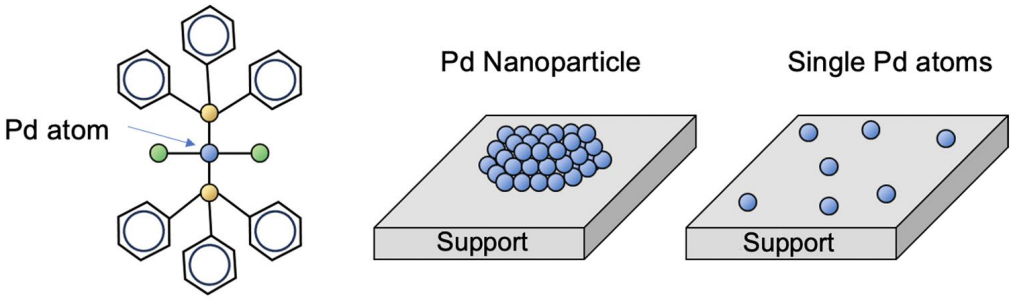

The carbon-carbon bond-formation via the Suzuki reaction is widely used in the pharmaceutical and chemical industries, typically catalyzed by homogeneous palladium (Pd)-ligand complexes. Despite their effectiveness, these catalysts face challenges such as difficult Pd separation and limited reusability. This study targets heterogeneous single atom catalysts (SACs) on varied supports, where Pd-UiO-66-NH_2 metal-organic framework (MOF), synthesized via a ball milling method, was evaluated against Pd/TiO_2 and Pd/C in Suzuki coupling reactions. Characterization data (TEM, XRD, DRIFTS, EDX, chemisorption) revealed that Pd-UiO-66-NH_2 predominantly features isolated Pd atoms, while Pd/TiO_2 contains both single atoms and nanoparticles and Pd/C has predominately nanoparticles. Turnover frequencies for varied substrates trended as Pd-UiO-66-NH_2>Pd/ TiO_2>Pd/C, consistent with fitted kinetic parameters. Hot filtration experiments indicated reactivity from each catalyst stemmed from leached Pd. These results highlight the potential of SACs and the importance of support choice for achieving high catalytic efficiency with minimal metal loading, aligning with green chemistry principles and demonstrating the promising role of MOFs as efficient platforms for SACs.

Status: published work in Applied Catalysis A, General 2025, **700**, 120279

Impact of Monomer Sequence and Interaction Parameter on Polymer Glass Transition Temperature

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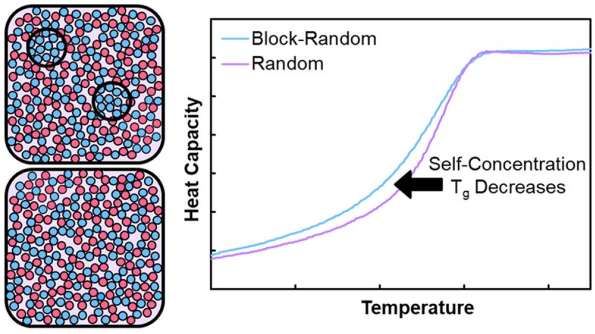

Control of the glass transition temperature (T_g) is a major goal in polymer engineering as T_g is a key determinant of mechanical behavior, barrier properties, and material processability. In copolymers of nonpolar monomers, the Fox equation can provide an approximate description of the dependence of T_g on copolymer composition (monomer ratio). However, the Fox equation does not consider the influence of intermonomer interactions. Here, we explore changes in T_g by altering copolymer sequence and the interaction parameter (χ) between monomer units, with the Fox equation as a benchmark. We synthesized styrene/isoprene random copolymers with varying sequence at a 50:50 wt % overall styrene:isoprene composition and a molecular weight of approximately 100 kg/mol. The sequence was altered from an entirely random copolymer by incorporating short (~5−10 kg/mol) homopolymer blocks of either polystyrene (PS) or polyisoprene (PI) at either the end or center of a random copolymer chain. Fully random styrene-isoprene copolymers show only a slight negative deviation (~3 °C) from the Fox equation. Incorporation of a short homopolymer block of either PS or PI into the chain resulted in an additional depression of the T_g (by ~2 °C). Additionally, we hydrogenated the isoprene units to increase χ and observed even larger negative deviations from the Fox equation (by ~13 °C). These results demonstrate that both sequence and monomer interactions are polymer design parameters that can be used to manipulate bulk T_g.

Status: published work in J. Phys. Chem. B 2025, **129**, 9485

Investigation of Pt Catalyst Dynamics under DBD Plasma Jet During CO Oxidation via Operando DRIFTS

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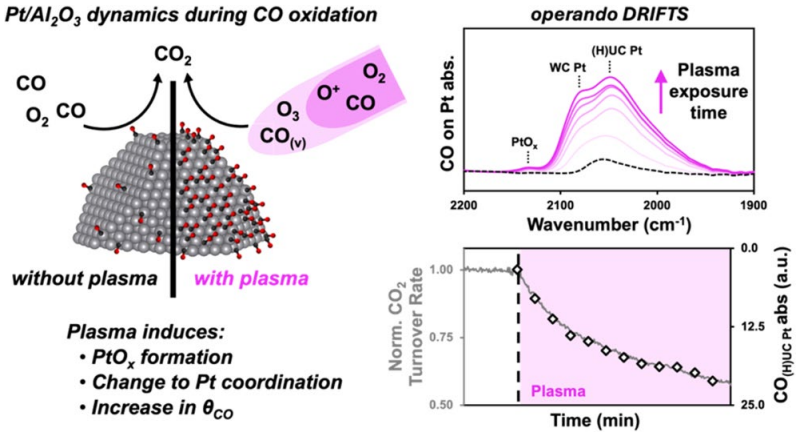

The understanding of catalyst dynamics under plasma exposure, given their impacts on reaction kinetics, is pertinent for effective catalyst design in nonthermal plasma (NTP)-assisted catalysis. However, it is obscured by complex plasma/catalyst interactions. Here, the dynamics of γ-Al_2O_3-supported Pt nanoparticles (NPs) during CO oxidation under dielectric barrier discharge (DBD) plasma jet exposure were investigated by operando diffuse reflectance infrared Fourier transform spectroscopy (DRIFTS) to understand plasma effects on the nature and number of active sites in NTP-assisted catalysis. This work reveals the ability of the plasma to oxidize Pt, to affect supported Pt NP reconstruction, which changes the effective Pt dispersion, and to change the surface CO coverage. Isolated reactant flow experiments identified plasma-activated O_2-derived species responsible for lower CO_2 turnover rates with plasma exposure at elevated temperatures, and transient DRIFTS measurements of CO−Pt binding were decomposed to identify a correlation in the prevalence of under-coordinated Pt sites with CO_2 turnover rates. The observed effects are consistent with the Eley−Rideal-type reaction of O_2-derived species with surface-bound CO to form CO_2. While NTP-assisted CO oxidation serves as a model reaction, insights from this study can be extended to NTP-assisted catalytic mechanisms, particularly those involving kinetically relevant CO−Pt binding such as methane reforming and CO_2 activation.

Status: published work in ACS Catalysis 2025, **15**, 13302

Impact of Processing Environment on Anti-Solvent Free $FAPbI_3$ Films and Solar Cells

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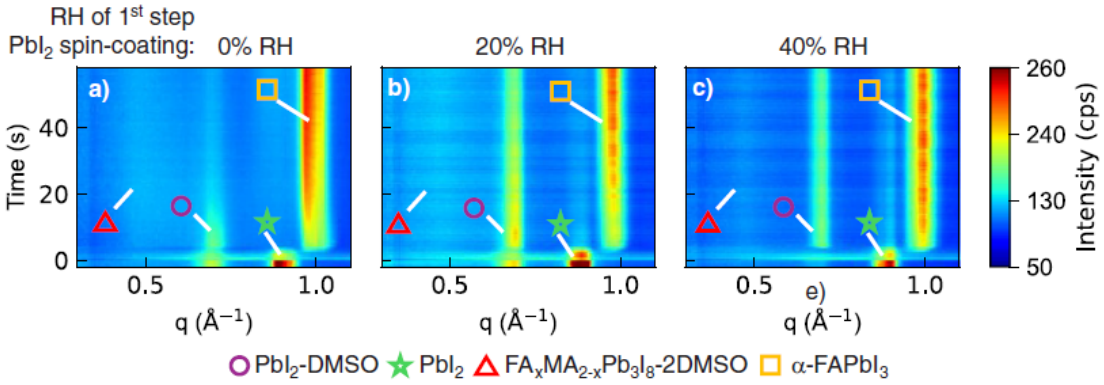

As perovskite solar cells approach commercialization, understanding the environmental sensitivities of perovskites during fabrication becomes increasingly important. In this work, the humidity-dependence of each deposition and annealing step in the anti-solvent-free two-step formamidinium lead iodide fabrication process is investigated in air and N_2. In-situ grazing-incidence wide-angle X-ray scattering measurements during spin-coating indicate that humidity affects the formation and dynamics of intermediate phases in perovskite precursor films. These differences, and those induced by annealing in humidity, impact the structure, morphology, and composition of resultant perovskite films, though the initial performance of solar cells fabricated using these active layers is relatively insensitive to humidity across the range studied. In contrast, stability is maximized in devices with dry-processed active layers and those terminally annealed in humidity. Spin-coating of PbI_2 is most environmentally sensitive—needle-like structures precipitate while spin-coating in 40% relative humidity leading to significantly reduced photovoltaic performance and device stability. Additionally, films and solar cells fabricated in air appear virtually identical to those fabricated in N_2. Collectively, these results show that optimal performance and stability of two-step processed formamidinium lead iodide solar cells is achieved when fabricating active layers in a dry atmosphere or with some humidity during the final anneal.

Status: published work in Advanced Energy Materials 2025, **X**, e03828

Chain ends excite polymer cooperative motion

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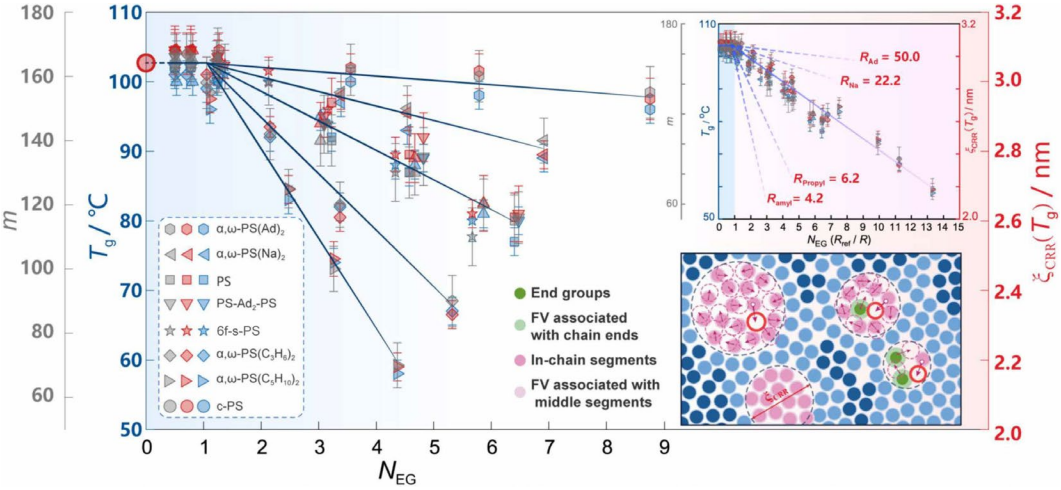

Among glasses, polymers stand out as the chain connectivity endows them with distinct properties in glass formation, among them the transition temperature (T_g) and dynamic fragility (m) varying with chain length. Here, we resolve the nature of the chain length–dependent behaviors, revealing the strong correlation between the number of chain ends within the cooperatively rearranging region and glassy properties including T_g and m. The correlations suggest a simple yet common mechanism of glass formation for the chain molecules, i.e., fast-relaxing chain ends alleviate the requirements of cooperativity for structural rearrangement, thus facilitating the cooperative motion that reduces T_g and m as chain length is shortened. We categorize the role of end groups between soft and rigid by proposing a physical quantifier—index of rigidity. Our results provide a unifying picture of polymer glass formation, regarding the role of chain end, length, and topology, a foundational phenomenon with implications across fields of chemistry, soft-condensed matters, and material science.

Status: published work in Science Advances 2025, **11**, eaea0786

Catalytic Consequences of Pore Structure, Nodal Identity, and Coordination Environment on Styrene Oxidation by Hydrogen Peroxide over Fe MOFs

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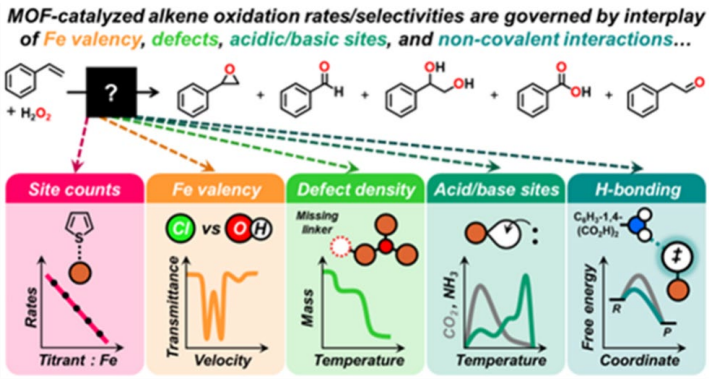

Selective hydrocarbon oxidation processes are central in fine and commodity chemical production and are sensitive to the nature of the active metal sites and their surrounding coordination environment. Isometallic Fe-based carboxylate MOFs (MIL-100, MIL-101, and NH2-MIL-101) are employed to elucidate how Fe coordination environments and framework topology influence a probe aryl (styrene) oxidation mediated by hydrogen peroxide (H_2O_2). MIL-101 shows the highest oxygenate production turnover rates, as normalized by in situ thiophene titrations, followed by NH_2-MIL-101 and MIL-100. Post reaction *ex situ* Mössbauer spectroscopy elucidates Fe(II) formation under reaction conditions; this Fe(II) formation was enabled by the reductive elimination of halide capping ligands unique to the MIL-101 family but not present in MIL-100 that only contains hydroxyls. Defect undercoordinated Fe sites promote unproductive H_2O_2 decomposition and secondary oxygenate formation but do not perturb primary oxygenate selectivities. Conversely, stabilizing hydrogen-bonding interactions between N−H donors and postulated benzaldehyde metallocycle transition state structures confer NH_2-MIL-101 100% selectivity for the primary oxygenate product benzaldehyde over styrene oxide at differential styrene conversions (<3%) compared to a maximum of 59% for MIL-101. Overall, this work showcases how seemingly subtle changes and perturbations to the coordination environments local to metal sites influence the observed reactivity, selectivity, and stability for oxidative transformations within MOF-catalyzed reaction systems.

Status: published work in J. Am. Chem. Soc. 2025, **147**, 34527

Interfacial wetting-induced nanorheology of thin polymer films

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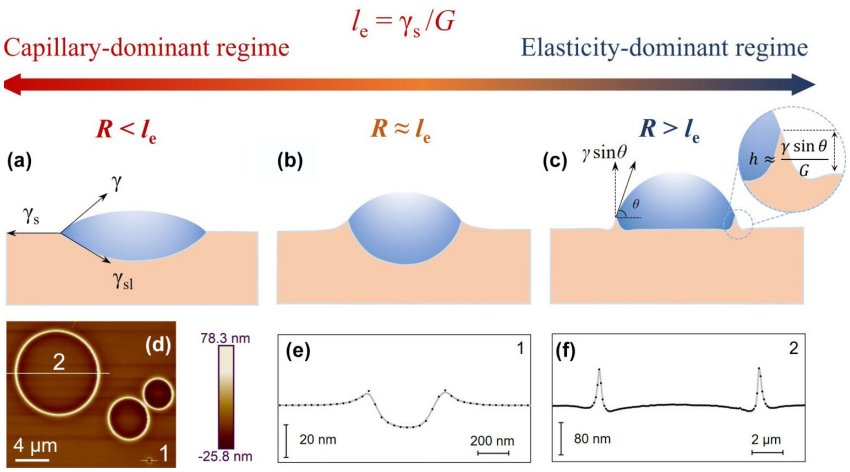

The rheological response and chain dynamics of thin polymer films underpin nanoscale polymer processing, yet molecular confinement alters such behavior. Using the interfacial wetting force of an immiscible liquid droplet to deform the films and linear elastic theory to describe the time evolution of the deformation profile, we demonstrated that the linear viscoelastic spectra, i.e., the frequency-dependent storage and loss moduli, of nanoscale polymer films are experimentally accessible over a wide frequency range. Our measurements on polystyrene nanofilms evidence an acceleration of polymer diffusion at a large confining length scale, i.e., at film thicknesses of hundreds of nanometers. This long-range perturbation in chain dynamics was interpreted as the fast relaxation of surface chains with reduced entanglements provoking loosening of entanglement constraints of the underlying chains, allowing the accelerated reptation mobility at the surface to extend deeply into the film interior. This suggests a surface-induced constraint release effect dominating the dynamics and rheology of polymers confined at a large length scale.

Status: published work in Physical Review Research 2025, **7**, 023226

Department of Civil and Environmental Engineering

Beyond cooling: Radiative thermoregulation in the Earth's glow with micropatterned directional emitters

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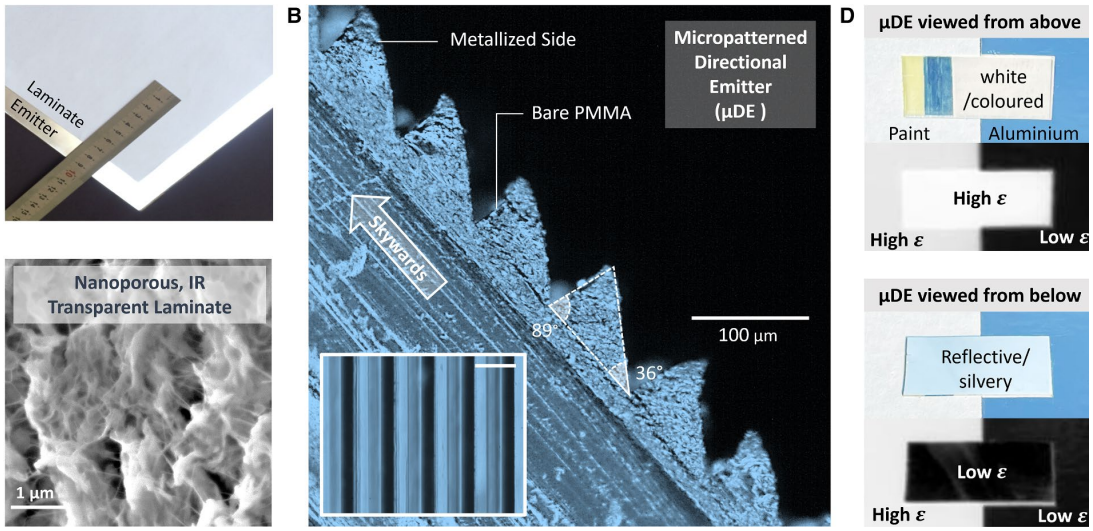

We demonstrate a micropatterned directional emitter (µDE) with an ultrabroadband directional thermal emittance. The µDE enables a previously unexplored passive seasonal thermoregulation of buildings by reducing terrestrial heat flows. µDEs with metallic and white appearances can be made using low-cost materials and scalable manufacturing techniques and have their directional emittance geometrically tailored to different urban scenarios. We also show a novel, visibly transparent variant. In outdoor experiments, µDEs stay 1.53◦C to 3.26◦C cooler than traditional omnidirectional building envelopes in warm weather and up to 0.46◦C warmer in cold weather. Additionally, our µDEs demonstrate significant cooling powers of up to 40 Wm^{-2} in warm conditions and heating powers of up to 35 Wm^{-2} in cool conditions relative to typical building envelopes. A building energy model shows that µDEs can achieve all-season energy savings similar to or higher than those of cool roofs. Collectively, our findings show µDEs as highly promising for thermoregulating buildings.

Status: published work in Joule 2025, **9**, 101956

Carbon Mineralization of Sulfate Wastes Containing Pb: Synchrotron Pb M3-Edge XANES Analysis of Simultaneous Heavy Metal and Carbon Sequestration

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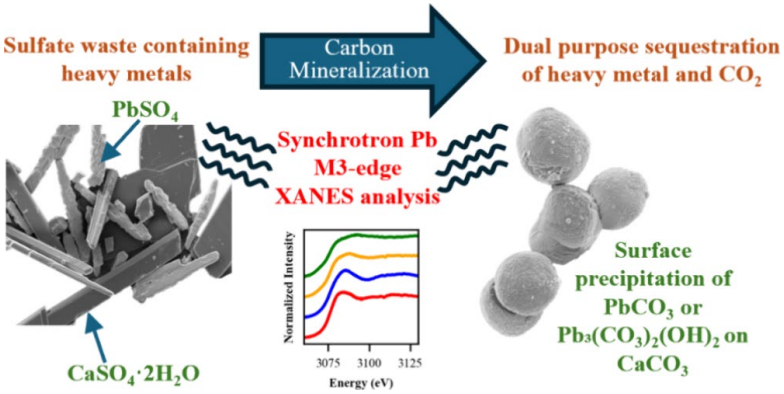

Sulfate wastes are produced in large quantities and contain toxic heavy metals such as lead (Pb), posing environmental risks. Because of favorable solubility differences, these wastes can be repurposed for engineered carbon dioxide (CO_2) sequestration. Understanding the fate and mobility of heavy metals during this process is important. This study focuses on Pb and the effect of zinc (Zn) on Pb in carbon mineralization. Synthesized gypsum was treated with a carbonate-rich solution at pH 11.5 to convert the sulfates to carbonates. Aqueous solutions and mineral solids were analyzed. Synchrotron-based micro-X-ray fluorescence and a novel application of Pb M3-edge X-ray absorption near-edge structure provided detailed insights into Pb distribution and mineral forms. Results showed significant reductions in aqueous Pb and Zn concentrations, indicating effective metal sequestration. Carbon mineralization transformed Pb from soluble anglesite ($PbSO_4$) into insoluble cerussite ($PbCO_3$) and hydrocerussite ($Pb_3(CO_3)_2(OH)_2$). Pb primarily precipitated onto calcium carbonate surfaces through surface-mediated precipitation reactions. While the presence of Zn modified crystallization dynamics, it did not impede Pb sequestration and potentially enhanced surface reactivity, facilitating greater Pb immobilization. These findings highlight carbon mineralization as a sustainable approach to immobilize toxic metals in sulfate wastes while advancing CO_2 sequestration efforts.

Status: published work in Environmental Science and Technology 2025, **59**, 7366

High efficiency selenium recovery via reactive evaporation driven by wood-based evaporator

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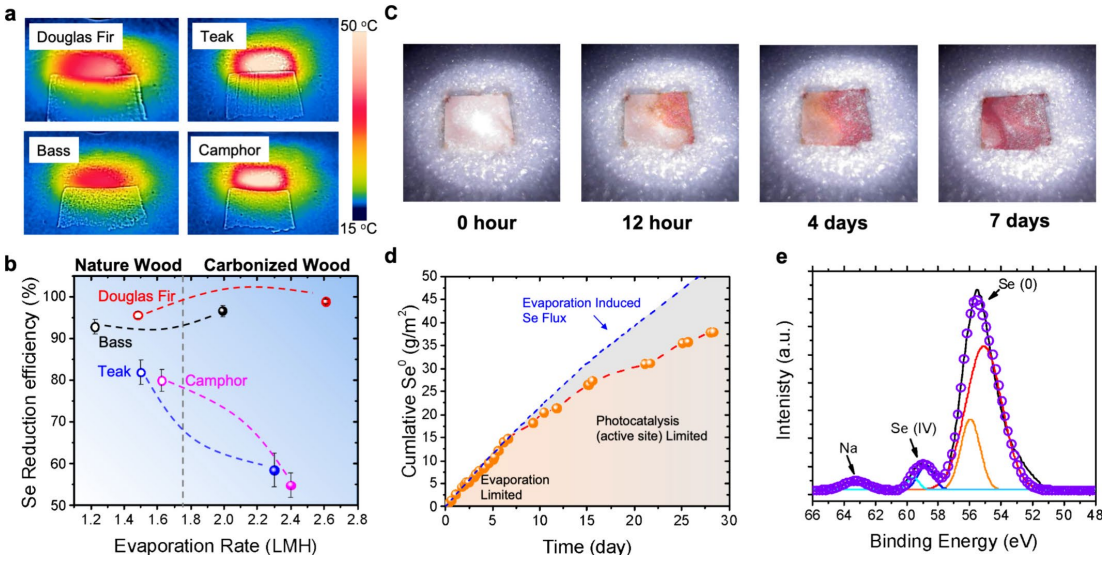

Selenium is a vital trace element for living organisms but also a contaminant released from industrial runoff. Conventional methods of removing selenium from solutions are complex and expensive due to low discharge limits and large volumes of wastewater. In this study, we developed and tested a wood-based reactive evaporator that offers a one-pot solution to simultaneously reduce wastewater volume in tailings ponds and recover selenium. The wood-based evaporator achieves a rapid evaporation rate of 2.6 LMH and 96 % selenium recovery by converting whole solar energy spectrum for photothermal water evaporation and photocatalytic selenium reduction. Additionally, the acidic nature of the wood provides a preferred pH environment for selenium reduction even with alkaline water sources, and the photocatalytic reaction can be sustained without additional hole scavengers. Furthermore, our evaporator has shown success in recovering other heavy metals and can be adjusted for selectivity.

Status: published work in Chemical Engineering Journal 2025, **524**, 169106

Department of Chemistry

Low-Temperature Topochemical Synthesis of $Cu_2Pd_3Se_4$ from Layered $Rb_2Pd_3Se_4$ via Molten Salts Ion Exchange

Sigalit Aharon, Sudipta Chatterjee, Fang Yuan, Gabrielle Carrel, Jiaze Xie, Tanya Berry, Brianna L. Hoff, and Leslie M. Schoop

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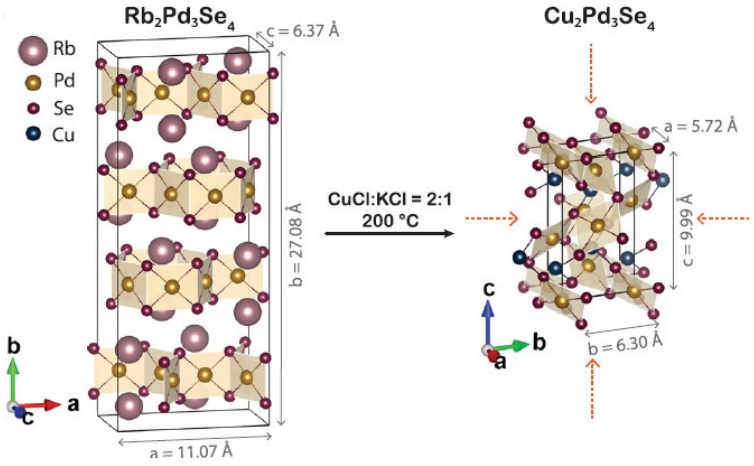

The preparation of kinetically favored inorganic crystals remains a major challenge, as high-temperature methods often prevent access to metastable phases with unique properties. To address this, post-synthetic processes that enable the preparation of kinetically favored structures have been developed. In this work, we employ a low-temperature (200 °C) post-synthetic ion exchange process to transform the parent layered kagome material, $Rb_2Pd_3Se_4$, into the nonlayered mineral $Cu_2Pd_3Se_4$. This mineral has previously only been synthesized under extreme conditions or was found in nature. Achieving such a structural transformation via ion exchange is unconventional; typical ion exchange reactions mediate transitions between closely related structures. Moreover, the ion exchange procedure developed here does not involve solvents, and the full ion exchange is accomplished at low temperature by the proper choice of a eutectic mixture of salts. Analysis of products synthesized under different conditions show that the $Cu_2Pd_3Se_4$ decomposition is limited at 200 °C when the mixture of CuCl and KCl is used, resulting in a pure-phase product. The magnetic and electrical characteristics of $Cu_2Pd_3Se_4$ are presented here for the first time and confirm our density functional theory calculations. Our findings demonstrate that low-temperature molten salt-mediated ion exchange may unlock new regions of the solid-state materials landscape.

Status: published work in ZAAC (J. of Inorg. and Gen. Chem.) 2025, **651**, e202500098

Photo-Iniferter RAFT Synthesis of Versatile, Nonalternating Poly(acrylate-co-isocyanides)

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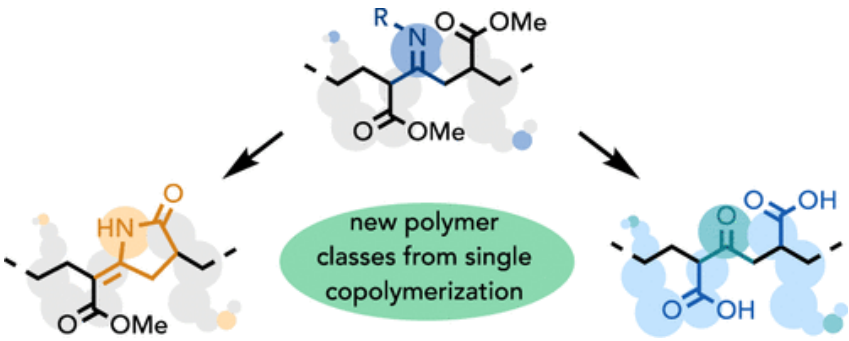

Nonalternating poly(isocyanide-co-acrylate) copolymers enable access to novel polymer microstructures with versatile chemistry and allow for designed mechanical properties, an important facet of combating the plastic waste crisis. While previous syntheses used cobalt-mediated radical polymerizations, the cobalt complex exhibits side reactivity, complicating control over polymerization. This work describes the application of an orthogonal, photocontrolled RAFT polymerization to a range of isocyanides with excellent temporal control. Under solvent-free conditions, adding monomers with a standard chain transfer agent (CTA) results in the synthesis of copolymers that are then transformed into several novel microstructures. Interestingly, we discover that the isocyanide units can undergo cyclization of the backbone, resulting in an unexampled polyamide-like copolymer containing the pyrrolidone ring. Moreover, we generate poly(acrylic acid)-like copolymers with small amounts of ketone linkages through hydrolysis, enabling faster degradation rates for this class of polymer.

Status: published work in Macromolecules 2024, **57**, 9250

Temperature-Dependent Translation-Rotation Diffusivity Divergence in Hot Brownian Motion Directly Observed by Single-Particle T-Jump Tracking

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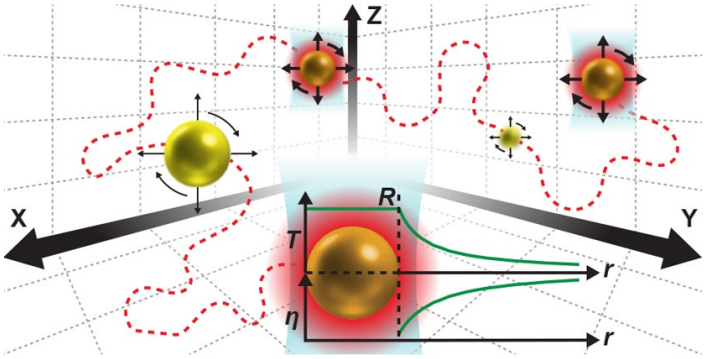

A nanoscale heat source suspended in fluids constitutes a highly localized yet mobile system that is far from equilibrium. Remarkably, its translational and rotational dynamics can still be theoretically described by Brownian-type equations of diffusion, a "hot Brownian motion" framework (HBM), while the original formulation of diffusive dynamics premises a system that is at or near thermal equilibrium. The HBM theory predicts a steeper temperature dependence for the nanoscale heat source's rotational dynamics over its translational movements a breakdown of the equipartition principle. Here, we present the first experiment that consistently assessed the HBM prediction by evaluating the diffusivities resulting from both types of motion on an equal footing. We simultaneously tracked the dynamics of all six translational and rotational degrees of freedom for single gold nanoparticles after laser-induced temperature jumps up to ~30 K above ambient. Without the need for adjustment parameters, the experimental data were recapitulated by the HBM theory across a panel of particle sizes and heating-laser intensities. Our results thus corroborated the translation-rotation diffusivity divergence predicted by the theory, solidifying its underlying microscopic picture which is expected to have important implications in such applications as photothermal imaging, molecular thermobiology and biophysics, nonequilibrium physics and active matters, as well as chemical dynamics, to name a few.

Status: published work in J. Phys. Chem. C 2025, **129**, 2083

Electroanalytical Implications of an Interfacial Insulating Metal Oxide Layer: Impact of a Porous Cr_2O_3−Ga_2O_3 Layer on Electron Transfer and Heterogeneous Electrocatalysis

Alma Paola Hernandez-Gonzalez,[1] Stephanie Dulovic,[1] Guangming Cheng,[2] Cynthia Bian,[1] Alyssa Ritchie,[1] and Andrew Bocarsly[1]

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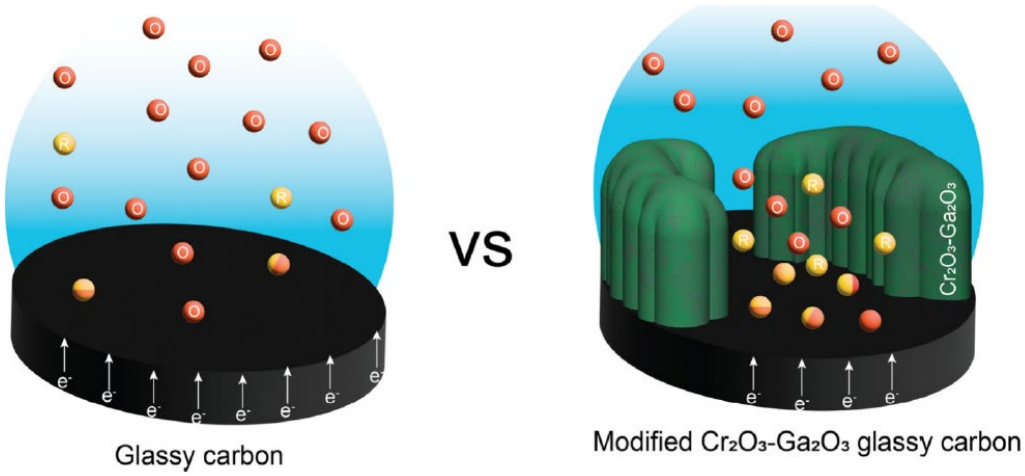

The electrochemical reduction of CO_2 into 1-butanol with high faradaic efficiencies (42%) using what has been described as a Ni-enhanced Cr_2O_3−Ga_2O_3 modified glassy carbon electrode provides a new electrochemical methodology for CO_2 utilization. Currently, the associated charge transfer dynamics and interfacial character that allow this reactivity are not well understood. Here, the electrochemical characteristics of the Cr_2O_3−Ga_2O_3 interface are explored using a toolkit of redox probes to study the electron transfer, proton transfer, and mass transfer characteristics of the electrode. Addition of the Cr_2O_3−Ga_2O_3 coating introduces a significant change in the electrochemical double layer characteristics, which is in part due to the underlying nanostructure of the oxide coating. This environment improves the electron and proton transfer rates, as well as increases the concentration of reactive species near the electrode. Much of this improvement is associated with the porous nonconducting nature of the oxide layer. These findings offer an improved understanding of the electrode and electrocatalytic nature needed to undertake the reduction of CO_2 to produce carbon−carbon bonded products.

Status: published work in ACS Electrochemistry 2025, **1**, 2223

Chemical Exfoliation for the Preparation of $CrSe_2$ Nanoribbons and $CrTe_{2-x}$ Nanosheets

Brianna L. Hoff,[1] Jaime M. Moya,[1] Fang Yuan,[1] Vojtech Kundrat,[2,3] Lothar Houben,[4] Jakub Zalesak,[5] Guangming Cheng,[6] Nan Yao,[6] and Leslie M. Schoop[1,6]

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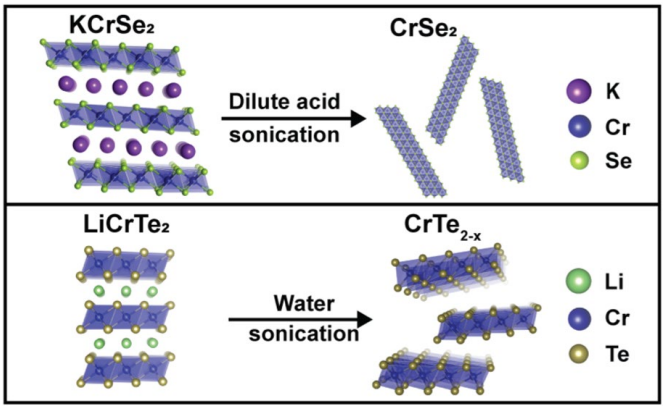

Recently, there has been interest in developing stable dispersions of freestanding, low-dimensional crystalline materials. These dispersions can be converted to inks, which in turn can be printed on substrates and used for a variety of applications. Chemical exfoliation has been a promising method for the acquisition of these inks. Here, we introduce the use of chemical exfoliation for preparing two freestanding transition metal dichalcogenides dispersions: $CrSe_2$ nanoribbons and $CrTe_{2-x}$ ($x \approx 0.2$) nanosheets. The former was exfoliated from $KCrSe_2$ in dilute acetic acid in isopropyl alcohol, whereas the latter was exfoliated from $LiCrTe_2$ in water. We explore the exfoliation of $KCrSe_2$ at various intervals throughout the process to better understand what led to the formation of nanoribbons instead of nanosheets. Meanwhile, we show that the chemically exfoliated $CrTe_{2-x}$ has room-temperature ferromagnetism, as evidenced by magnetization data. The different products of chemical exfoliation processes presented here, ranging from freestanding nanoribbons and sheets to processable ink that is ferromagnetic at room temperature, emphasize the versatility of chemical exfoliation and their potential in future applications.

Status: published work in Chemistry of Materials 2025, **37**, 5333

Recipe for Flat Bands in Pyrochlore Materials: A Chemist's Perspective

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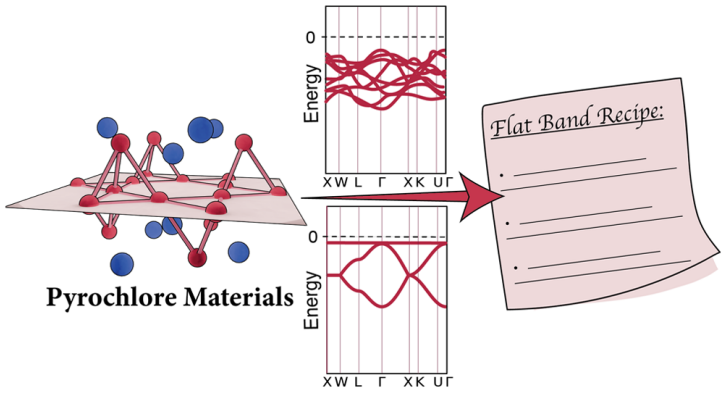

Materials in which atoms are arranged in a pyrochlore lattice have found renewed interest, as, at least theoretically, orbitals on that lattice can form flat bands. However, real materials often do not behave according to theoretical models, which is why there has been a dearth of pyrochlore materials exhibiting flat band physics. Here, we examine the conditions under which ideal "pyrochlore bands" can exist in real materials and how to have those close to the Fermi level. We find that the simple model used in the literature does not apply to the bands at the Fermi level in real pyrochlore materials. However, surprisingly, we find that certain oxide compounds that have oxygen orbitals inside the pyrochlore tetrahedra do exhibit near-ideal pyrochlore bands near the Fermi level. We explain this observation by a generalized tight-binding model, including the oxygen orbitals. We further classify all known pyrochlore materials based on their crystal structure, band structure, and chemical characteristics and propose materials to study in future experiments.

Status: published work in J. Am. Chem. Soc. 2025, **147**, 18166

Transport signatures of Fermi arcs at twin boundaries in Weyl materials

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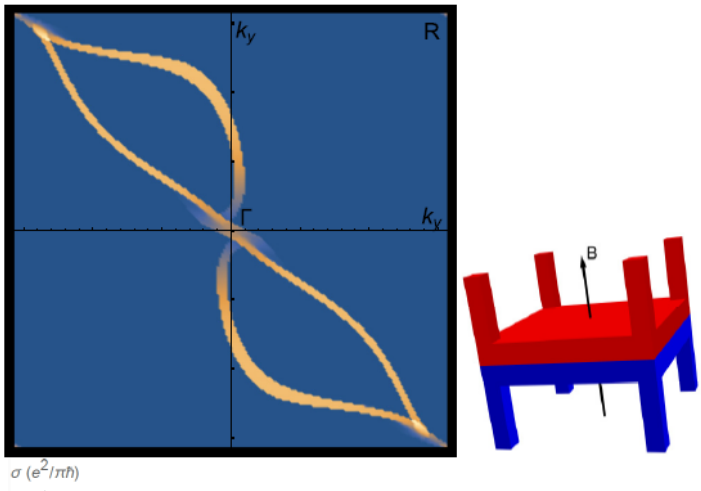

One of the most striking signatures of Weyl fermions in solid-state systems is their surface Fermi arcs. Fermi arcs can also be localized at internal twin boundaries where two Weyl materials of opposite chirality meet. In this work, we derive constraints on the topology and connectivity of these "internal Fermi arcs." We show that internal Fermi arcs can exhibit transport signatures, and we propose two probes: quantum oscillations and a quantized chiral magnetic current. We propose merohedrally twinned B20 materials as candidates to host internal Fermi arcs, verified through both model and ab initio calculations. Our theoretical investigation sheds light on the topological features and motivates experimental studies on the intriguing physics of internal Fermi arcs.

Status: published work in Physical Review B 2025, **111**, 085133

Mixed-Valence Trimers in Organic−Inorganic Hybrid Chromium and Vanadium Chlorides

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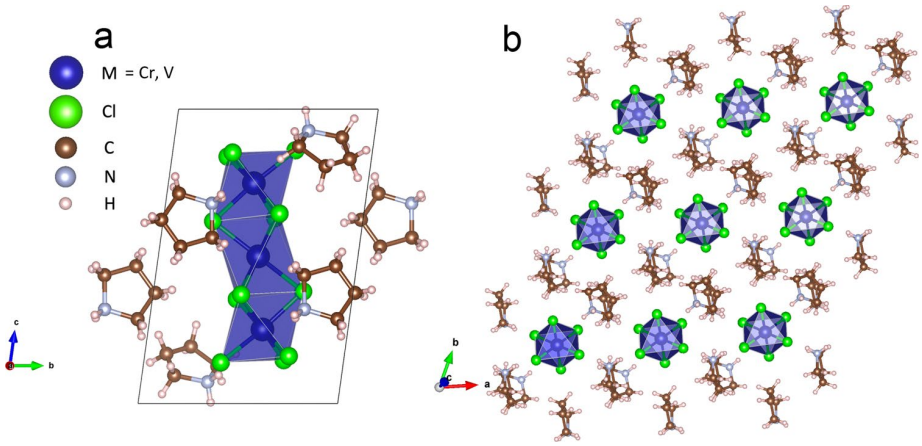

The crystal structures and basic magnetic properties of $Prd_4Cr_3Cl_{12}$ and $Prd_4V_3Cl_{12}$ (Prd = pyrrolidinium, $C_4H_{10}N^+$), previously unreported organic−inorganic hybrid compounds, are described. These compounds are synthesized via solid-state methods, and their crystal structures contain face-sharing $[M_3Cl_{12}]^{4-}$ trimers possessing the configuration $M^{3+}–M^{2+}–M^{3+}$ that are isolated from one another by pyrrolidinium cations. Magnetic analyses reveal that the dominant magnetic correlations for both materials are antiferromagnetic, with particularly strong coupling observed in $Prd_4V_3Cl_{12}$. Neither compound exhibits long-range magnetic ordering down to 0.8 K, though sharp upturns in heat capacity data may signify the onset of such transitions.

Status: published work in Chemistry of Materials 2025, **37**, 5724

Chemical enhancement of superconductivity in $LaRu_3Si_2$ with mode-selective coupling between kagome phonons and flat bands

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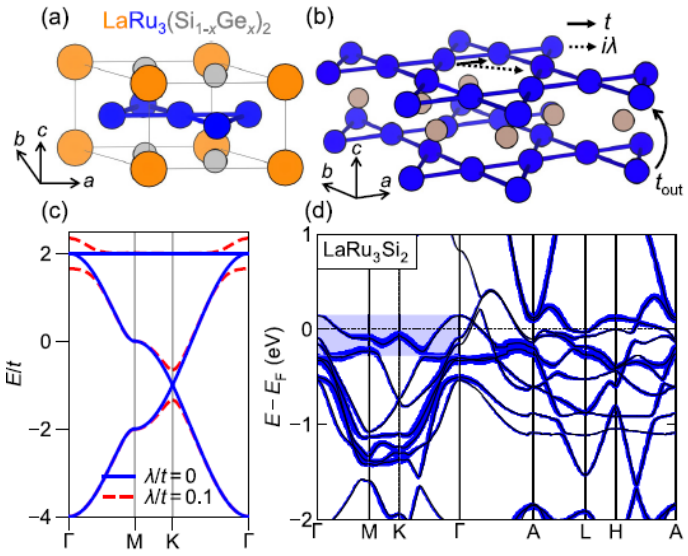

In kagome metals, flat electronic bands induced by frustrated hopping are a platform for strong electron correlations. Here, we investigate the superconductivity in the kagome system $LaRu_3(Si_{1-x}Ge_x)_2$ by chemical pressure tuning while preserving the Ru-4*d* states that constitute the kagome flat bands. We observe a sizable enhancement in the density of states up to x = 0.07, as determined by the specific heat, with a concomitant increase in the superconducting transition temperature T_c. Ge dopants induce a uniaxial lattice expansion along the c axis. Our first-principles calculations suggest that this mitigates the detrimental effect of hybridization between kagome layers and reduces the dispersion of the Ru-d_{x2-y2} flat band. The calculated chemical potential moves closer to the maximum in the energy-dependent density of states. Our result is consistent with a theoretical prediction of tunable flat-band superconductivity in $LaRu_3Si_2$ by mode-selective coupling between specific kagome phonons and the Ru-d_{x2-y2} orbitals.

Status: published work in Physical Review Research 2025, **7**, 033032

Synthesis, Crystal Structure, and Elementary Electrical Characterization of Quasi-One-Dimensional $TiSe_3$

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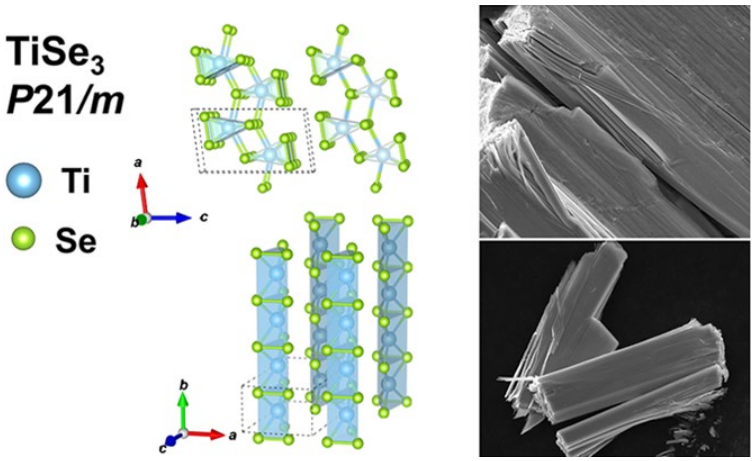

The solid-state synthesis at an applied pressure of 6 GPa, crystal structure, and elementary electronic properties of the previously unreported compound $TiSe_3$ are described. The crystal structure, which is based on 1D chains of Ti−Se triangular prisms that are coupled to each other, with two-thirds of the Se involved in a Se−Se pair, is similar to that of TiS_3. Unlike the trisulfide, the triselenide is only made under pressure at temperatures between 800 and 900 °C. The material is semiconducting and weakly diamagnetic.

Status: published work in Inorganic Chemistry 2025, **64**, 4062

Low-Dimensional VS_3 Synthesized at Elevated Pressure

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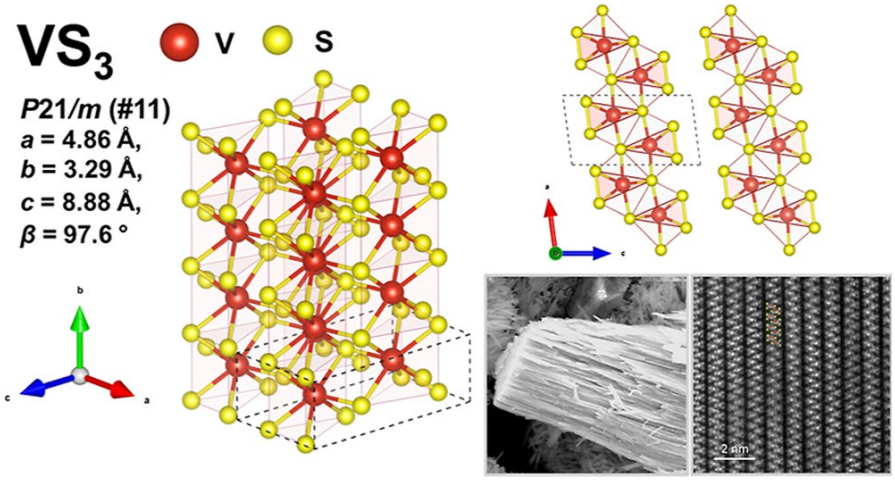

VS_3, a transition metal trichalcogenide that has not been previously reported, was successfully prepared by a high-pressure solid-state synthesis method. Its low-dimensional crystal structure, refined by Rietveld PXRD and confirmed by HR-STEM, features both uncommon V−S coordination polyhedra and S−S dimers. Preliminary characterization reveals low-moment paramagnetic behavior and a semiconducting nature.

Status: published work in Inorganic Chemistry 2025, **64**, 22174

Tuning Magnetism Through Stoichiometric Potassium Intercalation into VOCl

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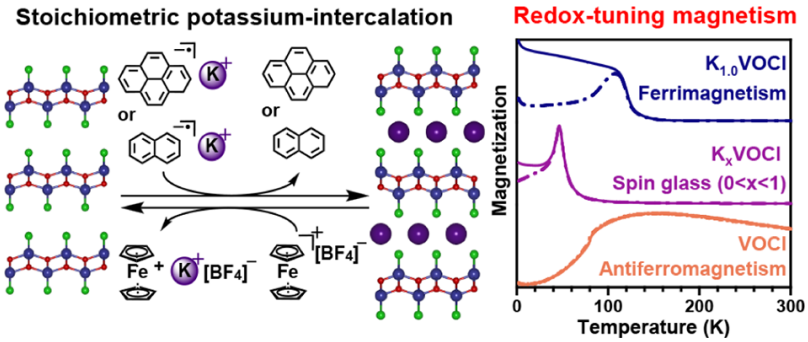

Layered van der Waals (vdW) materials, characterized by their interlayer vdW gaps, offer exceptional tunability of magnetic properties via intercalation chemistry. A wide range of magnetic behaviors have been observed in nonmagnetic transition-metal dichalcogenides intercalated with magnetic atoms. Beyond the incorporation of magnetic ions, we propose the controlled alkali-ion intercalation of intrinsic vdW magnets as a strategy to probe and manipulate spin populations and exchange interactions within individual magnetic layers. Unlike conventional solid-state methods typically used for atomic intercalation, this approach depends on postsynthetic, solution-based reactions. In this work, we demonstrate precise potassium intercalation of VOCl, a layered antiferromagnet, potassium naphthalene and potassium pyrene. Our synthetic approach addresses thermodynamic and kinetic challenges via redox-matching reductants and electrolyte-assisted homogenization. Magnetic measurements reveal a continuous evolution from antiferromagnetism ($x = 0$) to a spin-glass state ($0 < x < 1$) with magnetic memory and ultimately to ferrimagnetism ($x = 1$) in K_xVOCl ($0 \leq x \leq 1$). Ab initio calculations support the existence of a spin-glass state, stabilized by mixed valence and competing magnetic interactions. This work establishes an intercalation methodology to access metastable phases and tailor magnetic properties, offering new insights into magnetism in layered compounds with complex spin interactions.

Status: published work in J. Am. Chem. Soc. 2025, **147**, 33559

Chemical Processing Methods for Deintercalation and Exfoliation of $NaCrO_2$

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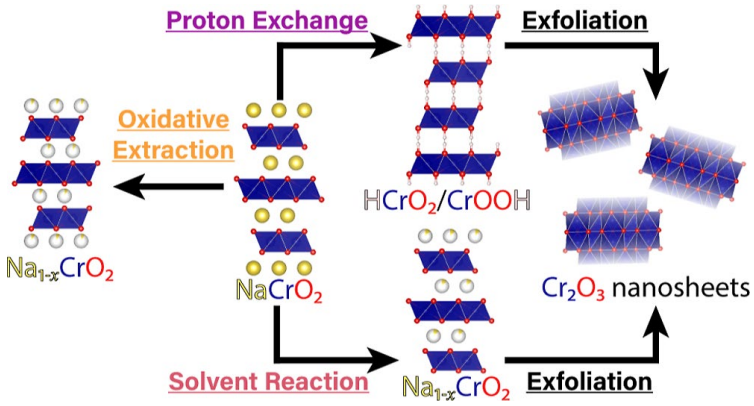

Chemical exfoliation of non-van der Waals (non-vdW) materials can be beneficial as an easily scalable method of obtaining high quality nanosheets, but is difficult due to the stronger interlayer bonds as compared to vdW compounds. Of the non-vdW materials, alkali-intercalated layered materials are a good candidate for exfoliation because they are quasi-2D, but previous research often focused on chalcogenide-based materials, thus leaving the effects of chemical processes on oxide-based ones unclear. In this work, we study the deintercalation and exfoliation of $NaCrO_2$ after three chemical processes: proton exchange, solvent reaction, and oxidative extraction. All resulting materials show different magnetic behavior compared to the parent material. Proton exchange and solvent reaction were both combined with a subsequent sonication step to make 3−4 nm thick Cr_2O_3 nanosheets. Finally, we compare the behavior of $NaCrO_2$ to $NaCrS_2$ to understand the differences in how oxides and chalcogenides behave. Our work demonstrates the structural complexity that can result from these deceptively simple chemical processing methods and how this can affect subsequent exfoliation.

Status: published work in Inorganic Chemistry 2025, **64**, 15552

De Novo Proteins Template the Formation of Semiconductor Quantum Dots

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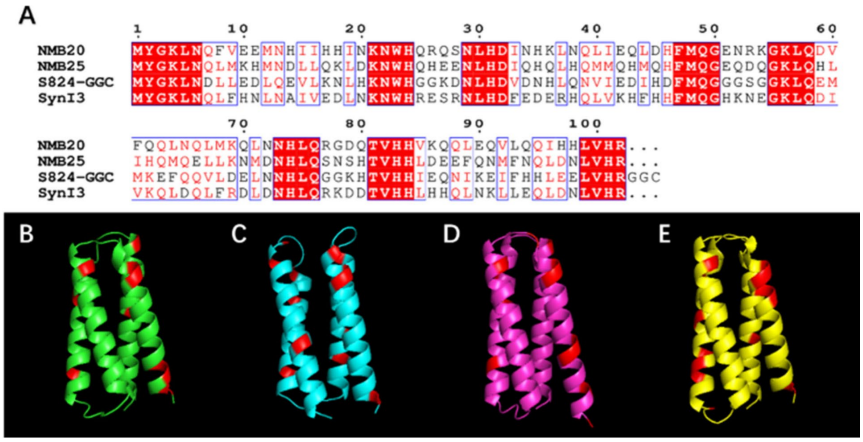

Here, we present the first instance of utilizing de novo proteins to regulate the size of cadmium sulfide (CdS) quantum dots. Four proteins were found to bind to CdS and cap the growth of CdS quantum dots, leading to precise size control, as evidenced by absorbance and fluorescence spectra. Increasing the concentration of CdS does not change the absorbance and emission peaks, thereby indicating that the proteins effectively constrain the size of the quantum dots. Employing different proteins also yielded quantum dots with distinct optical and physical properties, including the appearance of biomediated nanorods when SynI3 was utilized. Moreover, the *de novo* proteins effectively maintained the stability of the quantum dots for up to 7 days, surpassing the stability of quantum dots capped by the small molecule, L-cysteine. The ability to cap CdS likely stems from their affinities for Cd^{2+}, yet there does not seem to be a direct correlation between the affinity for Cd^{2+} and the size of resulting quantum dots.

Status: published work in ACS Central Science 2025, **11**, 983

Peptide surfactants with post-translational C-methylations that promote bacterial development

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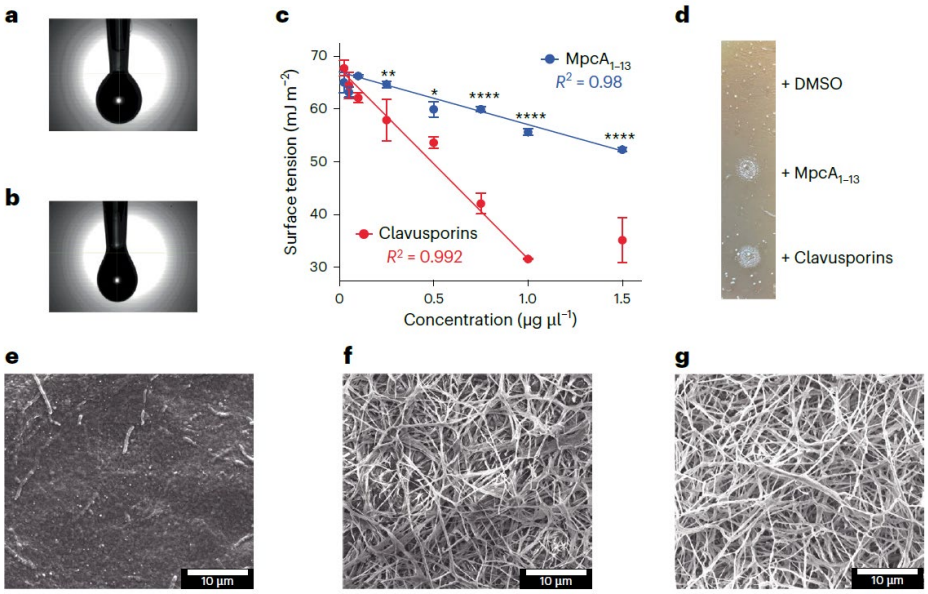

Bacteria produce a variety of peptides to mediate nutrient acquisition, microbial interactions and other physiological processes. Of special interest are surface-active peptides that aid in growth and development. Herein we report the structure and characterization of clavusporins, unusual and hydrophobic ribosomal peptides with multiple *C*-methylations at unactivated carbon centers, which help drastically reduce the surface tension of water and thereby aid in Streptomyces development. The peptides are synthesized by a previously uncharacterized protein superfamily, termed DUF5825, in conjunction with a vitamin B_{12}-dependent radical *S*-adenosylmethionine metalloenzyme. The operon encoding clavusporins is widespread among actinomycete bacteria, suggesting a prevalent role for clavusporins as morphogens in erecting aerial hyphae and thereby advancing sporulation and proliferation.

Status: published work in Nature Chemical Biology 2025, **21**, 1069

Tracking Spatially Heterogeneous Dynamics of Single Nanoparticles Near Liquid−Solid Interfaces

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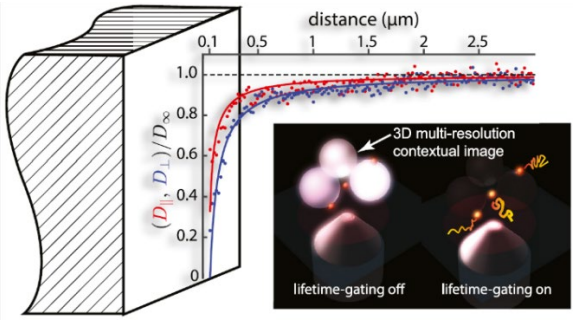
[1]Department of Chemistry, Princeton University, Princeton, NJ, United States; [2]Department of Biological Science and Technology, Institute of Bioinformatics and Systems Biology, Institute of Molecular Medicine and Bioengineering, Center for Intelligent Drug Systems and Smart Bio-Devices, National Yang Ming Chiao Tung University, Hsinchu, Taiwan.



A classical problem in colloidal physics is the behavior of a spherical particle when it randomly walks close to the interface between a fluid and a rigid wall. Solutions to the two complementary aspects of this problem have been provided by Faxén and Brenner, respectively, based on continuum mechanics. Their results predict that the closer the particle is to the interface the slower it moves, but the pace of the slow-down depends on whether the particle steps parallel with or perpendicular to the interface. While the theoretical predictions enjoy unequivocal experimental supports for μm-sized particles, their applicability on the smaller length scales remains unclear. Here we present the first direct experimental test for the complete Faxén-Brenner solutions on the nanoscale. Our experiment was enabled by a new multiresolution instrument which concurrently and synchronously recorded both the high-resolution lifetime-gated μs 3D tracking of a single diffusing nanoparticle and the lower-resolution two-photon laser-scanning microscopy images for the nanoparticle's location relative to the wall interface. The directional diffusivity divarication predicted by Faxén and Brenner was reproduced on the single-nanoparticle level. Our results provided experimental supports for the fluid-dynamics physical picture down to ~ 65 nm, the radius of the nanoparticle sample used in this work, and pointed to next experimental challenges being in the sub-100 nm regime where finite-temperature fluctuations and the molecularity of the fluid are expected to become increasingly noticeable.

Status: published work in J. Phys. Chem. B 2025, **129**, 4229

Department of Electrical and Computer Engineering

Millisecond lifetimes and coherence times in 2D transmon qubits

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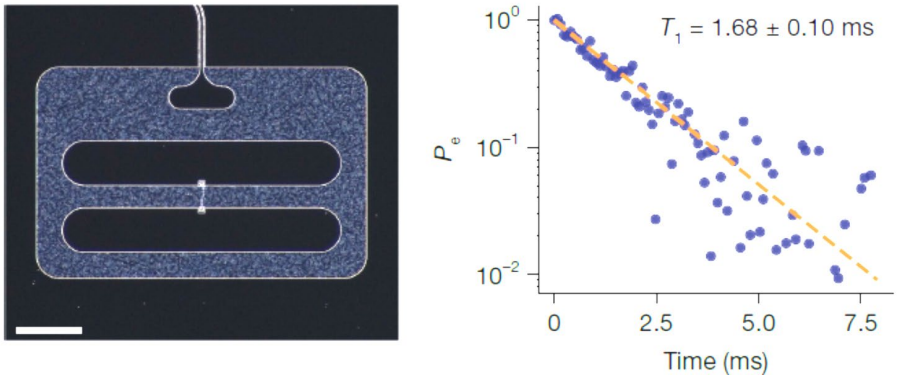
[1]Department of Electrical and Computer Engineering, Princeton University, Princeton, NJ, USA. [2]Princeton Materials Institute, Princeton University, Princeton, NJ, USA. [3]Department of Chemistry, Princeton University, Princeton, NJ, USA.



Materials improvement is a powerful approach to reducing loss and decoherence in superconducting qubits, because such improvements can be readily translated to large-scale processors. Recent work improved transmon coherence by using tantalum as a base layer and sapphire as a substrate. The losses in these devices are dominated by two-level systems with comparable contributions from both the surface and bulk dielectrics, indicating that both must be tackled to achieve substantial improvements in the state of the art. Here we show that replacing the substrate with high-resistivity silicon markedly decreases the bulk substrate loss, enabling 2D transmons with time-averaged quality factors (Q^{avg}) of 9.7×10^6 across 45 qubits. For our best qubit, we achieve a Q^{avg} of 1.5×10^7, reaching a maximum Q of 2.5×10^7, corresponding to a lifetime (T_1) up to 1.68 ms. This low loss also allows us to observe decoherence effects related to the Josephson junction, and we use an improved, low-contamination junction deposition to achieve Hahn echo coherence times (T_{2E}) exceeding T_1. We achieve these material improvements without modifying the qubit architecture, allowing us to readily incorporate standard quantum control gates. We demonstrate single-qubit gates with 99.994% fidelity. The tantalum-on-silicon platform comprises a simple material stack that can potentially be fabricated at the wafer scale and therefore can be readily translated to large-scale quantum processors.

Status: published work in Nature 2025, **647**,343

Eliminating Surface Oxides of Superconducting Circuits with Noble Metal Encapsulation

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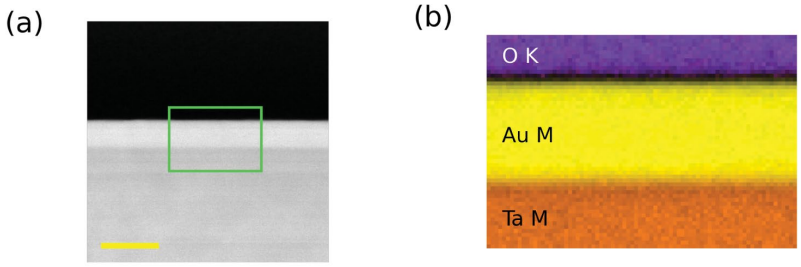

The lifetime of superconducting qubits is limited by dielectric loss, and a major source of dielectric loss is the native oxide present at the surface of the superconducting metal. Specifically, tantalum-based superconducting qubits have been demonstrated with record lifetimes, but a major source of loss is the presence of two-level systems in the surface tantalum oxide. Here, we demonstrate a strategy for avoiding oxide formation by encapsulating the tantalum with noble metals that do not form native oxide. By depositing a few nanometers of Au or AuPd alloy before breaking vacuum, we completely suppress tantalum oxide formation. Microwave loss measurements of superconducting resonators reveal that the noble metal is proximitized, with a superconducting gap over 80% of the bare tantalum at thicknesses where the oxide is fully suppressed. Our findings suggest that losses in resonators fabricated by subtractive etching are dominated by oxides on the sidewalls, pointing to total surface encapsulation by additive fabrication as a promising strategy for eliminating surface oxide two-level system loss in superconducting qubits.

Status: published work in Physical Review Letters 2025, **134**, 097001

Nonlinear transport of Wigner solid phase surrounding the two-flux composite fermion liquid

Yu-jiang Dong,[1] Xinghao Wang,[1] Jianmin Zheng,[1] Weiliang Qiao,[1] and Rui-Rui Du,[1] Loren N. Pfeiffer,[2] Kenneth W. West,[2] and Kirk W. Baldwin[2]

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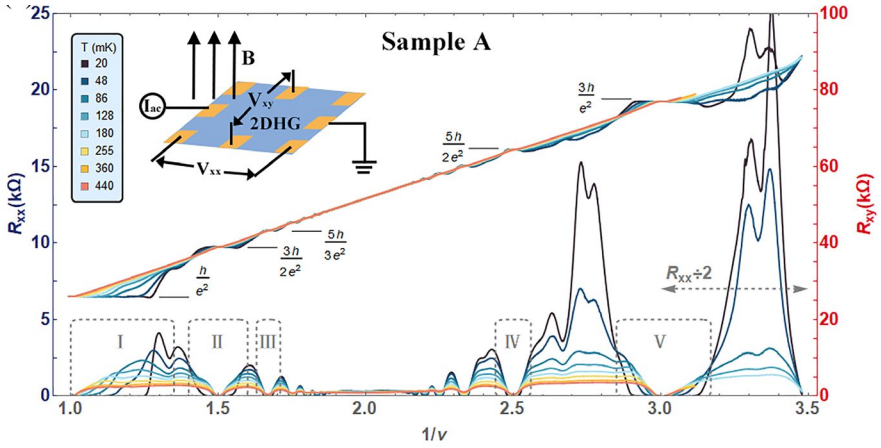

We have investigated the low temperature (T) transport properties of fractional quantum Hall (FQH) states in a high-mobility two-dimensional hole gas. According to the composite fermion (CF) model, FQH states stemming from a half-filled Landau level, specifically at filling factors $\nu = p/(2p + 1)$ ($p = \pm1,\pm2,\pm3, \ldots$), can be associated with two-flux-attached CFs at the corresponding Lambda filling factor p. The zero-resistance minima and Hall plateaus of these states exhibit unusual temperature dependencies, characterized by rapid increases in width below a threshold temperature around 100 mK. Differential conductivity measurements from Corbino samples reveal that the regimes surrounding the CF liquid display clear nonlinear transport characteristics. This nonlinearity implies that each CF liquid is surrounded by CF solid phase composed of dilute CF excitations. Quantitatively, the applied electric field E influences the motion of CF solid in a way analogous to T, which is dubbed the "$E-T$ duality." Our analysis indicates that this $E-T$ duality is consistent with the Berezinskii-Kosterlitz-Thouless theory in two-dimensional phase transitions.

Status: published work in Physical Review Research 2025, **7**, L022011

Sensing Few Electrons Floating on Helium with High-Electron-Mobility Transistors

M. M. Feldman,[1,2] G. Fuchs,[1] T. Liu,[1] L. A. D'Imperio,[3] M. D. Henry,[3] E. A. Shaner,[3] S. A. Lyon,[1,4]

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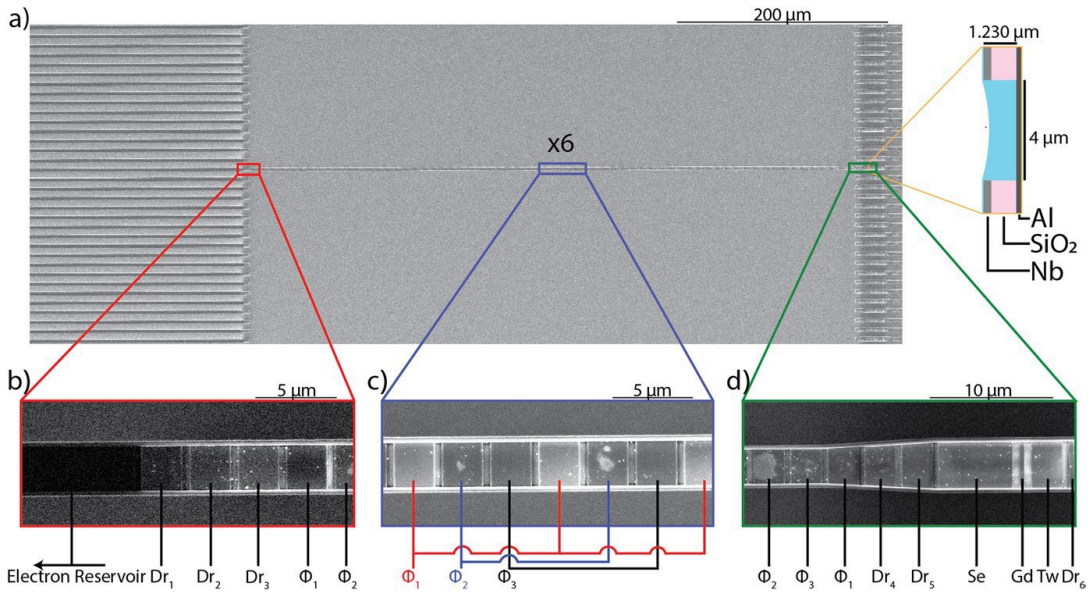

We report on low-frequency measurements of few electrons floating on superfluid helium using a bespoke cryogenic cascode amplifier circuit built with off-the-shelf GaAs high-electron-mobility transistors (HEMTs). We integrate this circuit with a charge-coupled device (CCD) to transport the electrons on helium and characterize its performance. We show that this circuit has a signal-to-noise ratio (SNR) of ~2 e/√Hz at 102 kHz, an order of magnitude improvement from previous implementations, and provides a compelling alternative to few electron sensing with high-frequency resonators.

Status: published work in Journal of Low Temperature Physics 2025, **219**, 242

Evolution of the Electronic Gap of Directly Synthesized Versus Mechanically Transferred WS_2 Monolayer to Multilayer Films

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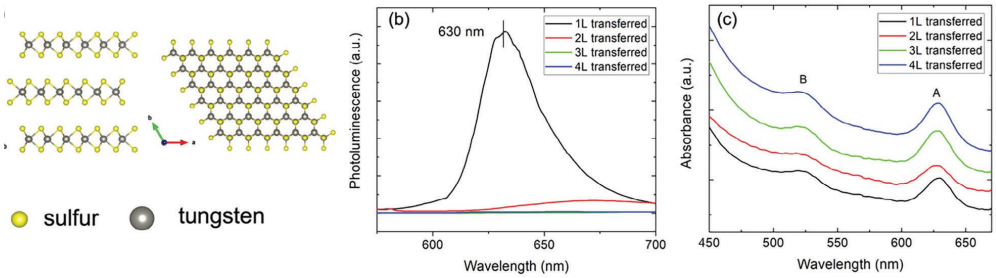

The electronic properties of 2D materials play a critical role in determining their potential for device applications. Despite rapid developments in 2D semiconductors, studies of fundamental electronic parameters, including the electronic gap and ionization energy, are limited, with significant discrepancies in reported values. The study focuses on tungsten disulfide (WS_2) and investigates the electronic structure of films comprising an increasing number of layers deposited with two different methods: direct synthesis via metal–organic chemical vapor deposition (MOCVD) and additive mechanical transfer of exfoliated single layers. The films are characterized via Raman, UV–vis, and photoluminescence spectroscopies, as well as ultraviolet photoelectron and inverse photoemission spectroscopies (UPS/IPES). The electronic gap of WS_2 is found to decrease from 2.43 eV for the monolayer to 1.97 eV for the trilayer, indicating a bulk transition at the trilayer thickness. This reduction in the electronic gap is primarily due to the downward shift of the conduction band minimum relative to the valence band maximum. A comparative analysis with MOCVD-grown WS_2 reveals a slightly larger electronic gap for MOCVD-grown samples, attributed to differences in defect densities. The electronic levels evaluated through UPS/IPES highlight the significant influence of preparation methods on the electronic properties of WS_2.

Status: published work in Adv. Mater. Interfaces 2025, **12**, 2401008

Evaporated organic–MoO_3 composite hole transport layers toward stable perovskite solar cells

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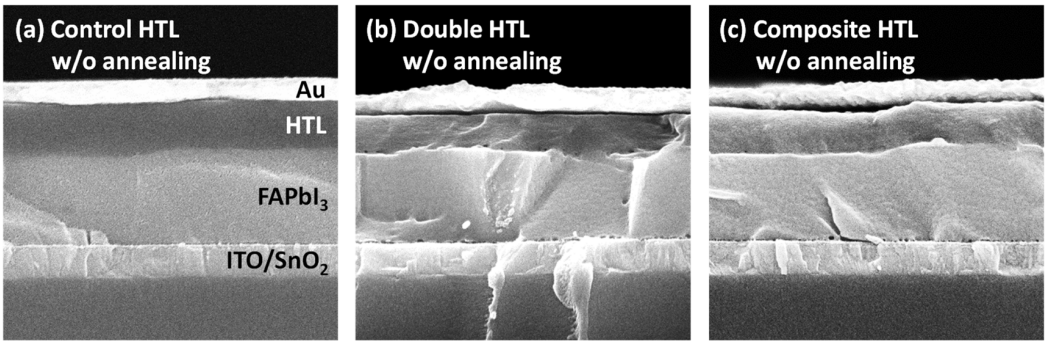

The release and diffusion of corrosive iodine species limits the stable operation of perovskite solar cells (PSCs). In this study, molybdenum trioxide (MoO_3) is employed for efficient oxidation of organic hole transport layers (HTLs), replacing the conventional dopant lithium bis(trifluoromethane)sulfonimide (LiTFSI) which compromises stability. Co-deposition of 2,2',7,7'-tetra(N,N-di-p-tolyl)amino-9,9-spirobifluorene (spiro-TTB) and MoO_3 via thermal evaporation produces a HTL with appropriate ionization energy of −5.06 eV, electrical conductivity of 6.02×10^{-5} S cm^{-1}, and homogeneous morphology. To investigate the stability of PSCs using the composite HTL, three types of PSCs with different HTLs are fabricated; the 2,2',7,7'-tetrakis[N,N-di(4-methoxyphenyl)amino]-9,9'-spirobifluorene (spiro-OMeTAD) control HTL with conventional dopants, the spiro-TTB:MoO_3 composite HTL, and the double HTL with doped spiro-OMeTAD and spiro-TTB:MoO_3 layers. The most efficient PSC with power conversion efficiency (PCE) of 21.3% is achieved by the double HTL. Since the efficient oxidation of spiro-TTB by MoO_3 and stable morphology under thermal stress mitigate iodine diffusion through the spiro-TTB:MoO_3 HTL, PSCs employing the composite HTLs demonstrate superior thermal stability, retaining 81% of their initial efficiency after 200 h aging at 85 °C.

Status: published work in EES Solar 2025, **1**, 107

Electrolytic gold plating, stripping, and ion transport dynamics through a solid-state iodide perovskite

Tuo Hu,[1] Ross A. Kerner,[2] Aishwarya Singh,[3] Yutong Ren,[1] Ayala V. Cohen,[3] Antoine Kahn,[1] Leeor Kronik,[3] Qiangfei Xia,[4] and Barry P. Rand[1,5]

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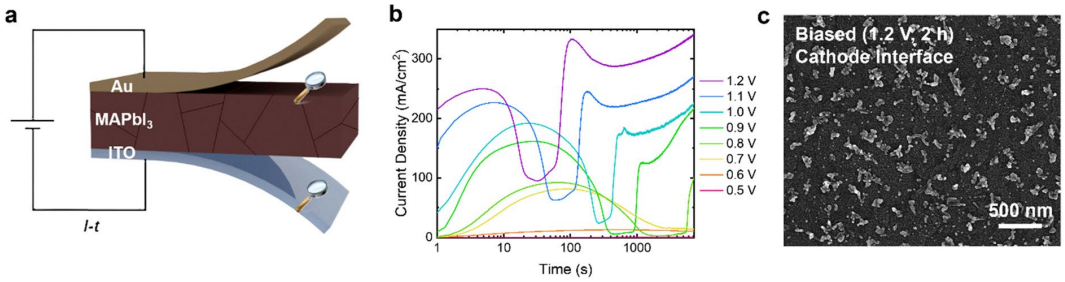

The pronounced electrochemical reactivity between halide perovskites and metal electrodes can introduce mobile extrinsic metal ions which can cause device instability or enable novel functionalities. Here we systematically investigate the kinetics of gold cation (Au+) migration in indium tin oxide (ITO)/methylammonium lead triiodide ($MAPbI_3$)/Au model devices under long-term potentiostatic biasing. Scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS), and density functional theory (DFT) analyses reveal that Au^+ ions, electrochemically generated at the Au anode, traverse the perovskite layer with diffusion coefficients on the order of 10^{-11} to 10^{-10} cm^2 s^{-1} and are subsequently reduced at the cathode as Au^0 clusters, resembling metal plating behavior in electrolytic cells and solid-state batteries during charging. Furthermore, reversing the applied bias strips the plated Au^0. Quantitatively determining diffusion coefficients and ion concentrations provides foundational inputs for future drift-diffusion modelling opportunities and allows us to relate our findings to implications on long term operation of devices like photovoltaic modules. These results clearly demonstrate the solid-state electrochemical nature of perovskite devices, highlight methods to be more quantitative about ion transport properties, emphasize the importance of disentangling electro-, photo-processes for understanding device performance and unlocking new functionalities.

Status: published work in Energy and Environmental Science 2025, **18**, 10483

Understanding the Structural Dynamics of 2D/3D Perovskite Interfaces

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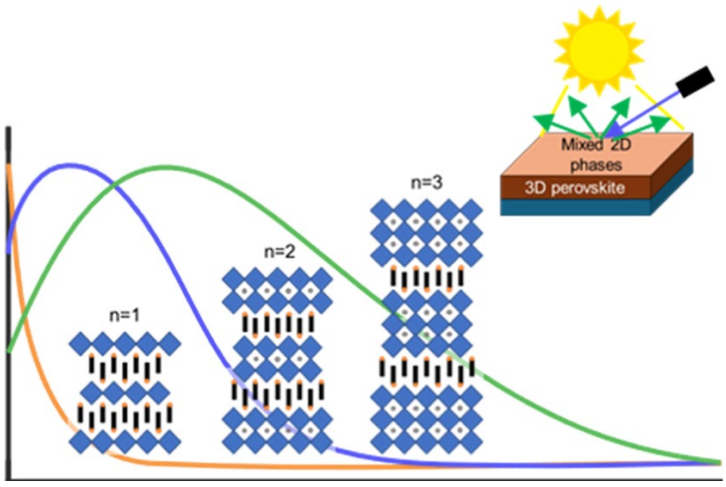

The use of 2D perovskite capping layers to passivate the surface defects of 3D perovskite active layers has become ubiquitous in high performance lead halide perovskite solar cells. However, these 2D/3D interfaces can be highly dynamic, with the structure evolving to form various mixed dimensional phases when exposed to thermal stress or illumination. Changes in the photoluminescence spectrum of formamidinium lead iodide ($FAPbI_3$) films capped with alkylammonium-based 2D perovskites as they age at 100 °C or under simulated 1 sun illumination indicate that the 2D perovskite transforms to progressively larger inorganic layer thicknesses (denoted by layer number n), eventually approaching a steady-state condition where only the 3D perovskite ($n = \infty$) is detectable. We find that this transformation slows by a factor of ~2 when the length of the alkyl chain in the organic monoammonium ligand is increased from butylammonium to dodecylammonium. Furthermore, replacing dodecylammonium with its diammonium ligand counterpart, 1,12-dodecanediammonium, slows the structural transformation by 10-fold. These results point to the use of diammonium ligands as a possible pathway to form stable 2D/3D interfaces.

Status: published work in ACS Appl. Mater. Interfaces 2025, **17**, 16963

Subnanosecond Electrical Control of Dipolariton-Based Optical Circuits with a Few Femtojoule per Bit Power Consumption

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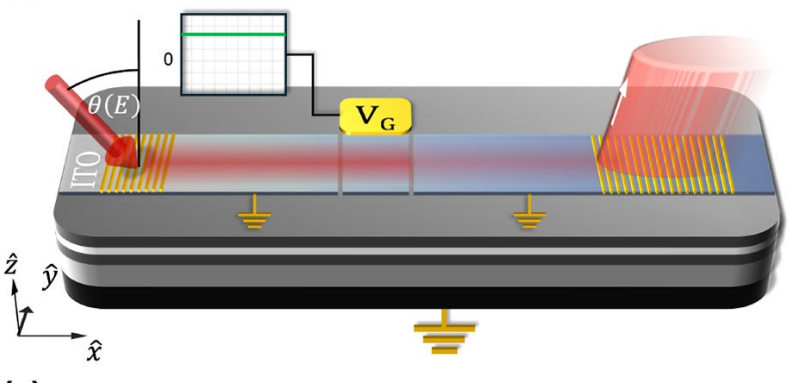

The next generation of photonic circuits will require programmable, subnanosecond, and energy-efficient components on a scalable platform for quantum and neuromorphic computing. Here, we present subnanosecond electrical control of highly nonlinear light−matter hybrid quasi-particles, called waveguide exciton-dipolaritons, in a highly scalable waveguide-on-chip geometry, and with extremely low power consumption. Our device performs as an optical transistor with a GHz-rate electrical modulation at a record-low total energy consumption <8 fJ/bit and a compact active area of down to 25 μm^2. This work establishes waveguide-dipolariton platforms for scalable, electrically reconfigurable, ultralow power photonic circuits for both classical and quantum computing and communication.

Status: published work in Nano Letters 2025, **25**, 12503

Nanoscale diamond quantum sensors for many-body physics

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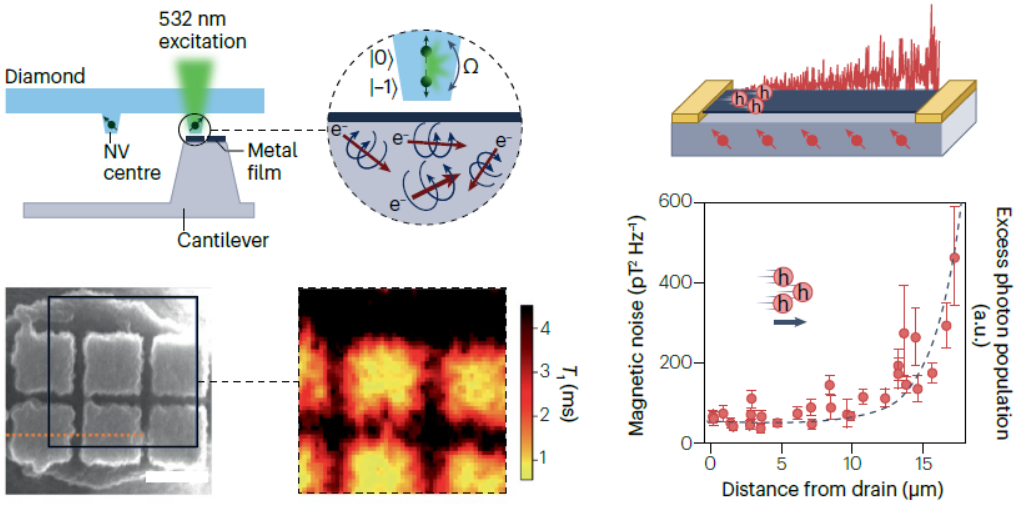

Nitrogen vacancy (NV) centre quantum sensors provide unique opportunities in studying condensed matter systems, as they are quantitative, non-invasive, physically robust, offer nanoscale resolution and may be used across a wide range of temperatures. These properties have been exploited in recent years to obtain nanoscale resolution measurements of static magnetic fields arising from spin order and current flow in condensed matter systems. Compared with other nanoscale magnetic-field sensors, NV centers have the advantage that they can probe quantities that go beyond average magnetic fields. Leveraging techniques from magnetic resonance, NV centres can perform high-precision noise sensing and have given access to diverse systems, such as fluctuating electrical currents in simple metals and graphene, as well as magnetic dynamics in yttrium iron garnet. In this Technical Review, we provide an overview of NV sensing platforms and modalities and discuss the connections between specific NV measurements and important physical characteristics in condensed matter, such as correlation functions and order parameters, that are inaccessible by other techniques. We conclude with our perspectives on the new insights that may be opened up by NV sensing in condensed matter.

Status: published work in Nature Review Physics 2025, **6**, 753

Spin-Photon Entanglement of a Single Er^{3+} Ion in the Telecom Band

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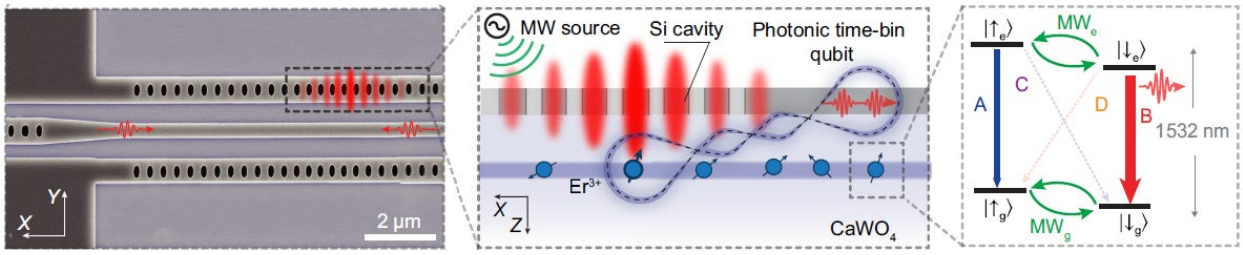

Entanglement between photons and a quantum memory is a key component of quantum repeaters, which allow long-distance quantum entanglement distribution in the presence of fiber losses. Spin-photon entanglement has been implemented with a number of different atomic and solid-state qubits with long spin coherence times, but none directly emit photons into the 1.5-μm telecom band where losses in optical fibers are minimized. Here, we demonstrate spin-photon entanglement using a single rare earth ion in the solid-state Er^{3+} coupled to a silicon nanophotonic cavity, which directly emits photons at 1532.6 nm. We infer an entanglement fidelity of 73(3)% after propagating through 15.6 km of optical fiber. This work opens the door to large-scale quantum networks based Er^{3+} ions, leveraging scalable silicon device fabrication and spectral multiplexing.

Status: published work in Physical Review X 2025, **15**, 011071

Partial Substitution of Er and V or Er and Nb into the $CaWO_4$ Scheelite

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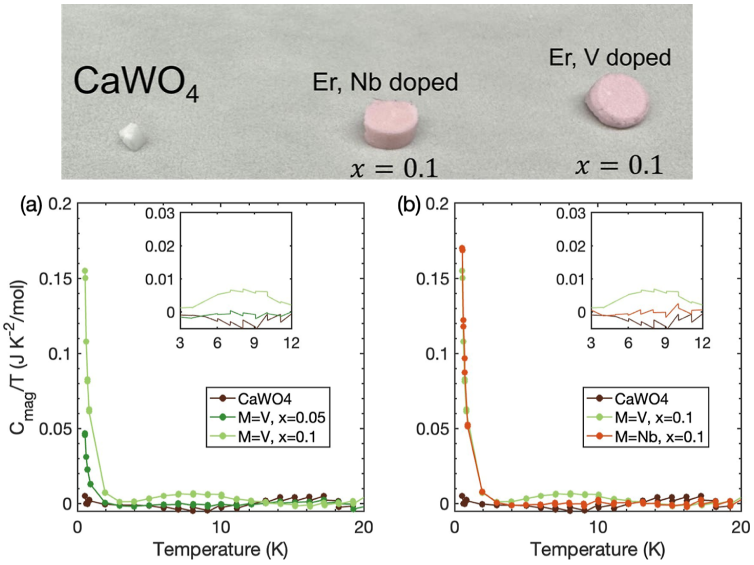

We successfully synthesized the erbium (Er)-doped optical material calcium tungstate ($CaWO_4$) while maintaining charge balance by codoping Er with vanadium (V^{5+}) and niobium (Nb^{5+}) into the optical material calcium tungstate ($CaWO_4$). The synthesized samples, with the general formula $Ca_{1-x}Er_xW_{1-x}M_xO_4$ (M = V or Nb), were annealed at 1200 °C in air. Er^{3+} dopants introduced localized visible−light transition states within the band gap, thus adding pink hues to the white $CaWO_4$ for both codoping systems. Phase-pure materials were obtained up to the doping levels of x = 0.10, beyond which impurity peaks in powder X-ray diffraction patterns emerged. Reduction in lattice constants and grain sizes due to dopant substitution was observed. No evidence was seen for long-range magnetic ordering above 0.5 K, and the local crystal field of Er^{3+} was different for the two codopants. Charge-compensated codoping is thus shown to be an effective strategy for tailoring scheelite optical properties.

Status: published work in Inorganic Chemistry 2025, **64**, 15680

Department of Ecology and Evolutionary Biology

Hidden white and black feather layers enhance plumage coloration in tanagers and other songbirds

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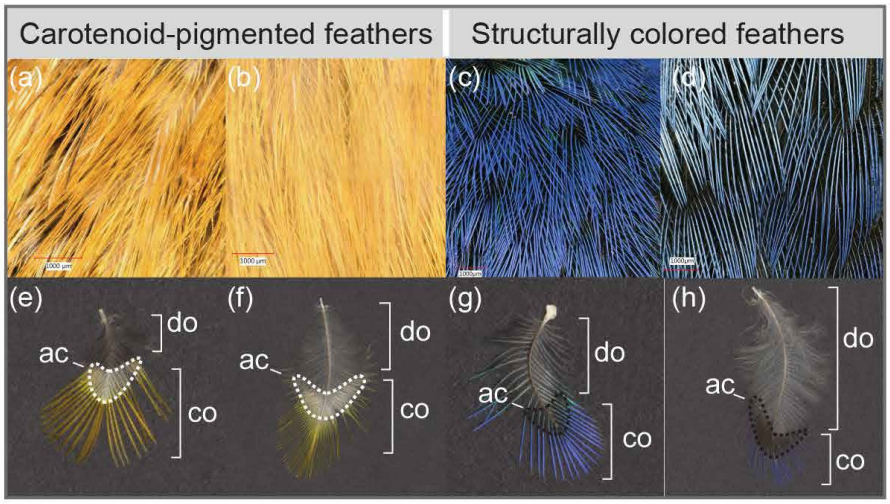

Birds are renowned for their diverse and colorful plumage. Here, we demonstrate that vibrant plumage in the tanager genus Tangara is substantially intensified by a "hidden" layer of achromatic (white or black) plumage concealed beneath the outermost colorful layer. Using hyperspectral imaging, multispectral photography, microspectrophotometry, reflectance spectrophotometry, and optical modeling, we show that hidden white and black feather layers are systematically distributed on the body to enhance the brightness and saturation of carotenoid-pigmented and structurally colored plumage, respectively, by increasing or decreasing the amount of backscattered light that interacts with pigments or nanostructures. We compare male and female coloration and show that sexual dichromatism in some Tangara carotenoid plumage stems primarily from white layers in males and black layers in females rather than from differences in carotenoid pigmentation. Last, we find that white and black hidden feather layers are widespread in colorful passerines. Hidden feather layers likely play a previously overlooked but critical role in colorful plumage evolution in birds.

Status: published work in Science Advances 2025, **11**, eadw5857

Lewis-Sigler Institute for Integrative Genomics

Morphogenesis of bacterial cables in polymeric environments

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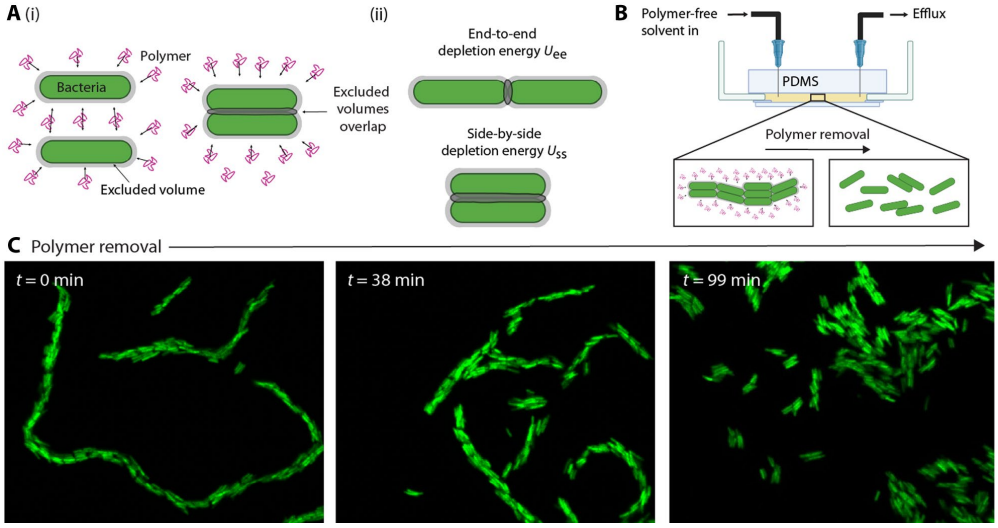

Many bacteria live in polymeric fluids, such as mucus, environmental polysaccharides, and extracellular polymers in biofilms. However, laboratory studies typically focus on cells in polymer-free fluids. Here, we show that interactions with polymers shape a fundamental feature of bacterial life—how they proliferate in space in multicellular colonies. Using experiments, we find that when polymer is sufficiently concentrated, cells generically and reversibly form large serpentine “cables” as they proliferate. By combining experiments with biophysical theory and simulations, we demonstrate that this distinctive form of colony morphogenesis arises from an interplay between polymer-induced entropic attraction between neighboring cells and their hindered ability to diffusely separate from each other in a viscous polymer solution. Our work thus reveals a pivotal role of polymers in sculpting proliferating bacterial colonies, with implications for how they interact with hosts and with the natural environment, and uncovers quantitative principles governing colony morphogenesis in such complex environments.

Status: published work in Science Advances 2025, **11**, eadq7797

Department of Mechanical and Aerospace Engineering

Bacterial spores respond to humidity similarly to hydrogels

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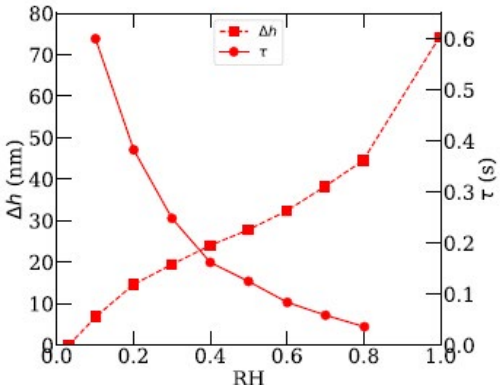

Bacterial spores have outstanding properties from the materials science perspective, which allow them to survive extreme environmental conditions. Recent work by studied the mechanical properties of Bacillus subtilis spores and the evolution of these properties with the change of humidity. The experimental measurements were interpreted assuming that the spores behave as water-filled porous solids, subjected to hydration forces. Here, we revisit their experimental data using literature data on vapor sorption on spores and ideas from polymer physics. We demonstrate that upon the change of humidity, the spores behave like rubber with respect to their swelling, elasticity, and relaxation times. This picture is consistent with the knowledge of the materials comprising the bacterial cell walls—cross-linked peptidoglycan. Our results provide an interpretation of the mechanics of bacterial spores and can help in developing synthetic materials mimicking the mechanical properties of the spores.

Status: published work in Proc. Nat. Acad. Sci. 2024, **121**, e2320763121

Laser Upcycling of Hemoglobin Protein Biowaste into Engineered Graphene Aerogel Architectures for 3D Supercapacitors

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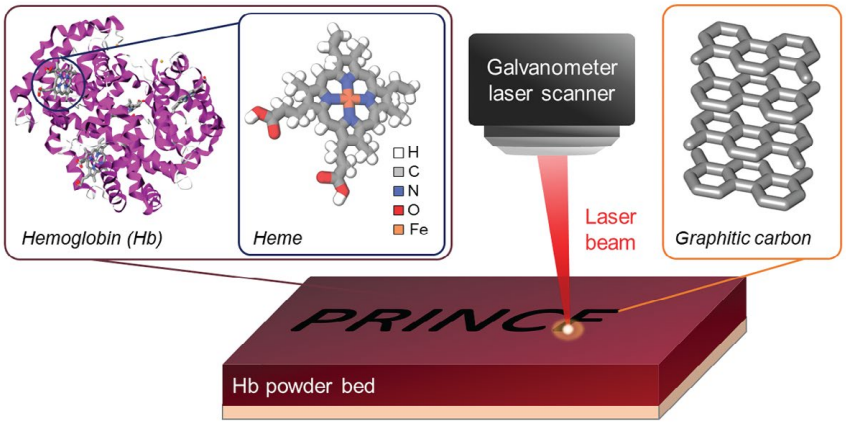

Graphene aerogels (GAs) with engineered architectures are a promising material for applications ranging from filtration to energy storage/conversion. However, current preparation approaches involve the combination of multiple intrinsically-different methodologies to achieve graphene-synthesis and architecture-engineering, complicating the entire procedure. Here, a novel approach to prepare GAs with engineered architectures based on the laser-upcycling of protein biowaste, hemoglobin, is introduced. Laser scanning achieves graphene-synthesis concurrently with architecture-engineering through the localized graphitization of hemoglobin along the laser-scan path, enabling the direct preparation of engineered GAs. The laser-upcycled GAs are uniquely decorated with fibrous graphitic structures, which significantly improves the surface area. By leveraging the high electrical conductivity and unique structural morphology, the laser-upcycled GAs are applied as electrodes of symmetrical 3D supercapacitors. The fabricated supercapacitors exhibited a high specific capacitance (≈54.9 F g^{-1}) and excellent cycle stability (≈94% retention), attributable to the laser-engineered architecture facilitating ion diffusion even for thick electrodes. Not only does this study provide a novel approach to prepare GAs with engineered architectures but showcases the potential of laser-upcycling in preparing advanced functional materials for future devices.

Status: published work in Advanced Science 2025, **12**, 2412588

Three-dimensional carbon fiber networks with self-orienting nano-textures enabled by femtosecond laser processing

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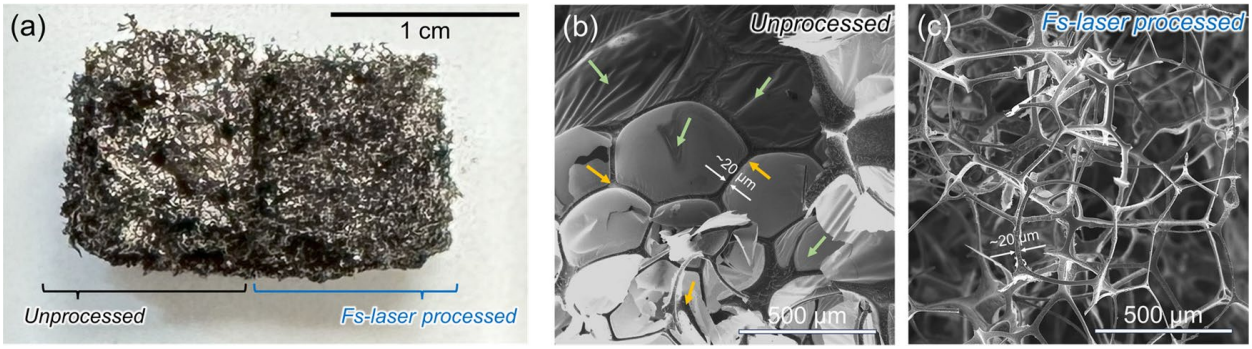

Here, an interconnected three-dimensional (3D) network of carbon fibers possessing nano-scaled ripples, or laser-induced periodic surface structures (LIPSS), is fabricated via laser processing with an 800-nm femtosecond laser. The unique architecture of the CF network realizes the coexistence of both ~800-nm low-spatial frequency LIPSS (LSFL) and ~100-nm high-spatial frequency LIPSS (HSFL) overlapping on the same fiber surface. It is suggested that LSFL formed through the interference with Fresnel diffraction patterns projected by the fiber edges, while HSFL formed through LSFL-splitting assisted by surface plasmons. Moreover, the fundamentally different formation mechanisms of the two types result in distinctively different LIPSS orientations, where the LSFL is structure-dependent and self-orients according to the fiber propagation direction, while the HSFL is structure-independent and self-orients perpendicularly to the polarization direction of the incident pulses. The findings not only introduce an optical approach to prepare nano-textured carbon materials for future energy and regenerative medicine applications but also reveal important insights into the underlying formation mechanisms of LIPSS on complex three-dimensional surfaces.

Status: published work in Applied Physics Letters 2025, **126**, 041601

Freeform monolithic graphitic aerogels by laser pyrolysis of pretreated blood-derived feedstocks

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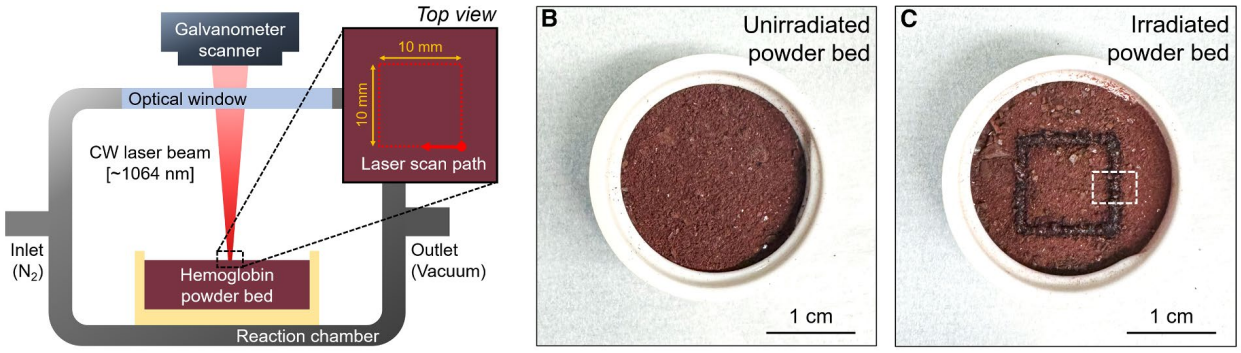

While 3D-printed graphitic aerogels (GAs) offer broad applications, existing manufacturing methods face limitations in scalability and material performance. This study presents a two-step laser pyrolysis strategy for the rapid direct manufacturing of freeform monolithic GAs using hemoglobin, a renewable biowaste-derived feedstock. Through targeted precursor pretreatment and digitally controlled laser processing, ultralightweight GAs with interconnected ultrathin sheets and denser strut-like boundaries are produced. Despite their low density, these GAs exhibit remarkable properties owing to their high graphitic crystallinity and seamless architecture, achieving rapid and stable Joule heating with superior efficiency (~137.43◦C W^{-1}), ideal for deicing applications. The programmable laser process enables geometry-customizable fabrication, allowing material and energy-efficient design optimization for next-generation automotive and aerospace systems. This work highlights the critical role of transient-state control in tuning structure-property relationships and establishes pretreatment as a powerful yet underexplored strategy for scalable sustainable manufacturing of high-performance architected carbon materials from renewable feedstocks.

Status: published work in Matter 2025, **8**, 102432

Powder-bed-fusion-inspired additive manufacturing of freeform graphene aerogels via laser upcycling of biowaste hemoglobin protein

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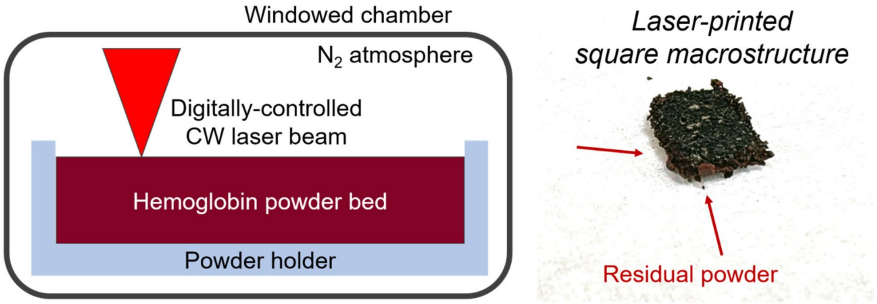

Three-dimensional (3D) cellular monoliths of graphitic materials, or graphitic aerogels (GAs), exhibit unique material properties offering applications in catalysis and energy storage. While conventional solution-based techniques enable the mass-production of GAs, the resulting features are highly randomized, and architecture-tunability had remained a challenge. Recently, the use of additive manufacturing (AM) towards the 3D printing of freeform GAs has been explored. In this study, we demonstrate the laser-based 3D printing of freeform GAs by employing the concept of laser-based powder bed fusion (PBF) using hemoglobin as the feedstock material, an iron-containing protein found in red-blood cells. Hemoglobin is an abundantly available biomass that is a common biowaste of the meat industry. Analogous to conventional PBF, a bed of the low-value biowaste was deposited, and subsequently irradiated to convert and assemble a 3D cellular monolith composed of turbostratic graphite. This process can be easily scaled up by simply depositing another layer of hemoglobin powder and subsequently scanning the laser beam. Through the repetition of these steps, a 3D macrostructure with arbitrary micro-scaled cellular geometries can be printed through a layer-by-layer approach. The laser printed macrostructures exhibited a low density, high electrical conductivity, and high surface area, suitable for energy-storage applications. The current PBF-inspired technique offers the freeform printing of GAs without any additional templates, binders, or chemical solutions, and the renewable resource, hemoglobin, is the only raw material required for the entire printing process.

Status: published work in Proceedings of SPIE 2025, **13350**, 1335006

Revealing Actual Viscoelastic Relaxation Times in Capillary Breakup

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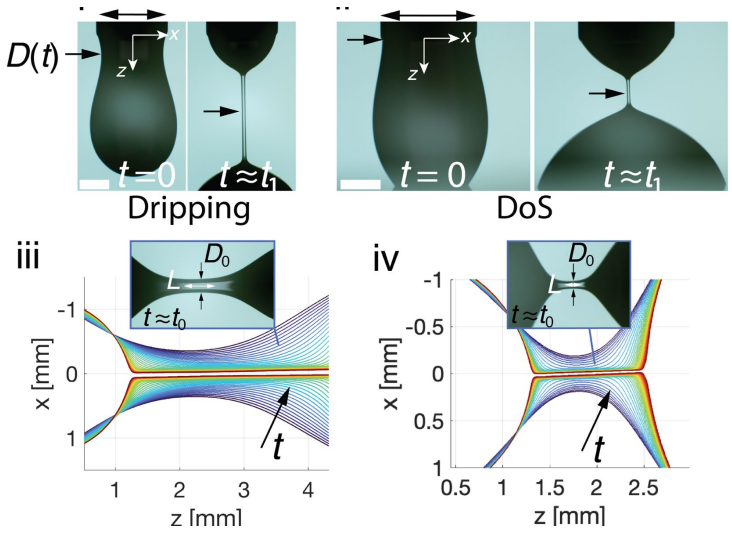

We use experiments and theory to elucidate the size effect in capillary breakup rheometry, where prestretching in the viscocapillary stage causes the apparent relaxation time to be consistently smaller than the actual value. We propose a method accounting for both the experimental size and the finite extensibility of polymers to extract the actual relaxation time. A phase diagram characterizes the expected measurement variability and delineates scaling law conditions. The results refine capillary breakup rheometry for viscoelastic fluids and advance the understanding of breakup dynamics across scales.

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Surface Furrowing Instability in Everting Soft Solids

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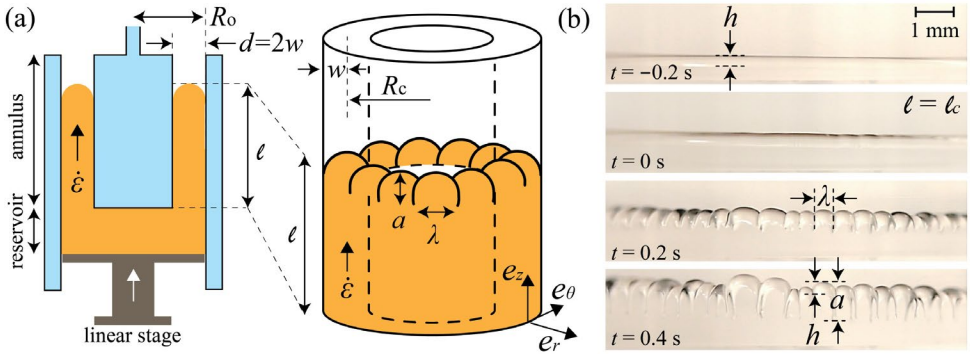

We report a surface instability observed during the extrusion of extremely soft elastic solids in confined geometries. Because of their unique rheological properties, these soft solids can migrate through narrow gaps by continuously everting the bulk material. The extrusion front spontaneously buckles in the direction transverse to the flow, resulting in a furrowlike morphology that deepens over time. We characterize the distinct features of this instability using experiments and theory and contrast the results with known elastic surface instabilities. Our Letter may provide insights into various processes involving the extrusion-like deformations of soft solids, including biomaterials.

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Electrically mediated self-assembly and manipulation of drops at an interface

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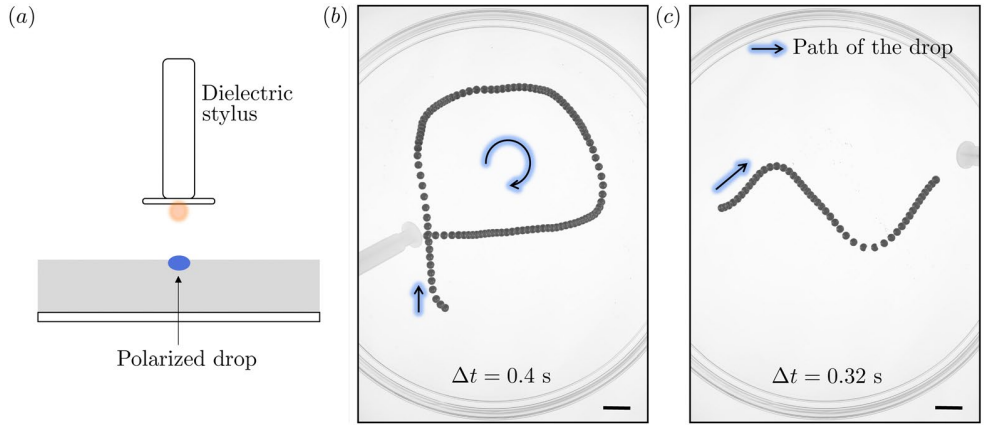

The fluid–fluid interface is a complex environment for a floating object where the statics and dynamics may be governed by capillarity, gravity, inertia, and other external body forces. Yet, the alignment of these forces in intricate ways may result in beautiful pattern formation and self-assembly of these objects, as in the case of crystalline order observed with bubble rafts or colloidal particles. While interfacial self-assembly has been explored widely, controlled manipulation of floating objects, e.g. drops, at the fluid–fluid interface still remains a challenge largely unexplored. In this work, we reveal the self-assembly and manipulation of water drops floating at an oil–air interface. We show that the assembly occurs due to electrostatic interactions between the drops and their environment. We highlight the role of the boundary surrounding the system by showing that even drops with a net zero electric charge can self-assemble under certain conditions. Using experiments and theory, we show that the depth of the oil bath plays an important role in setting the distance between the self-assembled drops. Furthermore, we demonstrate ways to manipulate the drops actively and passively at the interface.

Status: published work in Soft Matter 2024, **20**, 5417

Microfiber suspensions for the removal of adhered colloids from surfaces, microdevices, and cavities

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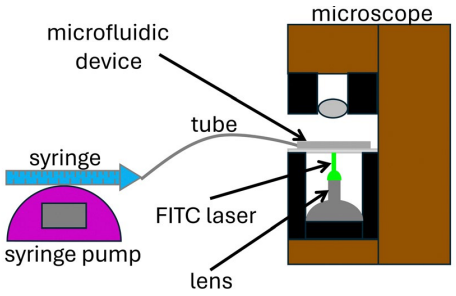

Effective methods for cleaning surfaces are important for applications including dentistry, healthcare, micro-devices, and the manufacturing of electronic components and semiconductors. For example, surgical and dental instruments are susceptible to accumulation of aggregates and biofilm formation, which can lead to cross-contamination. Complex fluids such as micro-fibrillated cellulose (MFC) can assist in mechanically cleaning surfaces by removing strongly adhered aggregates without abrading the underlying material. We demonstrate that the heterogeneous structure of micro-fibrillated cellulose is effective in removing adhered particulates from surfaces and we characterize the cleaning efficiency of MFC suspensions in representative flow configurations. The experiments reported here involve flowing MFC solutions through a rectangular microfluidic channel. Fluorescence microscopy is used to measure the removal of fluorescent particles that are adhered to the glass surface of the microfluidic device by electrostatic and surface forces. The particle removal with time is analyzed for each concentration of the MFC suspension and each shear rate to determine cleaning effectiveness. The rheology of the MFC solutions is also characterized and correlated to cleaning performance. We find that cleaning effectiveness increases with increasing fiber concentration and with increasing shear rate. Additionally, we compared the cleaning performance of the MFC suspensions with fluids that share similar rheological properties. Finally, we examine how sharp corners/edges within a microfluidic channel hinder cleaning and identify strategies for mitigating this hindrance.

Status: published work in Soft Matter 2025, **21**, 3304

Fiber formation mechanisms of jet-assisted wet spinning (JAWS)

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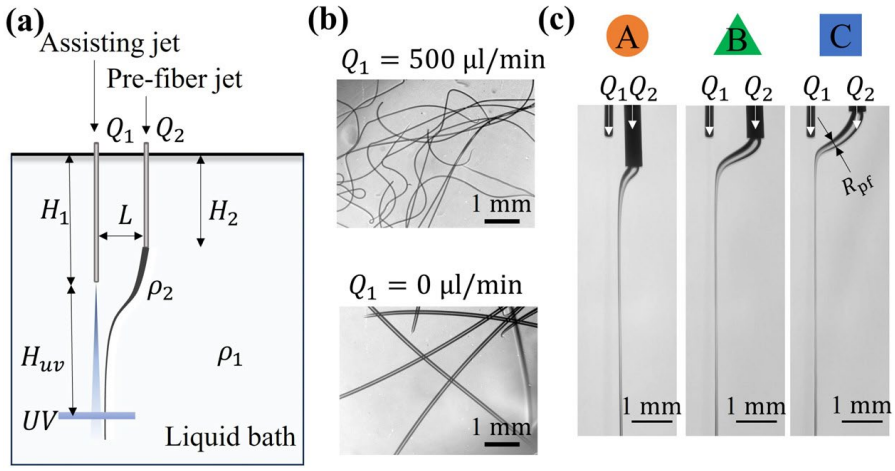

In fiber spinning of photopolymers, surface tension limits the diameter of the fiber that can be produced due to the Rayleigh–Plateau instability. Submerging a pre-fiber jet in a miscible environment liberates the system from capillary effects, thus allowing the jet to be stretched into thin threads without instability. In this work, we systematically investigated a spinning method using miscible liquids, called jet-assisted wet spinning (JAWS), where stretching is achieved by a nearby submerged liquid jet. The diameter of the pre-fiber jet is a function of its flow rate and position relative to the assisting submerged liquid jet. A particular case where the main jet is modeled as the Landau–Squire jet is used to demonstrate the tracer-like thinning behavior of the pre-fiber jet. Experiments show that buoyancy has a significant impact on the pre-fiber jet diameter because of its influence on the entrainment trajectory. Overall, our results demonstrate the potential for the parallelization of JAWS for high-throughput fiber production.

Status: published work in Applied Physics Letters 2024, **125**, 241601

Room-Temperature Aerosol Dehydration of Green Fluorescent Protein

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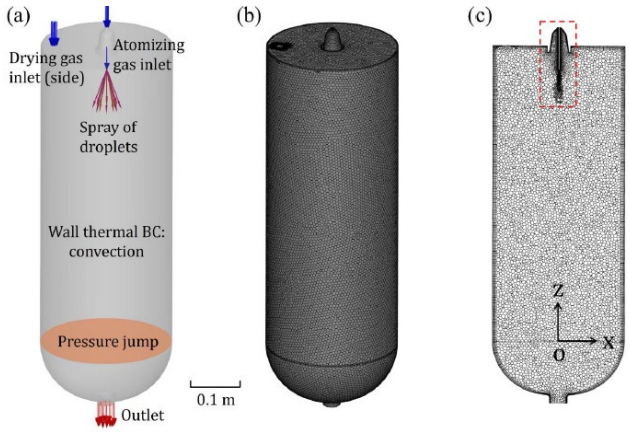

Rapid Room-Temperature Aerosol Dehydration (RTAD) is a novel, scalable drying technology for powderization and thermal stabilization of pharmaceutical drug products. Compared to conventional spray drying processes, typically using droplets of 10–200 μm in diameter generated by high-shear spraying, RTAD uses much smaller droplets with diameter 0.1 to 20 μm produced in modified liquid atomization processes. These fine droplets evaporate rapidly within 10–100 ms under room-temperature conditions, thereby reducing drying-induced stresses for thermally sensitive biologics. In this study, we used Green Fluorescent Protein (GFP) as a model biological molecule to optimize the design of the RTAD system and the process parameters. We experimentally investigated the effects of droplet size, multiphase flow patterns in the drying chamber, and application of polysorbate 20 as a model surfactant on GFP fluorescence after drying and powder reconstitution. The experiments demonstrated that the presence of surfactant in the formulation significantly influenced the GFP fluorescence intensity. The numerical studies using Computational Fluid Dynamics simulations revealed that the drying of droplets was dependent on the patterns of multiphase flow in the drying chamber. Through iterative optimization of the chamber design, process parameters and feedstock formulation, we achieved recovery of the GFP fluorescence intensity that exceeded 96% in the obtained dry powders. This work establishes GFP as a sensitive model biologic and its fluorescence intensity as a powerful tool to rapidly assess process efficiency and the ability to preserve bioactivity after dehydration.

Status: published work in Drying Technology 2025, **43**, 2068

A calibration-free model of micropipette aspiration for measuring properties of protein condensates

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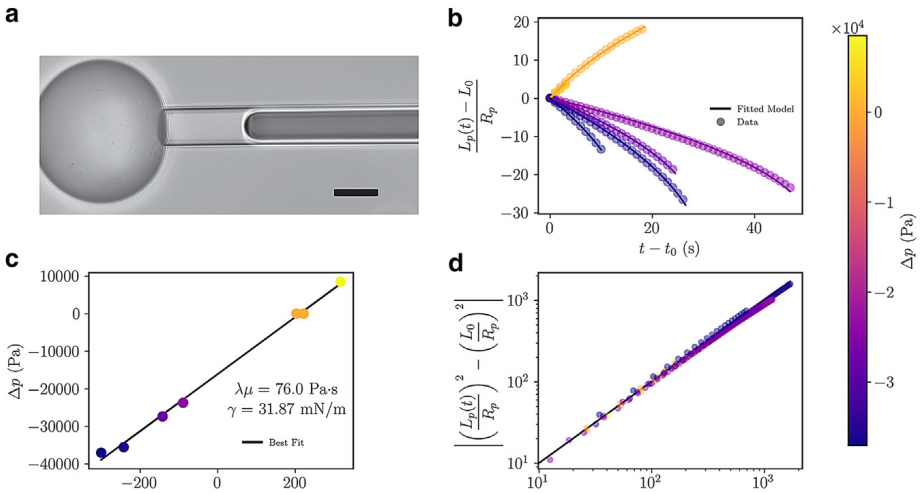

There is growing evidence that biological condensates, which are also referred to as membraneless organelles, and liquid-liquid phase separation play critical roles regulating many important cellular processes. Understanding the roles these condensates play in biology is predicated on understanding the material properties of these complex substances. Recently, micropipette aspiration (MPA) has been proposed as a tool to assay the viscosity and surface tension of condensates. This tool allows the measurement of both material properties in one relatively simple experiment. While this technique has been commonly used in the literature to determine the material properties of membrane-bound objects dating back decades, the model describing the dynamics of MPA for objects with an external membrane does not correctly capture the hydrodynamics of unbounded fluids, leading to a calibration parameter several orders of magnitude larger than predicted. In this work we derive a new model for MPA of biological condensates that does not require any calibration and is consistent with the hydrodynamics of the MPA geometry. We validate the predictions of this model by conducting MPA experiments on a standard silicone oil of known material properties and are able to predict the viscosity and surface tension using MPA. Finally, we reanalyze with this new model the MPA data presented in previous works for condensates formed from LAF-1 RGG domains.

Status: published work in Biophysical Journal 2024, **123**, 1393

Translation of a sphere towards a rigid plane in an Oldroyd-B fluid

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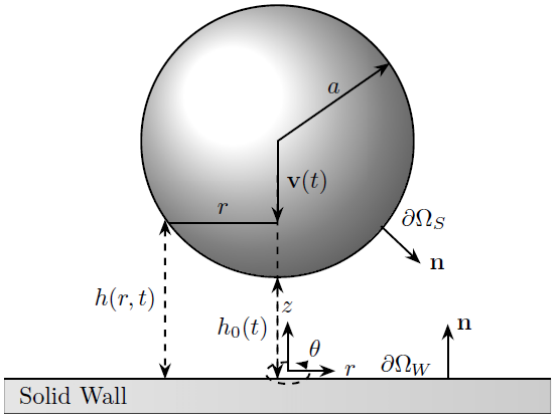

We analyze the low-Reynolds-number translation of a sphere towards or away from a rigid plane in an Oldroyd-B fluid under two scenarios: prescribing the sphere's translational velocity, and prescribing the force on the sphere. Leveraging the lubrication approximation and a perturbation expansion in powers of the Deborah number, we develop a comprehensive theoretical analysis that yields analytical approximations for velocity fields, pressures, and forces acting on the sphere. Our framework aids in understanding temporal microstructural changes as the particle-wall gap evolves over time. For cases with prescribed velocity, we present a theoretical approach for calculating resistive forces at any order in the Deborah number and utilize a reciprocal theorem to obtain higher-order corrections based on velocity fields in the previous orders. When the sphere translates with a constant velocity, the fluid viscoelasticity decreases the resistive force at the first order. However, at the second-order correction, the direction of the sphere's movement determines whether viscoelasticity increases or decreases the resistive force. For cases with prescribed force, we show that understanding the influence of viscoelasticity on the sphere's translational velocity necessitates a more intricate analysis. Specifically, we introduce an ansatz for constant force scenarios, and we derive solution forms for general prescribed forces using the method of multiple scales. We find that when a sphere undergoes sedimentation due to its own weight, the fluid viscoelasticity results in a slower settling process, reducing the leading-order sedimentation rate.

Status: published work in Physical Review Fluids 2024, **9**, 083303

Laser driven melt pool resonances through dynamically oscillating energy inputs

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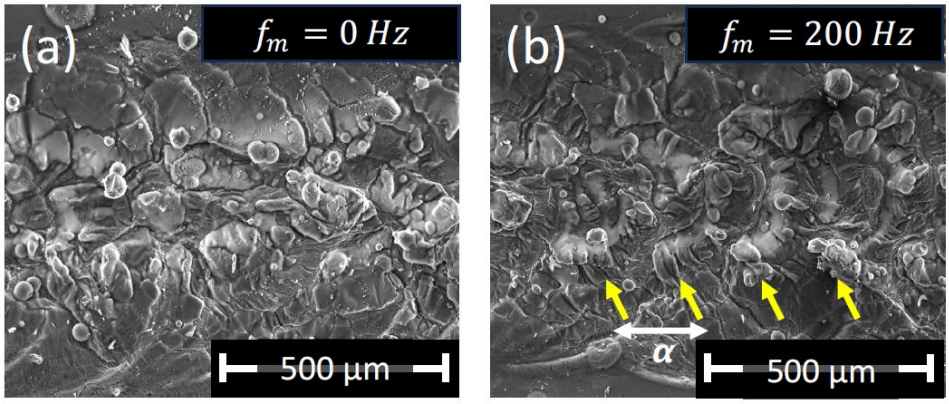

Spatially selective melting of metal materials by laser irradiation allows for the precise welding as well as the 3D printing of complex metal parts. However, the simple scanning of a conventional Gaussian beam typically results in a melt track with randomly distributed surface features due to the complex and dynamic behavior of the melt pool. In this study, the implications of utilizing a dynamically oscillating energy input on driving melt track fluctuations is investigated. Specifically, the laser intensity and/or intensity distribution is sinusoidally modulated at different scan speeds, and the effect of modulation frequency on the resulting surface features of the melt track is examined. The formation of periodically oriented surface features indicates an evident frequency coupling between the melt pool and the modulation frequency. Moreover, such a frequency coupling becomes most prominent under a specific modulation frequency, suggesting resonant behavior. The insights provided in this study will enable the development of novel methods, allowing for the control and/or mitigation of inherent fluctuations in the melt pool through laser-driven resonances.

Status: published work in Journal of Manufacturing Processes 2024, **131**, 1624

Engineering Cellular Self-Adhesions Inside 3D Printed Micro-Arches to Enhance Cell: Biomaterial Attachment

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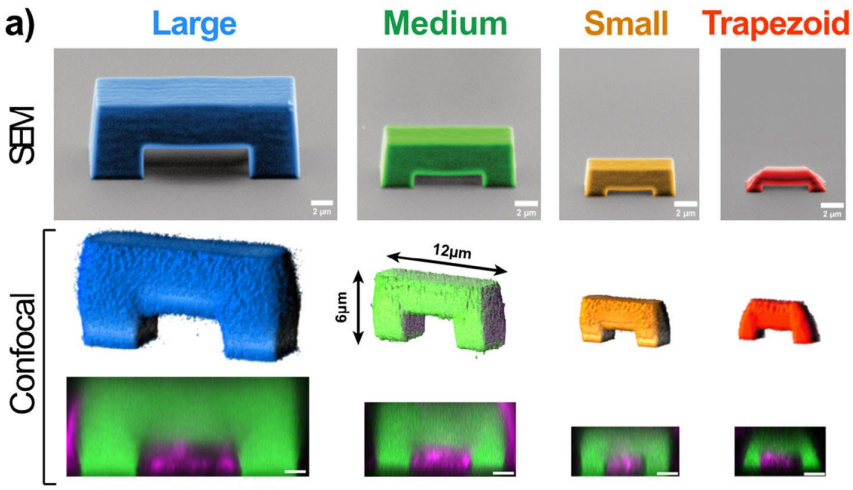

A cell can bind to itself and form a self-adhesion that can be engineered and harnessed as a new way to adhere cells to engineered materials–a key challenge for biomaterials are demonstrated. Here, a 3D structure smaller is developed than a single cell, that a Self-Adhesion-Tunnel (SAT) is called, that causes cells to wrap around it and bind to themselves. This process is driven through the cadherin proteins that regulate cell-cell adhesion, and it is shown that many of the key elements of a normal cell-cell adhesion are found in self-adhesions. Size and shape of the SAT determine the efficiency of self-adhesion formation, and >90% efficient formation of self-adhesions are observed in both kidney and skin cells per SAT. Self-adhesions can persist for at least 24 hrs and act to stabilize the cell-material interface and reduce migration. Overall, this ability to co-opt the native cell-cell adhesion machinery in cells and use it as an attachment strategy can provide new approaches for soft-tissue implant integration and tissue engineering scaffolds where stable tissue-material interfaces are critical.

Status: published work in Advanced Materials 2025, **37**, 2502425

Highly elastic fibers in a shear flow can form double helices

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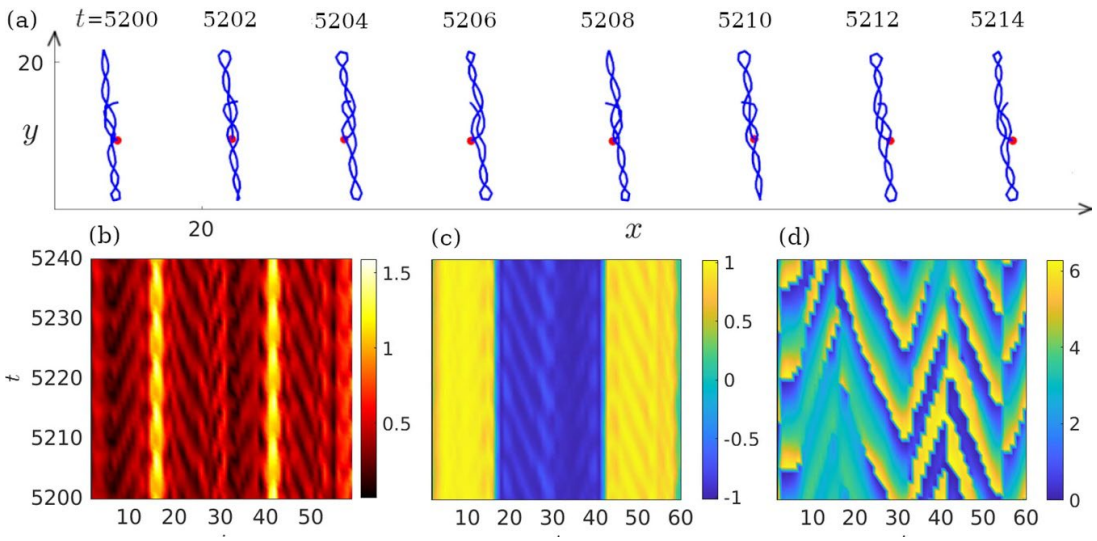

The long-time behavior of highly elastic fibers in a shear flow is investigated experimentally and numerically. Characteristic attractors of the dynamics are found. It is shown that for a small ratio of bending to hydrodynamic forces, most fibers form a spinning elongated double helix, performing an effective Jeffery orbit very close to the vorticity direction. Recognition of these oriented shapes, and how they form in time, may prove useful in the future for understanding the time history of complex microstructures in fluid flows and considering processing steps for their synthesis.

Status: published work in New Journal of Physics 2024, **26**, 073011

Hierarchically Porous Graphitic Aerogels via Thermal Morphogenesis of Proteins for Environmental Remediation

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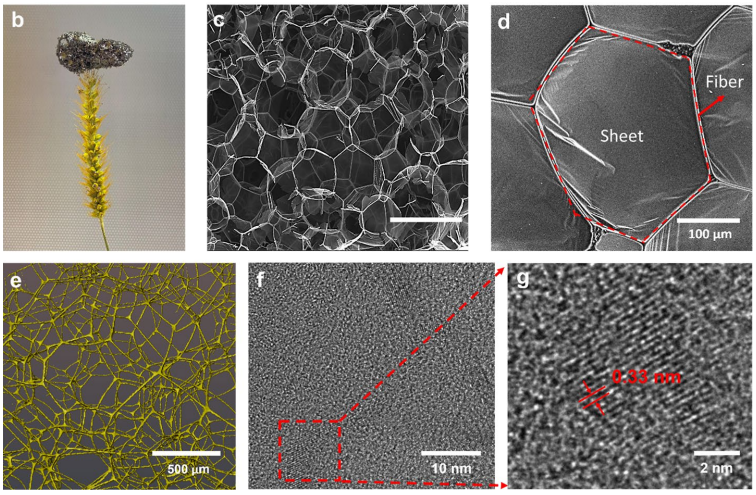

Hierarchically porous monolithic graphitic sheet-based aerogels (HGA) with high surface area and ultralow density have drawn massive attention for applications in catalysis, energy storage/conversion, water purification, and beyond. However, syntheses of these materials rely on harsh and nonsustainable chemical reagents and/or template-based methods, while the resulting structures generally lack covalent integration, compromising their properties. Herein, we demonstrate a self-foaming mechanism for green and scalable synthesis of HGA using protein precursors. The controlled heating of protein induces intrinsic foaming via softening, gas evolution, and carbonization/graphitization, resulting in an HGA composed of a sheet and fiber-like framework. Our investigation of processing-structure−property relationships elucidates the interplay between synthesis variables and aerogel structure/properties, enabling deliberate control over microstructural features. Notably, we demonstrate more than an order-of-magnitude variation in density and over a 7-fold increase in compressive strength by controlling the synthesis protocol. This study opens doors to a green and scalable approach to synthesizing HGAs with customizable microstructures and properties, making them promising for a broad spectrum of applications such as environmental remediation and energy storage.

Status: published work in ACS Appl. Nano Mater. 2025, **8**, 8464

Department of Molecular Biology

Phrixotoxin-3 binds to three distinct antagonistic sites on human $Na_v1.6$

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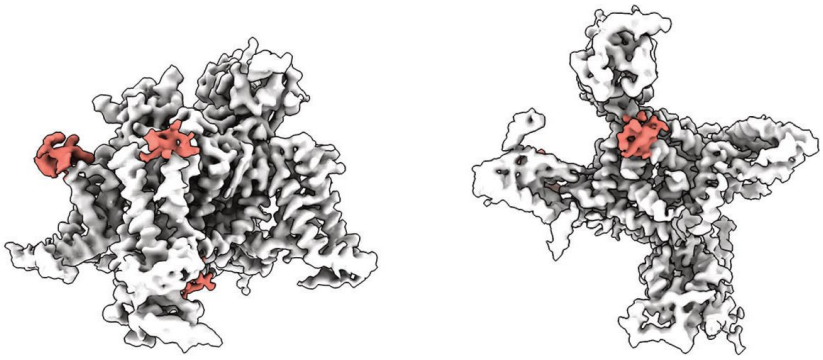

Voltage-gated sodium (Na_v) channels govern the membrane excitability of neurons and muscles by mediating the rapid influx of Na^+ ions in response to membrane depolarization. These functions are driven by the core Nav structure, which consists of a central pore domain (PD) and four surrounding voltage-sensing domains (VSDs). Among the nine human Na_v subtypes ($Na_v1.1$–1.9), $Na_v1.6$, encoded by the SCN8A gene, is widely expressed in nervous systems, with particularly high density at the distal axon initial segmentιo We identified three distinct PaurTx3-binding sites on $Na_v1.6$, including an uncharacterized site I, providing critical insights into the structural mechanisms underlying $Na_v1.6$ modulation by specific toxins. These findings not only advance our understanding of Na_v channel modulation but also open new avenues for developing targeted therapies for sodium channelopathies. Future research should build on these findings to explore the diverse and intricate interactions between toxins and ion channels to unlock new therapeutic potentials.

Status: published work in Cell Research 2025, **35**, 610

Proteomic analysis of the pyrenoid-traversing membranes of *Chlamydomonas reinhardtii* reveals novel components

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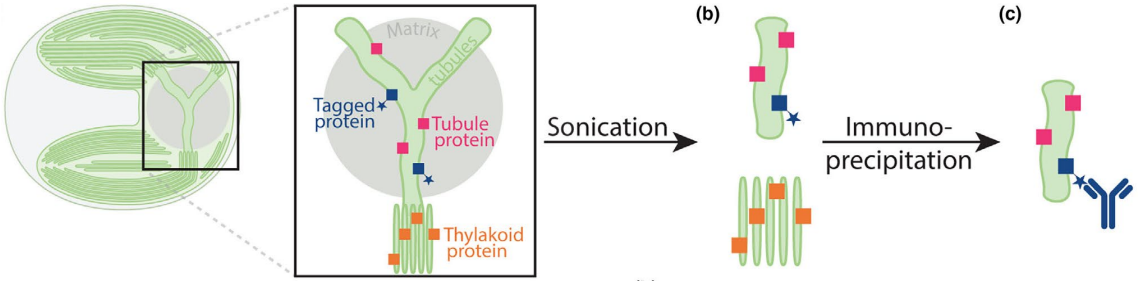

Pyrenoids are algal CO_2-fixing organelles that mediate approximately one-third of global carbon fixation. Most pyrenoids are traversed by membranes that are thought to supply them with concentrated CO_2. Despite the critical nature of these membranes for pyrenoid function, they are poorly understood, with few protein components known in any species. Here, we identify protein components of the pyrenoid-traversing membranes from the leading model alga, *Chlamydomonas reinhardtii*, by affinity purification and mass spectrometry of membrane fragments. Our proteome includes previously known proteins as well as novel candidates. We further characterize two of the novel pyrenoid-traversing membrane-resident proteins: Cre10.g452250, which we name Pyrenoid Membrane Enriched 1 (PME1), and Cre02.g143550, also known as Low-CO_2-Induced 16 (LCI16). We confirm the pyrenoid-traversing membrane localization of LCI16 and observe that PME1 and LCI16 physically interact. We find that neither protein is required for normal membrane morphology or growth under CO_2-limiting conditions, but that both mutants show a similar proteomic profile to those of established pyrenoid mutants. Taken together, our study identifies the proteome of the pyrenoid-traversing membranes and initiates the characterization of a novel pyrenoid-traversing membrane complex, building toward a mechanistic understanding of the pyrenoid.

Status: published work in New Phytologist 2026, **249**, 359

How augmin establishes the angle of the microtubule branch site

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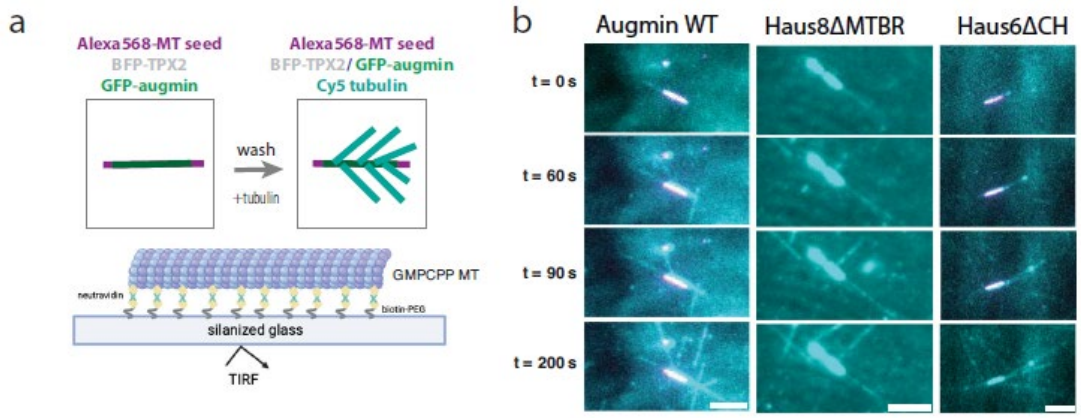

How microtubules (MTs) are generated in the proper orientation is essential to understanding how the cytoskeleton organizes a cell and MT-dependent events such as cell division. In the spindle, most MTs are generated through the branching MT nucleation pathway. In this pathway, new MTs are nucleated from the side of existing MTs and oriented at a shallow angle by the branching factor augmin, ensuring that both MTs have the same polarity. Yet, how augmin binds MTs and sets the branch angle has remained unclear. Here, we report the cryo-electron microscopy structure of an augmin subcomplex on the MT. This structure resembles that of NDC80 bound to the MT, with the conserved CH domain of augmin's Haus6 subunit directly proximal to the MT lattice. We find that the Haus6 CH domain is a bona fide MT binding site that increases augmin's affinity for the MT and helps establish branch angle. A second binding site, located in the disordered N-terminus of Haus8, also establishes branch angle. Thus, we find that augmin regulates MT branching using two domains, each tuned to modulate MT affinity and MT branch angle. This work expands our mechanistic understanding of branching MT nucleation and thus spindle formation.

Status: published work in Nature Communications 2025, **16**, 9646

Department of Physics

Fractional quantization in insulators from Hall to Chern

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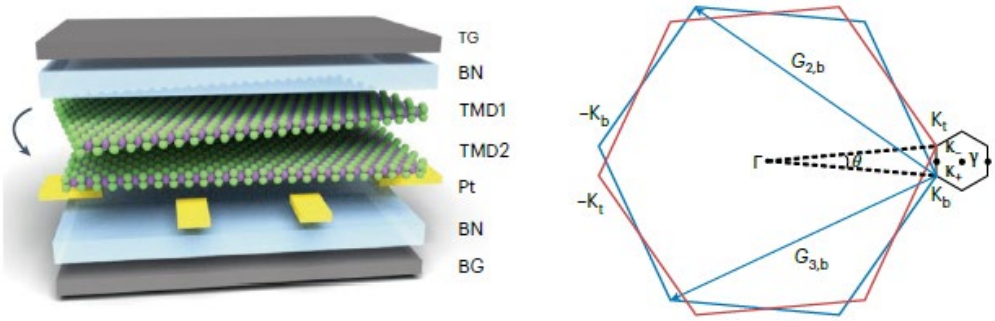

The discovery of the integer and fractional quantum Hall effects naturally prompted the question of whether these effects can be realized without a magnetic field. Answering this is fundamentally important and requires a synthesis of the concepts of band topology, quantum geometry and electronic correlations. Here we summarize the basic concepts of both fractional Chern and fractional topological insulators and illustrate them with the theoretical lattice models that support the flat Chern bands in which the states were first predicted. We then examine their experimental realizations in twisted bilayer transition metal dichalcogenides and moiré rhombohedral few-layer graphene. We also discuss the future challenges and opportunities in this research field.

Status: published work in Nature Physics 2025, **21**, 1702

Competing phases in the kagome magnet FeGe from functional renormalization

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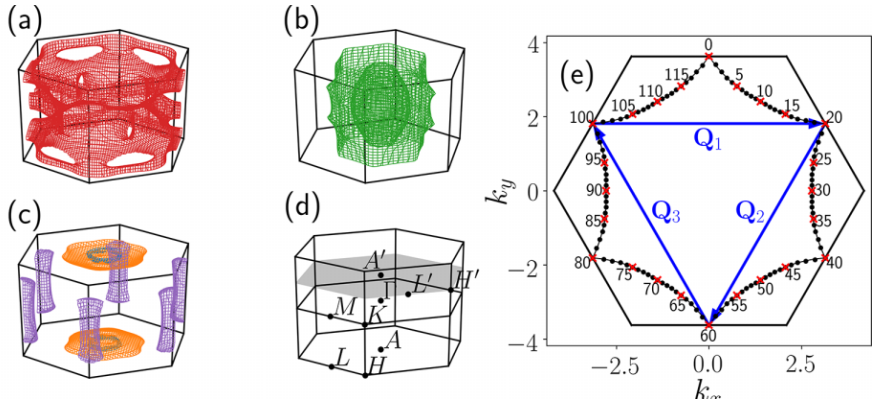

The discovery of a charge density wave in FeGe extends the discussion of the nature of charge order in kagome metals to a magnetic compound. Motivated by this observation, we combine density functional theory (DFT) and functional-renormalization-group calculations to study interaction-induced Fermi-surface instabilities of the magnetic state of FeGe. We argue that the leading intra-band contribution to electronic correlations are approximately two-dimensional (2D) and come from Van Hove points at the projected *M* points. By varying parameters around DFT values, we determine a phase diagram for the quasi-2D scenario as function of on-site and nearest-neighbor interactions. We discuss universal aspects in the electronic mechanisms for the resulting phases, as well as the role of SU(2) symmetry breaking. We find FeGe to be in a regime of strong competition between *p*-wave charge density wave, *f*-wave pairing, and *d*-wave spin Pomeranchuk instabilities. This interplay can be influenced in favor of superconducting pairing for slightly increased nearest-neighbor interaction, suggesting a potential to induce superconductivity in FeGe.

Status: published work in Physical Review B 2025, **112**, L220405

Moiré materials based on M-point twisting

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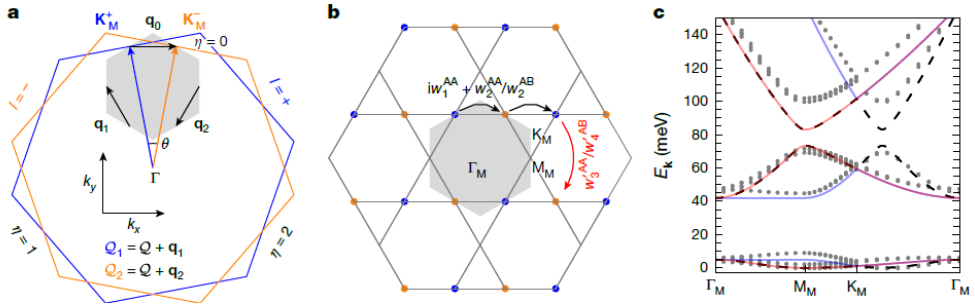

When two monolayer materials are stacked with a relative twist, an effective moiré translation symmetry emerges. Previous studies have focused almost exclusively on monolayers with triangular lattices and low-energy states near the Γ or K points of the Brillouin zone (BZ). Here we introduce a new class of moiré systems based on low-energy states at the M points of the BZ. These M-point moiré materials feature three time-reversal-preserving valleys related by threefold rotational symmetry. We propose twisted bilayers of exfoliable 1T-$SnSe_2$ and 1T-ZrS_2 as realizations of this new class. Using *ab initio* simulations, we identify twist angles that yield flat conduction bands, provide accurate continuum models, analyze their topology and charge density and explore the platform's rich physics. The M-point moiré Hamiltonians exhibit emergent momentum-space non-symmorphic symmetries and a kagome plane-wave lattice structure. This represents, the first experimentally viable realization of projective representations of crystalline space groups in a non-magnetic system. With interactions, these systems act as six-flavour Hubbard simulators with Mott physics. The presence of a momentum space non-symmorphic in-plane mirror symmetry renders some of the M-point moiré Hamiltonians quasi-one-dimensional.

Status: published work in Nature 2025, **643**, 376

High spatial resolution charge sensing of quantum Hall states

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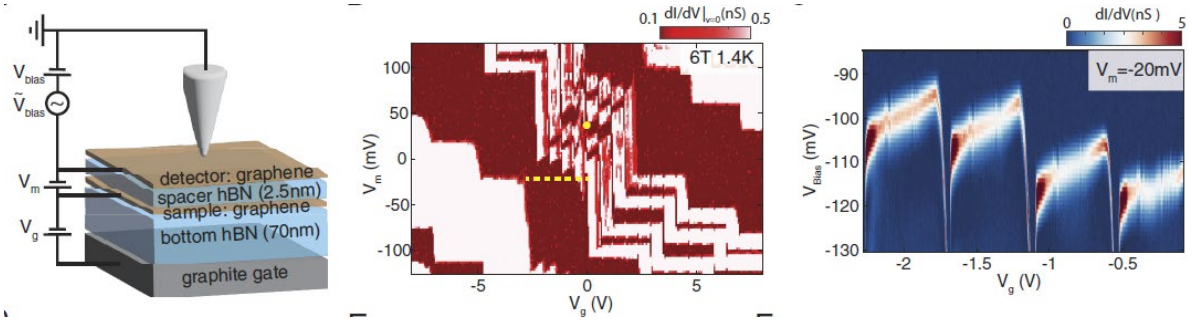

Charge distribution offers a unique fingerprint of important properties of electronic systems, including dielectric response, charge ordering, and charge fractionalization. We develop an architecture for charge sensing in two-dimensional electronic systems in a strong magnetic field. We probe local change of the chemical potential in a proximitized detector layer using scanning tunneling microscopy, allowing us to infer the chemical potential and the charge profile in the sample. Our technique has both high energy (<0.3 meV) and spatial (<10 nm) resolution exceeding that of previous studies by an order of magnitude. We apply our technique to study the chemical potential of quantum Hall liquids in monolayer graphene under high magnetic fields and their responses to charge impurities. The chemical potential measurement provides a local probe of the thermodynamic gap of quantum Hall ferromagnets and fractional quantum Hall states. The screening charge profile reveals spatially oscillatory response of the quantum Hall liquids to charge impurities and is consistent with the composite Fermi liquid picture close to the half-filling. Our technique also paves the way to map moiré potentials, probe Wigner crystals, and investigate fractional charges in quantum Hall and Chern insulators.

Status: published work in Proc. Nat. Acad. Sci. 2025, **122**, e2424781122

Topological excitonic insulator with tunable momentum order

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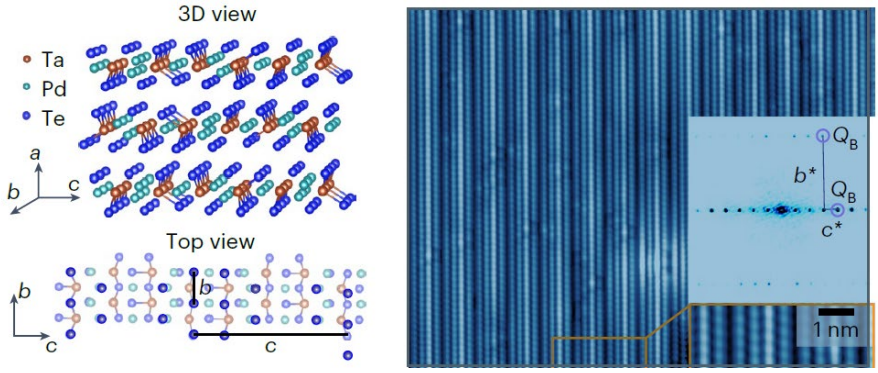

Correlated topological materials often maintain a delicate balance among physical symmetries. Many topological orders are symmetry protected, whereas most correlated phenomena arise from spontaneous symmetry breaking. Here we demonstrate the presence of two such phases in $Ta_2Pd_3Te_5$, where Coulomb interactions form excitons that condense below 100 K, one with zero and the other with finite momentum. We observed a full spectral bulk gap, which stems from exciton condensation. This topological excitonic insulator state spontaneously breaks mirror symmetries but involves a weak structural coupling. Scanning tunnelling microscopy shows gapless boundary modes in the bulk insulating phase. Their magnetic field response, together with theoretical modelling, indicates a topological origin. These observations establish $Ta_2Pd_3Te_5$ as a topological excitonic insulator in a three-dimensional crystal. Thus, our results manifest a unique sequence of topological exciton condensations in a bulk crystal, offering exciting opportunities to study critical behaviour and excitations.

Status: published work in Nature Physics 2025, **21**, 1250

High-resolution tunnelling spectroscopy of fractional quantum Hall states

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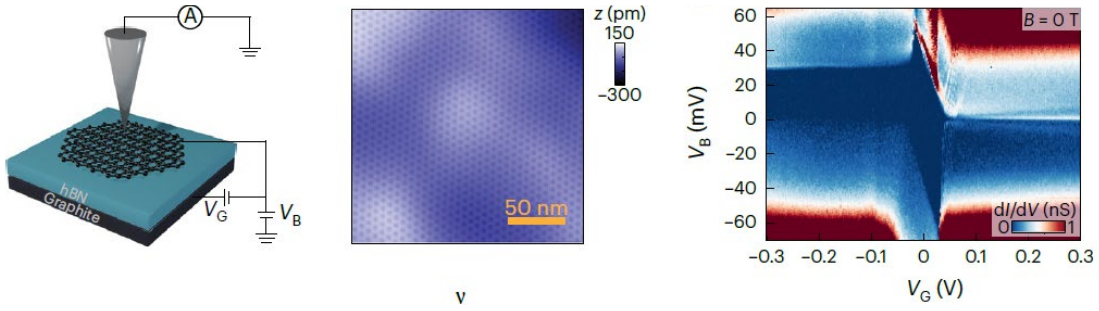

Strong interactions between electrons in two-dimensional systems in the presence of a high magnetic field give rise to fractional quantum Hall states that host quasiparticles with a fractional charge and fractional exchange statistics. Here we demonstrate high-resolution scanning tunneling microscopy and spectroscopy of fractional quantum Hall states in ultra-clean Bernal-stacked bilayer graphene devices. Spectroscopy measurements show sharp excitations that have been predicted to emerge when electrons fractionalize into bound states of quasiparticles. We found energy gaps for candidate non-abelian fractional states that are larger by a factor of five than those in other related systems, for example, semiconductor heterostructures, and this suggests that bilayer graphene is an ideal platform for manipulating these quasiparticles and for creating topological quantum bits. We also found previously unobserved fractional states in our very clean graphene samples.

Status: published work in Nature Physics 2025, **21**, 716

$CeCo_2P_2$: An antiferromagnetic topological heavy-fermion system with a PT -protected Kondo effect and nodal-line excitations

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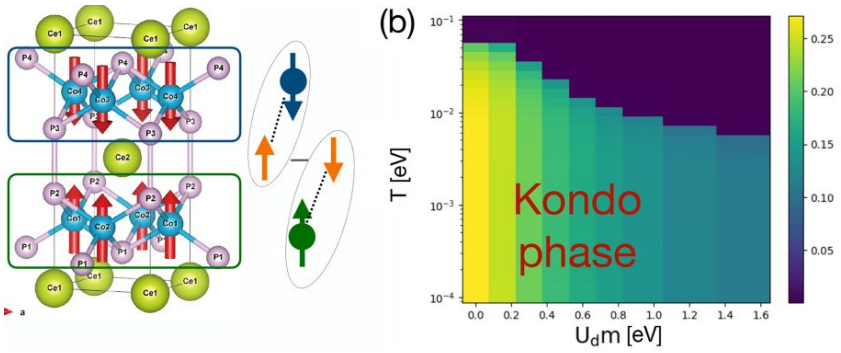

Based on high-throughput screening and experimental data, we find that $CeCo_2P_2$ is unique in heavy-fermion materials: It has a Kondo effect at a high temperature which is nonetheless below a Co antiferromagnetic ordering temperature. How is the Kondo singlet formed? We theoretically explain these observations and show the multifaceted uniqueness of $CeCo_2P_2$: a playground for Kondo, magnetism, flat band, and topological physics. At high temperatures, the itinerant Co c electrons of the system form nonatomic bands with a narrow bandwidth, leading to a high antiferromagnetic transition temperature. We show that the quantum geometry of the bands promotes in-plane ferromagnetism, while the weak dispersion along the z direction facilitates out-of-plane antiferromagnetism. At low temperatures, we uncover a phase that manifests the coexistence of Co antiferromagnetism and the Kondo effect, linked to the *PT*-protected Kramers' doublets and the filling-enforced metallic nature of c electrons in the antiferromagnetic phase. Our results emphasize the importance of lattice symmetry and quantum geometry, Kondo physics, and magnetism in the understanding of the correlation physics of this unique compound. We also test our theory on the structurally similar compound $LaCo_2P_2$.

Status: published work in Physical Review B 2025, **112**, 195107

Scaling behavior and giant field enhancement of the thermal conductivity in the honeycomb antiferromagnet $BaCo_2(AsO_4)_2$

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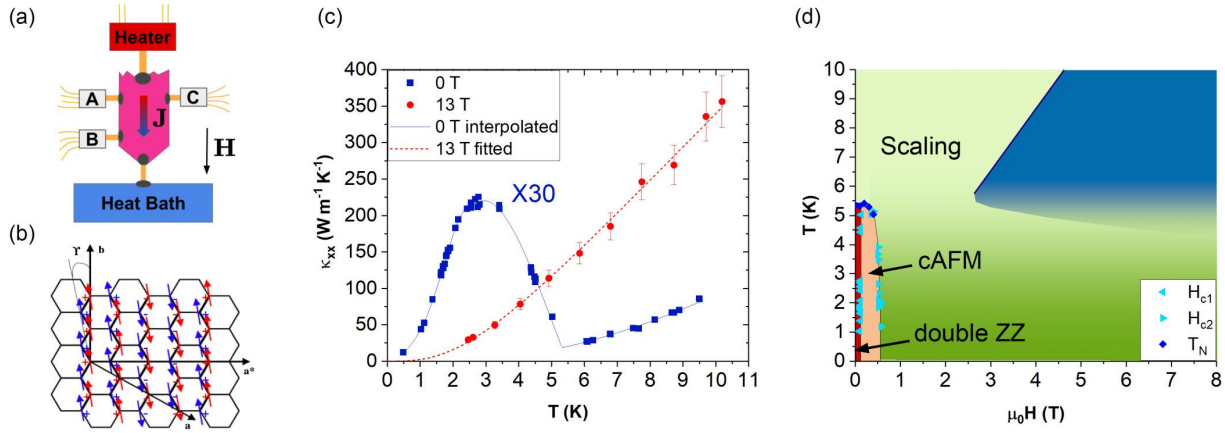

The layered honeycomb material $BaCo_2(AsO_4)_2$ is of topical interest because its magnetic state is related to that of the Kitaev magnet α-$RuCl_3$. Using thermal transport to probe how magnetic excitations interact with phonons in the magnetically disordered regime, we have uncovered an unusually large enhancement of the thermal conductivity κ_{xx} in an in-plane magnetic field **H**. Just above the Néel temperature T_N, a field of 13 T increases κ_{xx} by a factor of ~211, which is very large compared to other magnetic insulators. Interestingly, $\kappa_{xx}(H, T)$ exhibits a scaling behavior in the entire magnetically disordered region that surrounds the ordered zigzag state. The ratio $\Delta\kappa_{xx}(H, T)/\kappa_{xx}(13, T)$, measured throughout the disordered region, collapses to a one parameter scaling function $\exp(-1/gx)$ (where $x = \mu_B B/k_B T$ and g is a constant).

Status: published work in Physical Review Materials 2025, **9**, L061401

Anomalous superconductivity in twisted $MoTe_2$ nanojunctions

Yanyu Jia,[1] Tiancheng Song,[1] Zhaoyi Joy Zheng,[1,2] Guangming Cheng,[3] Ayelet J. Uzan,[1] Guo Yu,[1,2] Yue Tang,[1] Connor J. Pollak,[4] Fang Yuan,[4] Michael Onyszczak,[1] Kenji Watanabe,[5] Takashi Taniguchi,[6] Shiming Lei,[7] Nan Yao,[3] Leslie M. Schoop,[4] N. P. Ong,[1] Sanfeng Wu[1]

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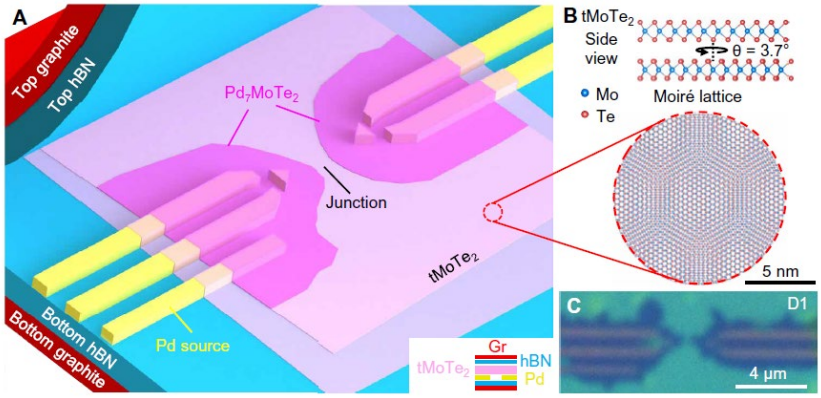

Introducing superconductivity in topological materials can lead to innovative electronic phases and device functionalities. Here, we present a unique strategy for quantum engineering of superconducting junctions in moiré materials through direct, on-chip, and fully encapsulated 2D crystal growth. We achieve robust and designable superconductivity in Pd-metalized twisted bilayer molybdenum ditelluride ($MoTe_2$) and observe anomalous superconducting effects in high-quality junctions across ~20 moiré cells. Unexpectedly, the junction develops enhanced, instead of weakened, superconducting behaviors, exhibiting fluctuations to a higher critical magnetic field compared to its adjacent Pd_7MoTe_2 superconductor. In addition, the critical current further exhibits a notable V-shaped minimum at zero magnetic field. These features are unexpected in Josephson junctions and absent in junctions of natural bilayer $MoTe_2$ created using the same approach. We discuss implications of these observations, including the possible formation of mixed even-and odd-parity superconductivity at the moiré junctions. Our results also demonstrate a pathway to engineer and investigate superconductivity in fractional Chern insulators.

Status: published work in Science Advances 2025, **11**, eadq5712

FeGe as a building block for the kagome 1:1, 1:6:6, and 1:3:5 families: Hidden d-orbital decoupling of flat band sectors, effective models, and interaction Hamiltonians

Yi Jiang,[1,2,3] Haoyu Hu,[3,4] Dumitru Calugaru,[4] Claudia Felser,[5] Santiago Blanco-Canosa,[3,6] Hongming Weng,[1,7] Yuanfeng Xu,[8] and B. Andrei Bernevig[3,4,6]

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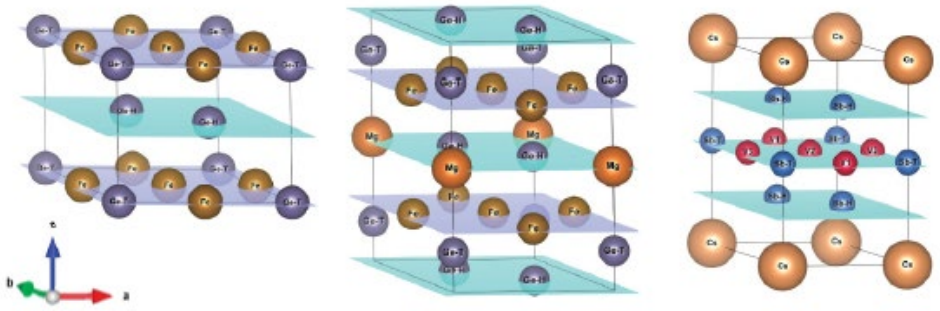

The electronic structure and interactions of kagome materials, such as the 1:1 (FeGe) and 1:6:6 ($MgFe_6Ge_6$) classes, are complicated and involve many orbitals and bands around the Fermi level. Current theoretical models treat the systems in an s-orbital kagome representation, unsuited and incorrect. In this work, we lay the framework of the electronic model for this large class of materials. We show that the "spaghetti" of electronic bands near the Fermi level can be decomposed into three groups of Fe *d* orbitals coupled to specific Ge orbitals via symmetry and chemical analysis. Our three minimal Hamiltonians can reproduce the quasiflat bands, van Hove singularities, topology, and Dirac points close to the Fermi level, which we prove by *ab initio* studies. We also obtain the interacting Hamiltonian for the d orbitals in FeGe using the constraint random phase approximation (cRPA) method, which describes the antiferromagnetic phase. We then use FeGe as a fundamental "LEGO-like" building block for a large family of 1:6:6 kagome materials. We apply the model to its kagome siblings FeSn and CoSn, and also $MgFe_6Ge_6$. We further extend the formalism developed for the 1:1 family to the 1:3:5 family AB_3Z_5, demonstrating the broad applicability of the LEGO-like building block approach. Our work serves as the first complete framework of the interacting phase diagram of kagome compounds.

Status: published work in Physical Review B 2025, **111**, 125163

Cascade of pressure-induced competing charge density waves in the kagome metal FeGe

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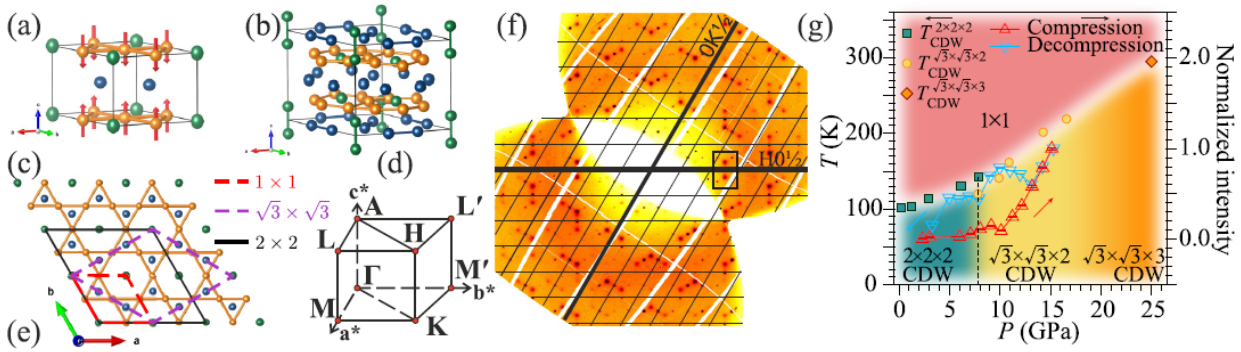

Electronic ordering is prevalent in correlated systems, which commonly exhibit competing interactions. Here, we use x-ray diffraction to demonstrate a cascade of pressure-induced order-disorder transformations, with propagation vectors q_{CDW} = (½ 0 ½), q^* = (⅓ ⅓ ½), and $q^\dagger$ = (⅓ ⅓ ⅓), in the kagome metal FeGe. In the pressure interval between 4 < p < 10 GPa, qCDW and q^* coexist and the spatial extent of the $\sqrt{3} \times \sqrt{3}$ order is nearly long range at ~15 GPa, ~30 unit cells. Above ~25 GPa, the periodic lattice distortion has a propagation wave vector of $q^\dagger$ = (⅓ ⅓ ⅓) at room temperature. The cascade of phase transitions is captured by the Ising model of frustrated triangular lattices and modeled by Monte Carlo simulations based on the dimerization of trigonal Ge_1. The pressure dependence of the integrated intensities and correlation lengths of q_{CDW}, q^*, and $q^\dagger$ demonstrating a competition between the 2 × 2 and $\sqrt{3} \times \sqrt{3}$ phases prove the tunability of order-disorder phase transitions under pressure and the rich landscape of metastable phases of FeGe.

Status: published work in Physical Review B 2025, **111**, 155101

Moiré fractional Chern insulators. III. Hartree-Fock phase diagram, magic angle regime for Chern insulator states, role of moiré potential, and Goldstone gaps in rhombohedral graphene superlattices

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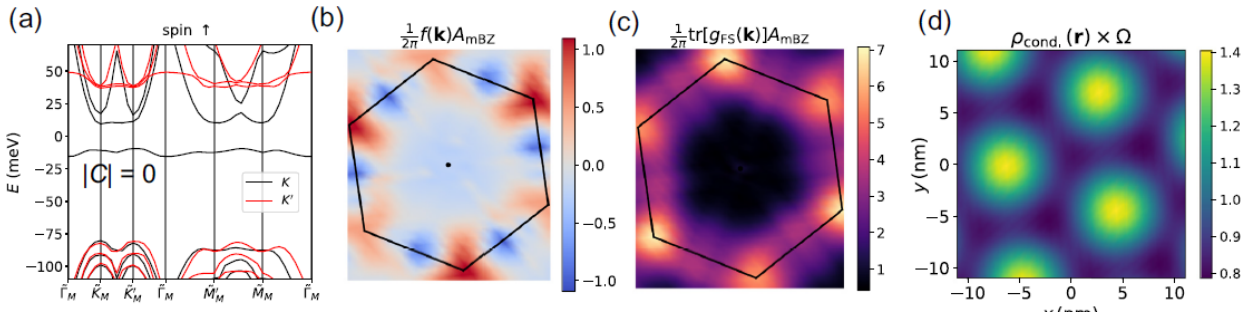

We investigate in detail the ν = +1 displacement-field-tuned interacting phase diagram of L = 3, 4, 5, 6, 7 layer rhombohedral graphene aligned to hBN (RLG/hBN). Our calculations account for the 3D nature of the Coulomb interaction, the inequivalent stacking orientations ξ = 0, 1, the effects of the filled valence bands, and the choice of "interaction scheme" for specifying the many-body Hamiltonian. We show that the latter has a dramatic impact on the Hartree-Fock phase boundaries and the properties of the phases. In this large D regime, the low-energy conduction bands are polarized away from the aligned hBN layer, making them well described by the folded bands of moiréless rhombohedral graphene at the noninteracting level. Despite this, the filled valence bands develop moiré-periodic charge density variations, which can generate an effective moiré potential. Within time-dependent Hartree-Fock theory, we further characterize the strength of the moiré pinning potential in the Chern insulator phase by computing the low-energy q = 0 collective mode spectrum, where we identify competing gapped pseudophonon and valley magnon excitations. Our results emphasize the importance of careful examination of both the single-particle and interaction model for a proper understanding of the correlated phases in RLG/hBN.

Status: published work in Physical Review B 2025, **112**, 075109

Multiband exact diagonalization and an iteration approach to search for fractional Chern insulators in rhombohedral multilayer graphene

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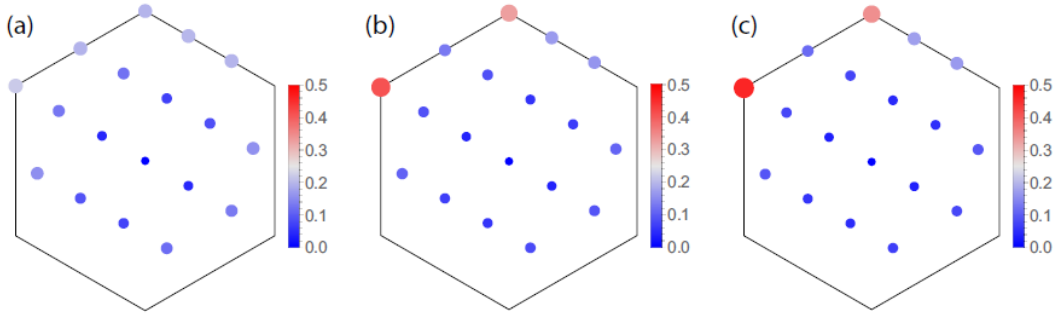

We perform a multi-band exact diagonalization (ED) study of rhombohedral pentalayer graphene twisted on hexagonal boron nitride with a focus on fractional Chern insulators (FCI) in systems with weak moiré gaps. We consider both the charge-neutrality (CN) and average (AVE) interaction schemes. Saliently and surprisingly, we now find using the particle entanglement spectrum that the FCI at filling factor 1/3 in the CN scheme predicted by single-(Hartree-Fock) band ED is unstable towards a transition to charge density wave once a small fraction of electrons is allowed to occupy the higher bands. Meanwhile, the FCI at filling 2/3 in the AVE scheme remains more robust under similar band mixing until being suppressed when increasing band mixing. To tackle truncation errors that arise from including multiple bands in larger system sizes, we propose an ED iteration method that iteratively optimizes the single-particle basis so that the particles in the ground state should residemainly in the lowest band. Nevertheless, we find that the FCI gap remains absent after convergence when the mixing with higher bands is considered. These findings highlight the delicate sensitivity of FCIs to multi-band effects and the shortcoming of all of the current models to explain the experimental emergence of such phases.

Status: published work in Physical Review B 2025, **112**, 075130

Discovery of a Stripe Phase in an Elemental Solid

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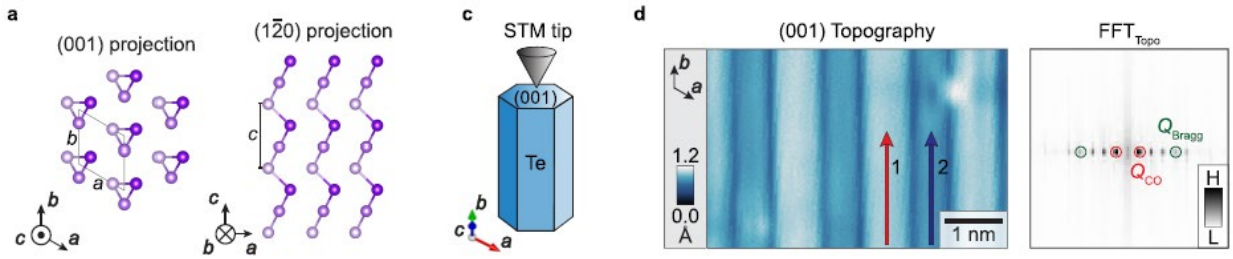

Translational symmetry breaking is foundational to condensed matter physics because it is associated with crystal formation. At much lower energy scales, the breaking of crystalline translational symmetry can be driven by electronic, rather than ionic, degrees of freedom and may give rise to stripe order, a unidirectional ordered state. Such symmetry breaking has been seen in two-dimensional and strongly correlated systems. Here, for the first time, we report the observation of stripe order in an elemental solid, tellurium. Through topographic and spectroscopic imaging, we discover a commensurate 4 × 1 stripe phase. Surprisingly, this exotic order is so robust that it survives close to room temperature. Notably, our diffraction experiments confirm the bulk nature of the stripe order, showing the minuteness of potential lattice distortion associated with the order. Our discovery of the stripe order in tellurium opens new windows to understanding the spontaneous symmetry breaking in elemental solids.

Status: published work in Nano Letters 2025, **25**, 10386

Nodal nematic superconductivity in multiple flat-band systems

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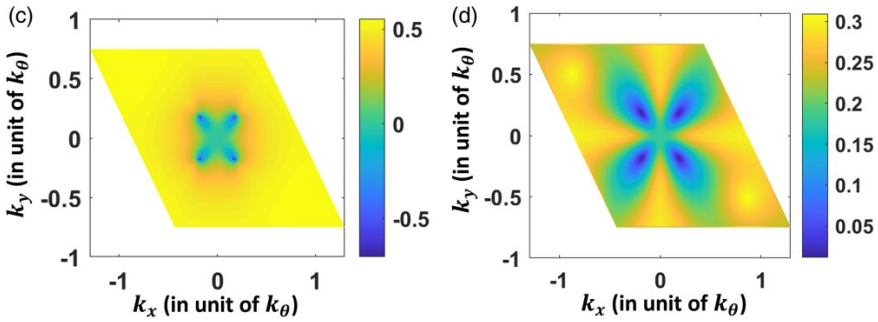

In this work, we propose a mechanism of inducing stable nodal superconductivity for multiple-flat-band systems. This mechanism is based on the degenerate flat band nature, so that not only intra-eigenband pairing, but also inter-eigenband pairing has a significant influence on the superconductivity properties. Based on the Bogoliubov-de Gennes formalism of the heavy fermion model for the twisted bilayer graphene as an example, we show that although the nodal nematic Euler obstructed pairing has higher energy around the nodal points compared to the fully gapped chiral d-wave pairing in the momentum space, the inter-eigenband pairing can lower the energy in other momenta away from the nodes, so that the nematic Euler obstructed pairing is energetically favored for its overall condensation energy. This type of mechanism is particular to multiple-flat-band systems with no Fermi surfaces.

Status: published work in Physical Review B 2025, **111**, L020502

Interplay between light and heavy electron bands in magic-angle twisted bilayer graphene

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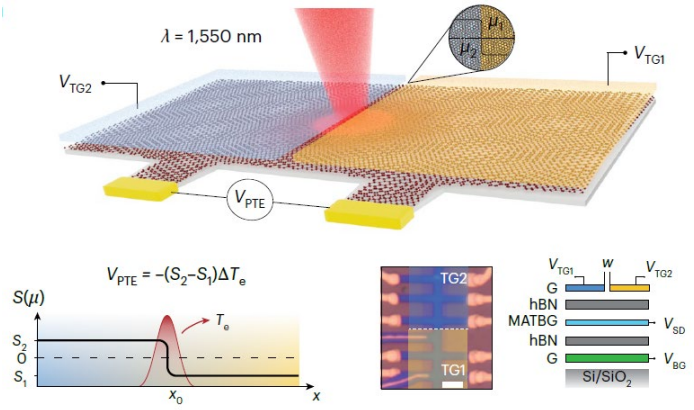

Recent studies have suggested that the strongly correlated flat bands of magic-angle twisted bilayer graphene may host coexisting light and heavy carriers. Although transport and spectroscopic measurements have hinted at this behaviour, distinct signatures of incoherent heavy carriers have not been reported. Here we provide evidence of this by performing thermoelectric transport measurements of magic-angle twisted bilayer graphene using the photo-thermoelectric effect in gate-defined p–n junctions. At low temperatures, we observe sign-preserving, filling-dependent oscillations of the Seebeck coefficient at non-zero integer fillings of the moiré superlattice. This suggests the preponderance of one carrier type even when the Fermi level is tuned through the charge neutrality point of the correlated states. At higher temperatures, the thermoelectric response provides evidence of strong electron correlations in the unordered, normal state. Our observations are explained by the interplay between light, long-lived electron states and heavy, short-lived hole excitations near the Fermi level of the symmetry-broken ground states. These findings are in qualitative agreement with the topological heavy fermion model.

Status: published work in Nature Physics 2025, **21**, 1078

Spectroscopy of the fractal Hofstadter energy spectrum

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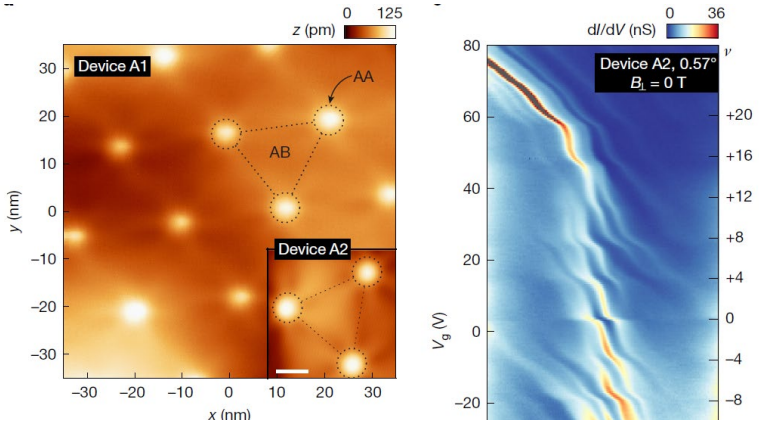

Hofstadter's butterfly, the predicted energy spectrum for non-interacting electrons confined to a two-dimensional lattice in a magnetic field, is one of the most remarkable fractal structures in nature. For most materials, Hofstadter's butterfly is predicted under experimental conditions that are unachievable using laboratory-scale magnetic fields. More recently, electrical transport studies have provided evidence for Hofstadter's butterfly in materials engineered to have artificially large lattice constants, such as those with moiré superlattices. Yet, so far, direct spectroscopy of the fractal energy spectrum predicted by Hofstadter nearly 50 years ago has remained out of reach. Here we use high-resolution scanning tunneling microscopy/ spectroscopy (STM/STS) to investigate the flat electronic bands in twisted bilayer graphene (TBG) near the predicted second magic angle, an ideal setting for spectroscopic studies of Hofstadter's spectrum. Our study shows the fractionalization of flat moiré bands into discrete Hofstadter subbands and discerns experimental signatures of self-similarity of this spectrum. Moreover, our measurements uncover a spectrum that evolves dynamically with electron density, showing phenomena beyond that of Hofstadter's original model owing to the combined effects of strong correlations, Coulomb interactions and the quantum degeneracy of electrons in TBG.

Status: published work in Nature 2025, **639**, 60

Photovoltage microscopy of symmetrically twisted trilayer graphene

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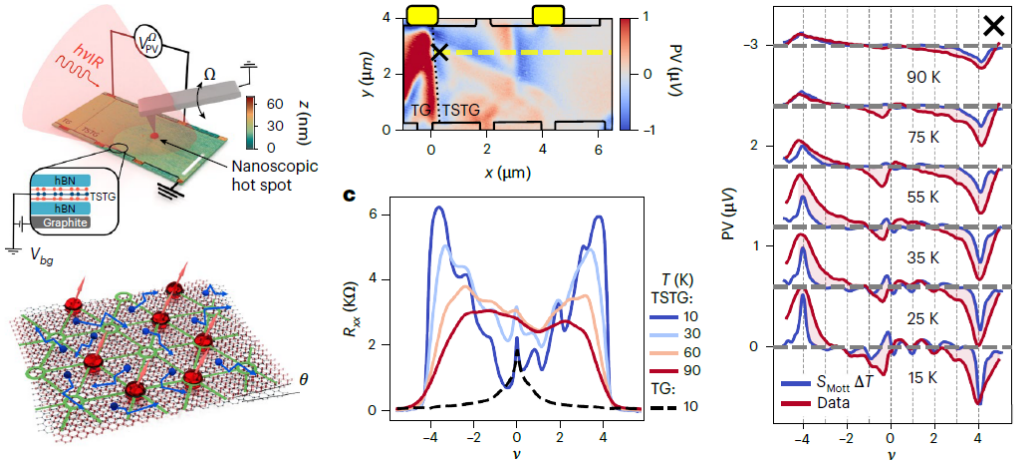

A full microscopic description of the correlated insulators and superconductivity that occur in the flat bands of magic angle twisted bilayer graphene has not yet been found. Electronic transport and scanning tunnelling microscopy experiments have suggested a dichotomy between local and extended electronic orbitals, but definitive evidence for the coexistence of these two carrier types is still sought after. Here we report local photothermoelectric measurements in the flat electronic bands of symmetrically twisted trilayer graphene. We observe oscillations of the Seebeck coefficient around integer fillings of the flat band, signalling the presence of electron correlations, coupled with a breakdown of the predictions of the Mott formula. Our measurements reveal an overall negative offset of the Seebeck coefficient and peaks of the local photovoltage values at all positive integer fillings of the moiré superlattice. This further indicates a deviation from the classical two-band semiconductor Seebeck response. Our findings may be interpreted using the heavy-fermion model in the topological flat bands of moiré graphene and highlight an avenue to apply local thermoelectric measurements to other strongly correlated materials.

Status: published work in Nature Physics 2025, **21**, 1934

New magnetic topological materials from high-throughput search

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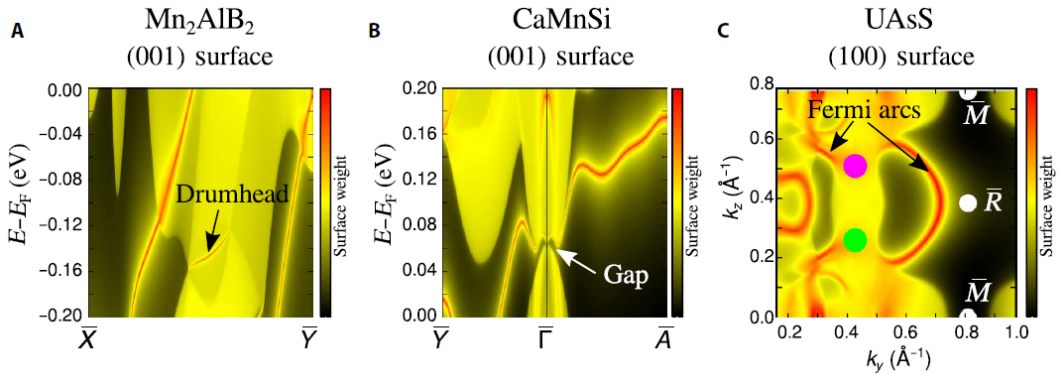

We conducted a high-throughput search for topological magnetic materials across 522 new, experimentally reported commensurate magnetic structures from MAGNDATA, doubling the number of available materials on the Topological Magnetic Materials database. This brings up to date the previous studies. For each material, we performed first-principles electronic calculations and diagnosed the topology as a function of the Hubbard U parameter. Our high-throughput calculation led us to the prediction of 250 experimentally relevant topologically nontrivial materials, which represent 47.89% of the newly analyzed materials. We present five remarkable examples of these materials, each showcasing a different topological phase: Mn_2AlB_2 (BCSID 1.508), which exhibits a nodal line semimetal to topological insulator transition as a function of SOC; CaMnSi (BCSID 0.599), a narrow gap axion insulator; UAsS (BCSID 0.594), a 5f-orbital Weyl semimetal; $CsMnF_4$ (BCSID 0.327), a material presenting a new type of quasi-symmetry protected closed nodal surface; and $FeCr_2S_4$ (BCSID 0.613), a symmetry-enforced semimetal with double Weyls and spin-polarized surface states.

Status: published work in Science Advances 2025, **11**, eadv8780

Unconventional superconducting phase diagram of monolayer WTe_2

Tiancheng Song,[1,2] Yanyu Jia,[1] Guo Yu,[1,3] Yue Tang,[1] Ayelet J. Uzan,[1] Zhaoyi Joy Zheng,[1,3] Haosen Guan,[1] Michael Onyszczak,[1] Ratnadwip Singha,[4] Xin Gui,[4,5] Kenji Watanabe,[6] Takashi Taniguchi,[7] Robert J. Cava,[4] Leslie M. Schoop,[4] N. P. Ong,[1] and Sanfeng Wu[1]

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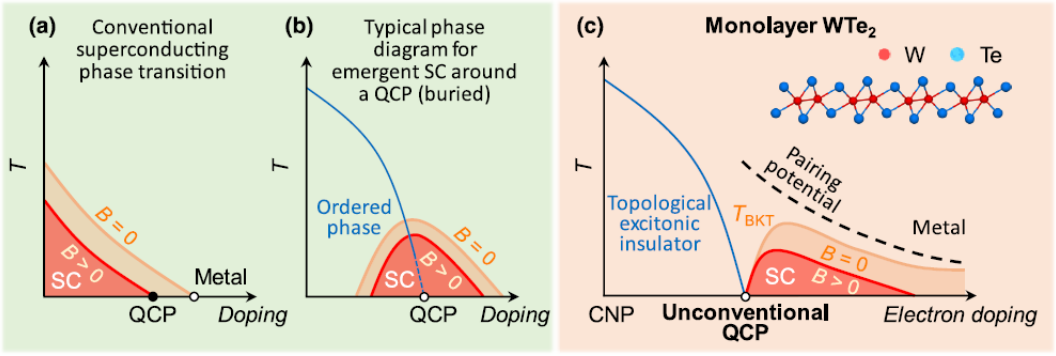

The existence of a quantum critical point (QCP) and fluctuations around it are believed to be important for understanding the phase diagram in unconventional superconductors such as cuprates, iron pnictides, and heavy fermion superconductors. However, the QCP is usually buried deep within the superconducting dome and is difficult to investigate. The connection between quantum critical fluctuations and superconductivity remains an outstanding problem in condensed matter. Here combining both electrical transport and Nernst experiments, we explicitly demonstrate the onset of superconductivity at an unconventional QCP in gate-tuned monolayer tungsten ditelluride (WTe_2), with features incompatible with the conventional Bardeen-Cooper-Schrieffer scenario. The results lead to a superconducting phase diagram that is distinguished from other known superconductors. Two distinct gate-tuned quantum phase transitions are observed at the ends of the superconducting dome. We find that quantum fluctuations around the QCP of the underdoped regime are essential for understanding how the monolayer superconductivity is established. The unconventional phase diagram we report here illustrates a previously unknown relation between superconductivity and QCP.

Status: published work in Physical Review Research 2025, **7**, 013224

Frustrated charge density wave and quasi-long-range bond-orientational order in the magnetic kagome FeGe

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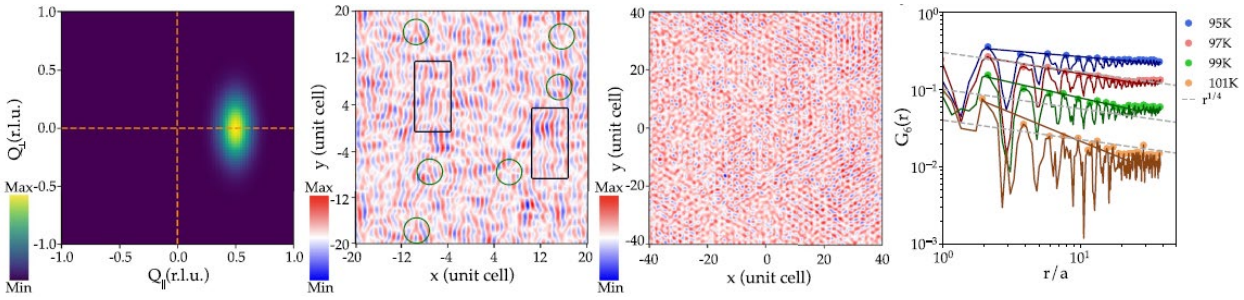

The intrinsic frustrated nature of a kagome lattice is amenable to the realization of exotic phases of matter, such as quantum spin liquids or spin ices, and the multiple-q charge density waves (CDW) in the kagome metals. Despite intense efforts to understand the mechanism driving the electronic modulations, its origin is still unknown and obscured by competing interactions and intertwined orders. Here, we identify a dimerization-driven 2D hexagonal charge-diffuse precursor in the antiferromagnetic kagome metal FeGe and demonstrate that the fraction of dimerized/undimerized states is the relevant order parameter of the multiple-**q** CDW of a continuous phase transition. The pretransitional charge fluctuations with propagation vector **q** = $\mathbf{q}_M$ at $T_{CDW} < T < T^*$(125 K) are anisotropic, hence holding a quasi-long-range bond-orientational order. The broken translational symmetry emerges from the anisotropic diffuse precursor. The temperature and momentum dependence of the critical scattering show parallels to the stacked hexatic B-phases reported in liquid crystals and transient states of CDWs and highlight the key role of the topological defect-mediated melting of the CDW in FeGe.

Status: published work in Nature Communications 2025, **16**, 4091

Emerging supersolidity in photonic-crystal polariton condensates

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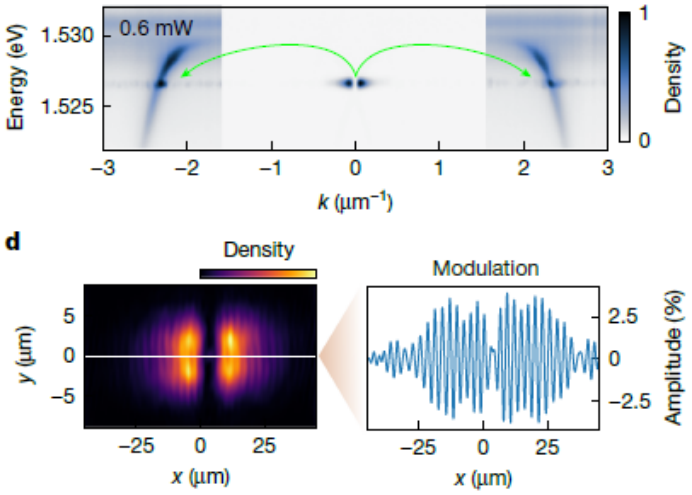

A supersolid is a counter-intuitive phase of matter in which its constituent particles are arranged into a crystalline structure, yet they are free to flow without friction. This requires the particles to share a global macroscopic phase while being able to reduce their total energy by spontaneous, spatial self-organization. The existence of the supersolid phase of matter was speculated more than 50 years ago. However, only recently has there been convincing experimental evidence, mainly using ultracold atomic Bose–Einstein condensates (BECs) coupled to electromagnetic fields. Here we provide experimental evidence of a new implementation of the supersolid phase in a driven-dissipative, non-equilibrium context based on exciton–polaritons condensed in a topologically non-trivial, bound state in the continuum (BiC) with exceptionally low losses, realized in a photonic-crystal waveguide. We measure the density modulation of the polaritonic state indicating the breaking of translational symmetry with a precision of several parts in a thousand. Direct access to the phase of the wavefunction allows us to also measure the local coherence of the supersolid. We demonstrate the potential of our synthetic photonic material to host phonon dynamics and a multimode excitation spectrum.

Status: published work in Nature 2025, **639**, 337

Quantum geometry in quantum materials

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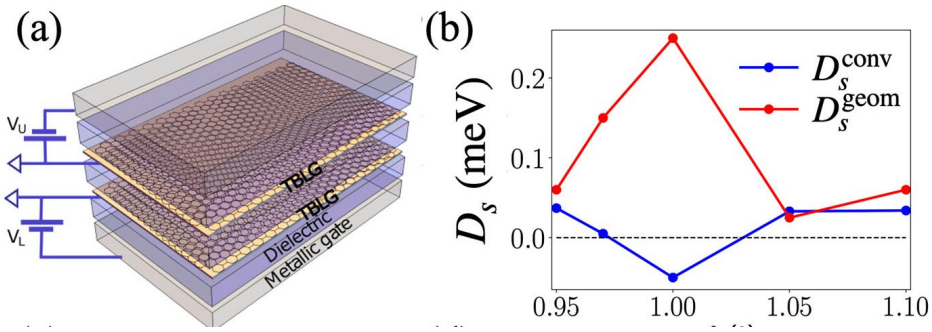

Quantum geometry, characterized by the quantum geometric tensor, plays a central role in diverse physical phenomena in quantum materials. This pedagogical review introduces the concept and highlights its implications across multiple domains, including optical responses, Landau levels, fractional Chern insulators, superfluid weight, spin stiffness, exciton condensates, and electron-phonon coupling. By integrating these topics, we emphasize the broad significance of quantum geometry in understanding emergent behaviors in quantum systems and conclude with an outlook on open questions and future directions.

Status: published work in npj Quantum Materials 2025, **10**, 101

Moiré fractional Chern insulators. IV. Fluctuation-driven collapse in multiband exact diagonalization calculations on rhombohedral graphene

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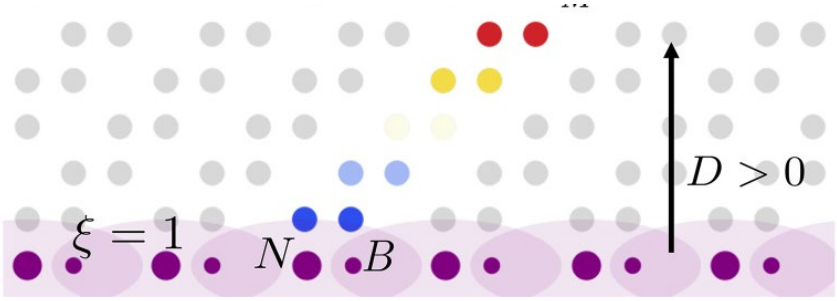

The fractional Chern insulators (FCIs) observed in pentalayer rhombohedral graphene/hexagonal boron nitride superlattices have a unique origin contrary to theoretical expectations: their noninteracting band structure is gapless, unlike standard FCIs and the Landau level. Hartree-Fock (HF) calculations at filling ν = 1 yield a gapped ground state with Chern number 1 through band mixing, identifying a possible parent state. However, many-body calculations restricted to the occupied HF band predispose the system toward FCIs and are essentially uncontrolled. In this work, we use unbiased multiband exact diagonalization (ED) to allow fluctuations into the gapless bands for two normal-ordering schemes. In the "charge neutrality" scheme, the weak moiré potential leads to theoretical proposals based on Wigner crystal-like states. However, we find that FCIs seen in one-band ED calculations are destroyed by band mixing, becoming gapless as fluctuations are included. In the "average" scheme, the Coulomb interaction with the periodic valence charge background sets up a stronger moiré potential. On small systems, FCIs at ν = 1/3 are destroyed in multiband calculations, while those at ν = 2/3 are initially strengthened. However, we do not converge to a stable FCI at ν = 2/3 even on the largest accessible systems. These findings question prior results obtained within projection to a single HF band. They suggest that current models do not support FCIs with correlation length small enough to be converged in current unbiased ED calculations, or do not support FCIs at all.

Status: published work in Physical Review B 2025, **112**, 075110

Universal Wilson Loop Bound of Quantum Geometry

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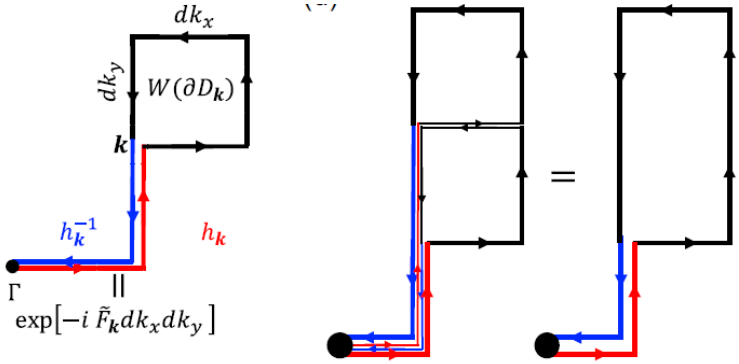

We define the absolute Wilson loop winding and prove that it bounds the (integrated) quantum metric from below. This Wilson loop lower bound naturally reproduces the known Chern and Euler bounds of the integrated quantum metric and provides an explicit lower bound of the integrated quantum metric due to the time-reversal protected Z_2 index, answering a hitherto open question. In general, the Wilson loop lower bound can be applied to any other topological invariants characterized by Wilson loop winding, such as the particle-hole Z_2 index. As physical consequences of the Z_2 bound, we show that the time-reversal Z_2 index bounds superfluid weight and optical conductivity from below and bounds the direct gap of a band insulator from above.

Status: published work in Physical Review Letters 2025, **135**, 086401

Princeton Materials Institute

Unique (Al,Cu)-alloys discovered in a micrometeorite from Southern Italy

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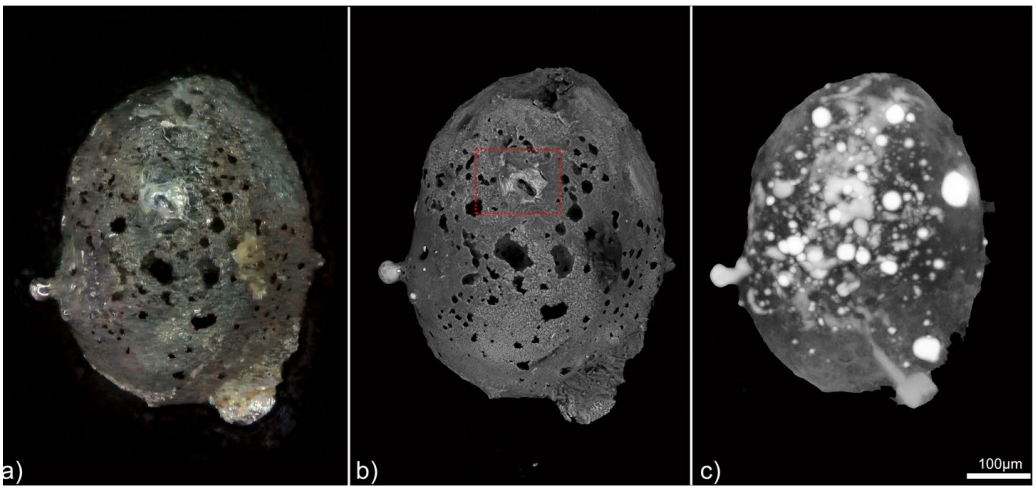

We report the discovery of a (Al,Cu)-bearing micrometeorite recovered at the top of Mt. Gariglione (Italy). The micrometeorite exhibits a highly vesicular scoriaceous structure characterized by broadly chondritic silicate-dominated composition (S-type) with relict phenocrystals of forsteritic olivine dispersed in a Ca-rich silicate glass with pyroxene composition, droplets of FeNi metal, oxides and sporadic Ni-rich sulphides embedded in a magnetite rim. The oxygen 3-isotope analyses give values close to the slope ~1 CCAM. A reduced assemblage of (Al,Cu)-alloys partially fills the open voids of the micrometeorite and shows variable compositions: from almost pure Cu up to Al-dominated phases with a predominance of khatyrkite, stolperite and unnamed Cu_3Al_2. Locally, small grains (about 1-2 µm in size) embedded in stolperite show a Fe-Si enrichment and are characterized by a long-range ordering resembling a quasicrystalline structure. This finding represents a unique natural quasicrystal approximant with composition $Al_{52}Cu_{31}Fe_{10}Si_7$.

Status: published work in Communications Earth and Environment 2025, **6**, 271

Jonlarsenite, Al_4Cu_9, a new intermetallic phase in the Al–Cu system discovered in a micrometeorite from Oslo, Norway

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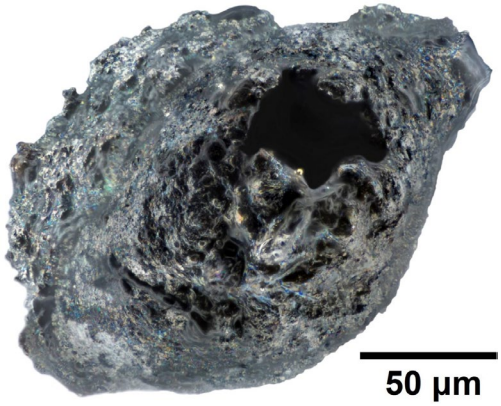

During project STARDUST, a systematic decade-long search for micrometeorites in Norway, over 5500 specimens were recovered. Among them, a micrometeorite labelled NMM/L2, collected from a rooftop in Oslo, Norway, revealed the presence of a previously unknown Al–Cu intermetallic alloy with Al_4Cu_9 stoichiometry. This new phase has been approved by the IMA Commission on New Minerals, Nomenclature and Classification as a new mineral species with the name jonlarsenite. Characterisation by electron probe microanalysis (EPMA), STEM energy-dispersive X-ray spectrometry (STEM-EDS), and HR-TEM indicated the mineral to be cubic, space group P-43m, with a ≈ 8:70Å and a calculated density of 6.979 g cm^{-3}. The ideal chemical formula is Al_4Cu_9, with minor Fe substituting for both Al and Cu. Selected area electron diffraction (SAED) and high-angle annular dark-field scanning TEM (HAADF-STEM) imaging showed a perfect match with the known ordered structure of synthetic γ-Al_4Cu_9. Due to micrometre-scale grain size, physical properties could not be measured. Jonlarsenite expands the suite of known natural intermetallic Al–Cu(–Fe) phases and highlights the significance of micrometeorites as repositories of exotic materials formed under extreme astrophysical conditions.

Status: published work in Eur. J. Mineral. 2025, **37**, 783

Metallic messengers from the cosmos: Rare (Al,Cu)-bearing meteorites from the Project Stardust collection

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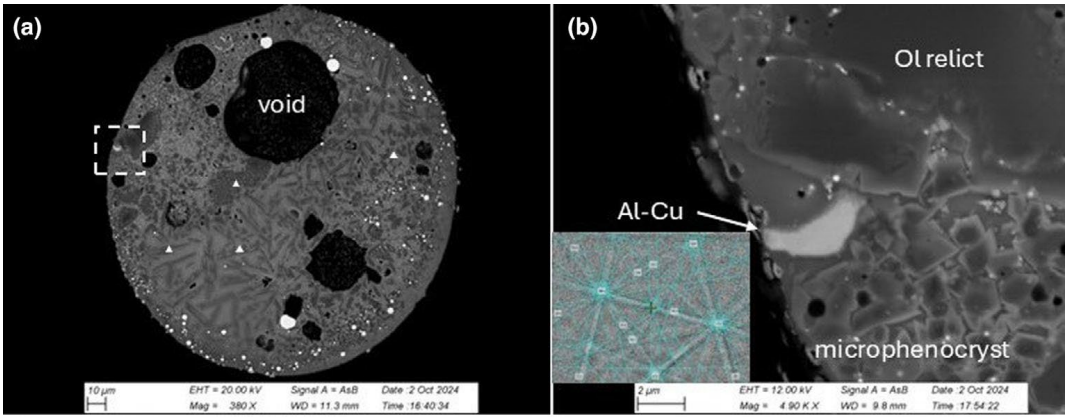

We report the discovery of (Al,Cu)-bearing metallic alloys in two micrometeorites found in the Project Stardust collection gathered from urban rooftop environments in Norway. Most of the alloys are the same as those found in the Khatyrka meteorite and other micrometeorites, though one has a composition that has not been reported previously. Oxygen isotope ratio measurements using secondary ion mass spectrometry show that the Project Stardust samples reported here, like all earlier examples of natural (Al,Cu)-bearing alloys, contain material of chondritic affinity.

Status: published work in Meteoritics and Planetary Science 2025, **60**, 1609

Anomalous Saturation of CO Adsorption at 26% on Cu(111) Governed by Nanometer-Scale Substrate-Mediated Interactions

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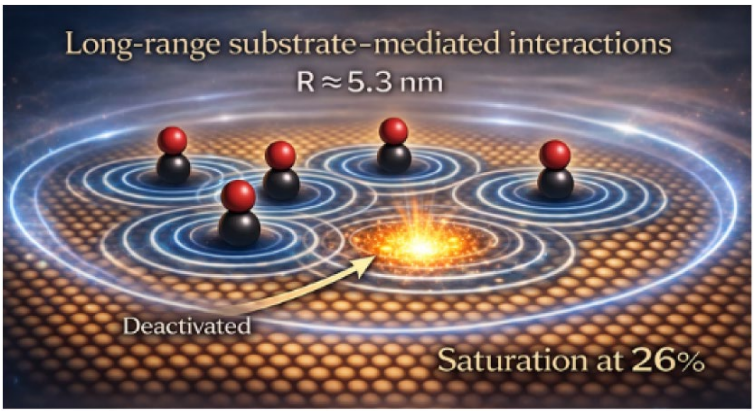

CO adsorption on metal surfaces is a process of fundamental importance in surface science and heterogeneous catalysis. Despite its apparent simplicity, its understanding has often posed a challenge to conventional models. Using scanning probe microscopy (SPM), we have observed that CO adsorption on Cu(111) saturates at ~26%, significantly below the anticipated 33% for the canonical 3 × 3 /R30° structure. This anomalous saturation persists across a wide range of dosing amounts and deposition temperatures, indicating an intrinsic thermodynamic constraint rather than kinetic trapping. Statistical analysis of the SPM images reveals a long-range adsorbate interaction radius of ~5.3 nm that governs the two-dimensional distribution of CO molecules. This nanometer-scale, substrate-mediated indirect interaction induces spatial correlations that suppress higher coverage. First-principles calculations show that increased coverage leads to confinement of Cu(111) surface-state electrons, with overlapping elastic strain fields, both of which reduce CO binding energy. These long-range interactions collectively enforce a self-limiting adsorbate density. Our findings establish that substrate-mediated forces can govern adsorbate arrangements well beyond nearest-neighbor scales. CO/Cu(111) provides a model system in which such effects can be observed directly, serving as a testbed for established theories of adsorption and substrate-mediated interactions.

Status: published work in J. Am. Chem. Soc. 2025, **XXX**, XXXX

Identification of Unique Pd-based Compounds in Twisted $MoTe_2$ Nanojunctions

Guangming Cheng and Nan Yao
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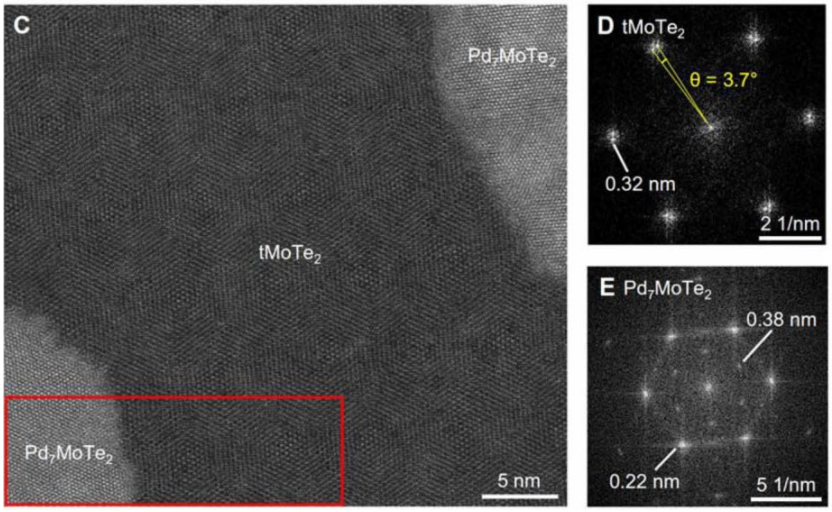

Introducing superconductivity in topological materials can lead to innovative electronic phases and device functionalities. Recent observations of the fractional quantum anomalous Hall effect in twisted bilayer molybdenum ditelluride have confirmed the existence of fractional Chern insulators in the absence of magnetic fields. In principle, the creation of superconductivity in fractional Chern insulators can lead to interesting electronic states of matter. However, creating superconductivity using traditional means in such air-sensitive two-dimensional (2D) moiré materials is challenging. We overcome such challenges by presenting a unique strategy for constructing high-quality superconducting junctions consisting of air-sensitive van der Waals moiré materials, such as twisted bilayer $MoTe_2$. We present systematic characterizations of the junction, including both the atomic structure and the electronic transport behaviors. The key to our approach to fabricating high-quality superconducting moiré junctions is the recently introduced on-chip 2D growth mechanism based on the unexpected discovery of rapid mass transport and crystal growth templated on 2D materials. We use this approach to find that a class of unique Pd-based compounds produced on topological chalcogenides are superconductors. Here, we demonstrated atomic-resolution visualization of a complicated compound (Pd_7MoTe_2) with high crystalline quality by using high-resolution scanning transmission electron microscopy (STEM).

Status: published work in Microscopy and Microanalysis 2025, **31**, 1396

Restructuring of Defective $PtSe_2$ Nanoparticles into Stable Catalyst for Oxygen Reduction Reaction

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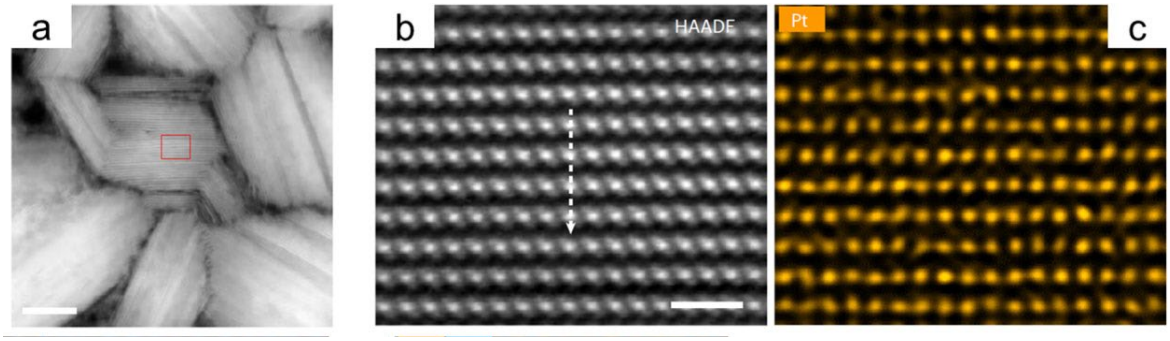

Efforts towards the commercialization of proton-exchange membrane fuel cells and direct methanol fuel cells require the development of efficient and durable catalysts for the oxygen reduction reaction at the cathode, which determines fuel cells' cost, output power, and operation life. Among the various approaches, alloying Pt with 3d transition metals (for example, Fe, Co, and Ni) has emerged as the most effective way to reduce costly Pt usage and simultaneously enhance Pt alloy catalysts' activity. However, despite notable improvements in the optimization of Pt alloy catalysts, they still suffer from durability issues, such as rapid leaching of the acid-soluble transition metal component in the extreme environment of strong acid and highly concentrated O_2 in the electrolyte. Furthermore, toxic gases (such as CO, SO_2, and CH_3OH) originating from hydrogen gas, membrane decomposition, and fuel molecule crossover inevitably deactivate most Pt-based catalysts. PtMe (Me = S, Se, Te) dichalcogenides are promising two-dimensional materials for electronics, optoelectronics, and gas sensors due to their high air stability, tunable bandgap, and high carrier mobility. However, their potential as electrocatalysts for the oxygen reduction reaction is often underestimated due to their semiconducting properties and limited surface area from van der Waals stacking. Here we demonstrate an approach for synthesizing a highly efficient and stable oxygen reduction reaction catalyst by restructuring defective $PtSe_2$ through electrochemical cycling in an O_2-saturated electrolyte. We investigate the atomic structure of the defective $PtSe_2$ by using high-resolution scanning transmission electron microscopy (STEM).

Status: published work in Microscopy and Microanalysis 2025, **31**, 1640

Dissociative chemisorption pathways of oxygen on Nb(100) surface: A first-principles study

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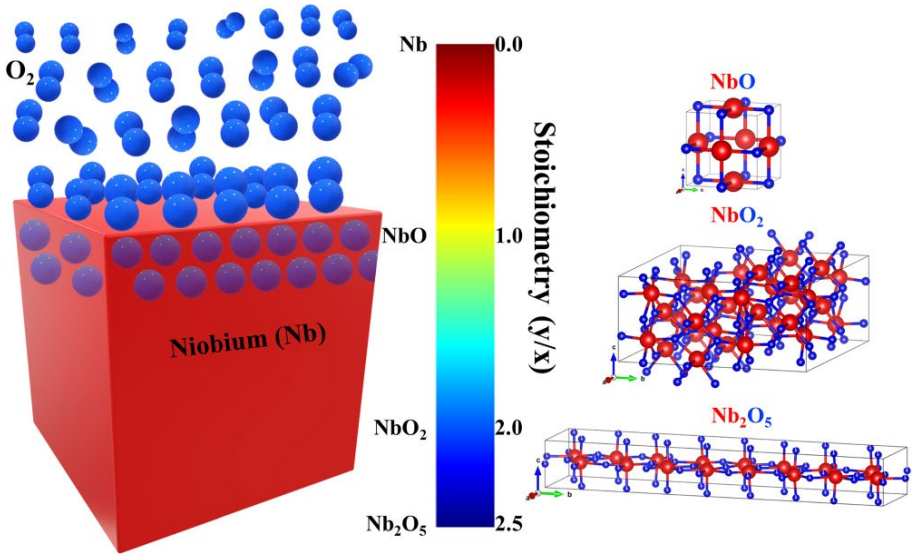

We investigate the dissociative chemisorption of O_2 on the Nb(100) surface using real-space density functional theory. We show that the adsorption process is governed by electrostatic interactions at large O_2–Nb separations, with a preference for the atop site before gradually moving toward the bridge or bridge/hollow site. As the separation decreases below 1.3 Å, O_2 fully shifts to the bridge/hollow site, triggering dissociation. We map the chemisorption channels, analyze the charge transfer, and assess the bond polarity, providing insights into Nb's oxidation mechanism. This understanding lays the foundation for studying oxidation processes and offers potential strategies to mitigate or enhance oxidation in Nb-based materials and devices.

Status: published work in Journal of Applied Physics 2025, **138**, 025302

Surface Atomic Defects and Self-Regulated CO Adsorption on Cu(111): Insights from High-Resolution Scanning Probe Microscopy

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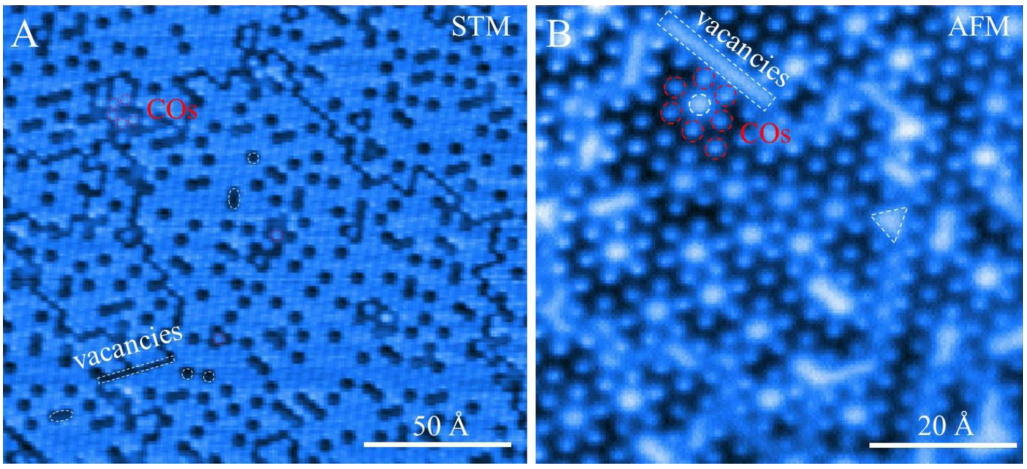

Recent advances in high-resolution scanning tunneling microscopy (STM) and atomic force microscopy (AFM) have enabledvbthe direct visualization and manipulation of individual molecules and atoms in real space. In this work, we investigated the adsorption of CO molecules on Cu(111) surfaces. The system was constructed using a CO-functionalized tip mounted on a qPlus sensor to perform STM/AFM imaging of CO molecules adsorbed on Cu(111) surfaces. Our study demonstrates that high-resolution scanning probe microscopy is a powerful tool not only for visualizing individual surface species but also for uncovering fundamental physical principles. The discovery of a conserved CO coverage of 26% on Cu(111) underscores the role of long-range interactions in surface adsorption phenomena. This work opens new avenues for research in surface science, catalysis, and the development of improved theoretical models that incorporate these nonlocal effects.

Status: published work in Microscopy and Microanalysis 2025, **31**, 1388

Geometric control of hyperbolic exciton-polariton condensate dimers

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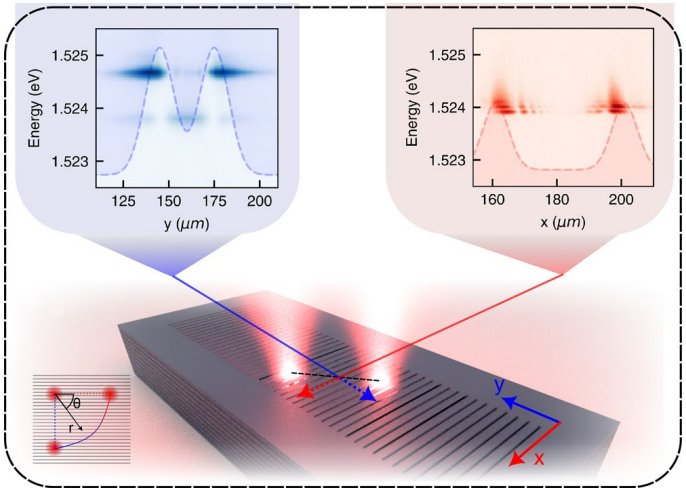

Coupled many-body quantum systems exhibit rich emergent physics with diverse stationary and dynamical behaviours. By engineering platforms with tunable and distinct coupling mechanisms, new insights emerge into the collective behaviour of coupled many body systems. Particles can be exchanged via evanescent or ballistic coupling: the former, based on proximity, yields large spectral splitting, while the latter requires strict phase-matching, analogous to phase-coupled harmonic oscillators and has a smaller impact on the energy landscape. We demonstrate an all-optically tunable quantum fluid dimer based on exciton-polariton condensates in a photonic crystal waveguide with hyperbolic (saddle-like) dispersion. Varying the dimer's angle relative to the grating tunes the coupling from evanescent to ballistic. We directly observe spectral features and mass flow shaped by the saddle dispersion. This work highlights photonic crystals as powerful platforms to explore condensed matter phenomena lying at the interface between delay-coupled nonlinear oscillators and tight binding physics.

Status: published work in Nature Communications 2025, **16**, 9794