Great Lakes Microscopy Society Annual Meeting 2025

October 7, 2025
University of Michigan, Ann Arbor, MI

Application Talks

Gatan: *Recent advances of fast cameras for low dose imaging*

JEOL: *New Developments in atomic resolution field-free S/TEM*

Physical Sciences

Invited speakers:

Qian Chen
University of Illinois, Urbana Champaign

Justin Warner
Michigan Technological University

Life Sciences

Invited speakers:

Alice Liang
New York University

Jotham Austin
University of Chicago

Students/Postdocs Awards

Platform & Poster awards

Travel award

Optional Tours to $(MC)^2$

University of Michigan

Great Lakes Microscopy Society

Who We Are:

Great Lakes Microscopy Society (GLMS), formerly the Michigan Microscopy and Microanalysis Society (MMMS), is a non-profit organization to advancing microscopy and microanalysis through education, collaboration, and knowledge-sharing. Established in 1992 as a local affiliate of Microscopy Society of America (MSA) and Microanalysis Society (MAS), GLMS serves professionals and researchers primarily in Michigan and northwest Ohio region, including the Toledo metropolitan area.

Our Mission:

The mission of GLMS is to foster education, career development and scientific insights in light and electron microscopy and their analytical applications.

Current Officers:

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University of Michigan

President-Elect
Vacant

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Your Microscopy Community Awaits!

GLMS is powered by people like you! To keep our society vibrant and responsive, we're holding open elections for all board positions. Do you have a vision for our community? Know someone who would be a fantastic leader? **Now is the time to act!** Help us build a stronger society by nominating your peers or throwing your own hat in the ring. Join us in leading the way. Scan the QR code to nominate and vote!

Open Elections: October 7th - December 31st, 2025

Great Lakes Microscopy Society Annual Meeting, 7 October 2025

8:00 – 8:45 ***Registration & Check-in with Coffee/Breakfast***

8:45 – 8:50 ***Introductions & Meeting Program Overview*** (Dr. Tao Ma, GLMS President)

8:50 – 9:00 ***Welcoming Remarks*** (Dr. Amit Misra, Director of Michigan Materials Research Institute (MMRI) and Michigan Center for Materials Characterization $(MC)^2$)

Session 1, Physical Sciences: session chair = Dr. Alyssa Fielitz, Dow

9:00 – 9:35 ***Invited GLMS Speaker:*** *Electron Videography and its Automation of Soft and Rare Materials* (Dr. Qian Chen, UIUC)

9:35 – 10:10 ***Invited MAS Student Tour Speaker:*** *The Role of Thermal History on Microstructural Evolution in 316L Stainless Steel Formed via Laser Powder Bed Fusion* (Justin Warner, MITech)

10:10-10:30 ***Break***

10:30-10:45 ***Student Platform Talk:*** *Stoichiometry Recovery via Fused Multi-Modal Electron Tomography* (Jason Manassa, University of Michigan)

10:45 – 11:00 ***Student Platform Talk:*** *Circularly Polarized Light Emission from Chiral Hedgehog Particles Coated with Nanofilms of Achiral Perovskites* (Michael Veksler, University of Michigan)

11:00 – 11:15 ***Student Platform Talk:*** *Unconventional Lattice Reconstruction in Twisted Multilayer* CrI_3 (Nishkarsh Agarwal, University of Michigan)

11:15 – 11:30 ***Vendor Platform Presentation:*** *New Developments in Atomic Resolution Field-Free S/TEM* (Dr. Thomas Isabell, JEOL)

11:30 - 12:30 ***Lunch Break & GLMS Society Business Meeting*** (GLMS Board)

12:30 – 2:00 ***Poster session & Vendor Showcase, Optional MC^2 tours***

Session 2, Life Sciences: session chair = Dr. Jing Liang, University of Michigan

2:00 – 2:35 ***Invited MSA Tour Speaker****: Driving Biological Imaging Through Core Facility: From 2D to 3D* (Dr. Alice Liang, NYU)

2:35 – 3:10 ***Invited MAS Tour Speaker:*** *Don't Call It A Comeback: High Pressure Freezing Has Been Here for Years!* (Dr. Jotham Austin, University of Chicago)

3:10 – 3:30 ***Break***

3:30 – 3:45 ***Student Platform Talk:*** *Exploration of Sex-Based Differences in Pulmonary Fibrosis* (Batoul Chalhoub, University of Michigan-Dearborn)

3:45 – 4:00 ***Student Platform Talk:*** *Endothelialization of Deep Vein Stents by Scanning Electron Microscopy* (Oscar Moreno, University of Michigan)

4:00 – 4: 15 ***Student Platform Talk:*** *Pharmacological Inhibition of Protein Kinase CK2 Rescues Neuron-Glia Dysfunction and Alleviates Striatal Pathology and Motor Deficits in a Mouse Model of Huntington's Disease* (Ross Pelzel, University of Minnesota)

4:15 – 4:30 ***Vendor Platform Presentation*** *Large-Format, Direct Detection Camera for 80-200 keV Cryo-EM Imaging* (Dr. Stephen Mick, Gatan)

4:30 – 4:50 ***Awards Presentation*** (Dr. Ellen Keene, GLMS Program Chair)

4:50 - 5:00 ***Wrap-up/Closing Remarks*** (Dr. Tao Ma, GLMS President)

Platform Presentations

Electron Videography and its Automation of Soft and Rare Materials

Professor Qian Chen, University of Illinois at Urbana-Champaign

I will present our group's recent progress on establishing and utilizing "electron videography" to image, understand, and engineer synthetic and natural nanoparticle systems, in space and time at a nanometer resolution. This involves systems that underpin the fundamentals of structure–functional relationship for a wide range of phenomena and applications. In this talk, we will discuss in detail two types of such systems. The first focuses on metallic nanoparticles assembling into various complex lattices such as Maxwell lattice, a chiral pinwheel lattice, a colloidal moiré pattern, and nanoparticle swarms as promising optical and mechanical metamaterials. The second is on the structural fluctuations and fingering dynamics of membrane protein lipid assemblies. We will show how we build electron videography upon liquid-phase transmission electron microscopy, electron tomography, and four-dimensional scanning transmission electron microscopy, while coupling them with machine learning, automation, and molecular dynamics simulations. I will end the talk by discussing the prospects of autonomous electron videography for understanding and discovery of dynamic multifunctional nanoparticle systems in liquid and at operation at the otherwise inaccessible spatiotemporal precision.

Figure: The Nanoverse. Lateral dimension is about 200 nm.

Dr. Chen is currently a full professor, Racheff Scholar, and University Scholar in the Department of Materials Science and Engineering at the University of Illinois, Urbana-Champaign. She got her B.S. in chemistry from Peking University and her PhD degree from the same department with Prof. Steve Granick (2012). She completed her postdoctoral research with Prof. Paul Alivisatos at the University of California, Berkeley, under a Miller Fellowship. She became a faculty in 2015 and since then has received awards for the research in her group, such as the Forbes 30 under 30 Science List (2016), the AFOSR YIP award (2017), the NSF CAREER award (2018), the Sloan Research

Fellow in Chemistry (2018), the ACS Unilever Award (2018), the Hanwha-TotalEnergies IUPAC Young Scientist Award (2022), the Soft Matter Lectureship (2023), the Provost's Award for Excellence in Graduate Student Mentoring (2024), the MRS Outstanding Early-Career Investigator Award (2024), the ACS *Langmuir* Lectureship (2025), and the *ACS Nano* Lectureship (2025). Her group's research focuses on imaging, understanding, and engineering soft, biological, and energy materials at the nanoscale.

The effect of varying build geometry and laser scan strategies on the microstructure of 316L Stainless Steel Fabricated via Laser Powder Bed Fusion

Justin Warner[1], Sriram Vijayan[1].
[1] Michigan Technological University, Materials Science and Engineering, Houghton, Mi, USA
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In recent years, Additive Manufacturing (AM) has gained attention for its ability to produce intricate parts with reduced tooling and material waste than traditional methods. Laser Powder Bed Fusion (LPBF), a leading AM technique, creates highly accurate components by fusing metal powder in a layer-by-layer process. 316L stainless steel (SS) produced by LPBF often shows superior mechanical properties compared to conventionally manufactured alloys [1]. These improvements are linked to the formation of metastable phases and complex microstructures, along with high dislocation densities caused by the unique thermal-mechanical conditions of LPBF. Processing parameters and part geometry strongly influence a material's thermal history, which in turn dictates its microstructure and defects. However, despite LPBF's processing advantages, gaps in our understanding of the physical metallurgy of these alloys still exist, which hinder its wider industrial adoption. A topic of particular interest is the development of new standards for qualifying parts for safety-critical applications. To address this gap, well-curated process-structure-property datasets of legacy alloys such as 316L SS need to be generated.This study explores how processing parameters affect the microstructure and the resulting mechanical properties of LPBF 316L. A series of samples fabricated with different thermal histories were created by varying part geometry and scan strategies. Sections of these samples were analyzed using Optical Microscopy (OM) and Scanning Electron Microscopy (SEM) to examine solidification structures such as melt pools and solidification cells. X-ray Diffraction (XRD) was used to identify phases and the total dislocation densities, while Electron Backscatter Diffraction (EBSD) provided information on texture and geometrically necessary dislocation densities. Representative images and spectra are shown in Figure 1 (A-D). Results indicate that even under similar laser processing parameters, the dislocation densities in LPBF 316L can be varied. Finally, the implications of the microstructural variations on the mechanical properties are discussed.

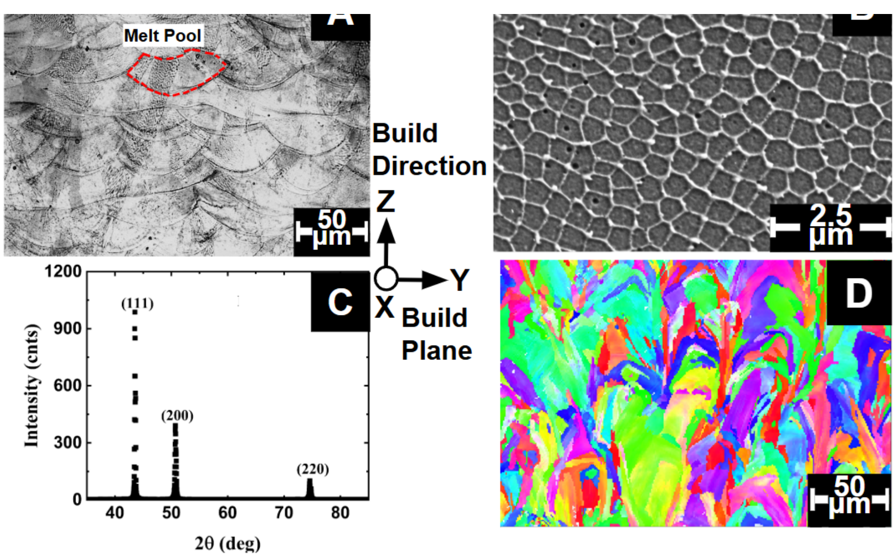

Figure 1: Representative (A) melt pool OM images,

(B) solidification cell SEM images,

(C) XRD spectra, and (D) EBSD inverse pole figure maps obtained parallel to the build direction of the samples.

1. S. R. Narasimharaju *et al. Journal of Manufacturing Processes* **vol. 75**, pp. 375–414.https://doi.org/10.1016/j.jmapro.2021.12.033.

Justin Warner is a second-year doctoral student in the Department of Materials Science and Engineering at Michigan Technological University, where he conducts research in Dr. Vijayan's group. He earned his bachelor's degree in Materials Science and Engineering from the University of Minnesota – Twin Cities. His doctoral work focuses on developing process–structure–property relationships in laser powder bed fusion (LPBF)–processed 316L stainless steel. He utilizes microscopy and spectroscopy techniques, including scanning electron microscopy (SEM), electron backscatter diffraction (EBSD), and X-ray diffraction (XRD), to investigate how processing conditions influence microstructural evolution. His research emphasizes building comprehensive characterization workflows rather than relying on direct mechanical testing, with the overarching goal of improving qualification criteria for LPBF stainless steel components. Beyond his research, he contributes to the microscopy community through his involvement with the Microscopy Society of America Student Council (MSA StC), where he serves as a regional liaison, facilitating collaboration, outreach, and engagement across the society's network.

Stoichiometry Recovery via Fused Multi-Modal Electron Tomography

Jason Manassa[1], Jonathan Schwartz[1,2], and Robert Hovden[1,3*]

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The integration of energy-dispersive X-ray spectroscopy (EDX) and electron energy loss spectroscopy (EELS) tomography with traditional electron tomography allows for nanoscale chemistry analysis in three dimensions. Traditionally, EDX/EELS tomography requires high radiation doses (e.g., > 10^7 e/Å2) that often exceed the threshold of specimen stability, especially for core excitation spectroscopy. The recent advent of fused multi-modal electron microscopy introduces opportunities to minimize the high dosage requirements [1]. Moreover, combining fused multi-modal microscopy with electron tomography (MM-ET) results in three-dimensional chemical analysis of materials with significantly lower electron doses—up to a hundredfold less [1]. Here we show fused MM-ET also improves chemical accuracy and provides stoichiometry without prior knowledge of elemental inelastic cross-sections.

Here we find stoichiometric precision is greatly enhanced by fused MM-ET when compared to traditional chemical tomography. Using a known ground truth specimen—here, nanocubes are either CoO or CuO—a standard deviation from the known stoichiometry can be measured and assessed across all voxels. In Figure 1 we see a wide error (~28% standard deviation) in the recovered stoichiometry. Even under ideal conditions of high SNR and over a hundred chemical projections, stoichiometric standard deviation is around ~9%. However, with fused MM-ET the chemical precision is reduced to a standard deviation of ~4%. At both low and high chemical SNR, data fusion's precision outperformed conventional chemical tomography with a fraction of the chemical tilts. Further experimental validation on eight additional real-world experimental tomographic datasets were also performed. Stoichiometric conclusions from the experimental data showed consistency with expected elemental distributions.

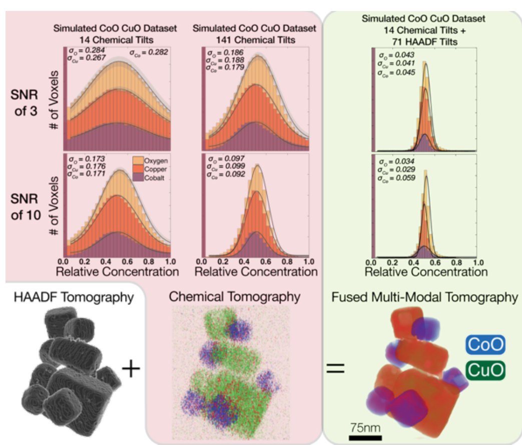

Fig. 1. Synthetic CoO/CuO nanocubes with known stoichiometry measured at various SNRs and chemical projections show imprecise stoichiometric recovery compared to a Fused MM-ET.

1. Schwartz J, et al. Nat Comm (2024) **15:3555**. https://doi.org/10.1038/s41467-024-47558-0

Circularly Polarized Light Emission from Chiral Hedgehog Particles Coated with Nanofilms of Achiral Perovskites

Michael Veksler[1,2,3], Jeffery Raymond[1,2,3], Tao Ma[4,5], David Fairhurst[6], Ravi Sharma[6], Nadine Schrenker[7], Sara Bals[7], Nicholas A. Kotov[1,2,3,4]

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Perovskites are known for strong and tunable luminescence, but the synthesis of materials with circularly polarized light emission is limited by sensitive metal-ligand interactions, variable crystallization patterns, and poorly predictable chirality transfer from molecular precursors. Here we show that generic achiral perovskites can be deposited on chiral 'hedgehog' particles (CHIPs), producing optically active perovskite-coated CHIPs (P-CHIPs) with spectroscopic bands specific of the perovskites and chirality specific of the template particles.[1] The spectral position and chiral polarization of the emission is varied with minimal modification of the deposition protocol or crystallization parameters. Through careful comparison of the polarization of emission to the circular dichroism of P-CHIPs, we demonstrate that the observed polarized emission is due to the post-emission scattering of photons off the chiral surfaces of CHIPs. This points to their application as single-particle sources of circularly polarized light emission, amenable to various applications. Furthermore, by examination of the inherent red-orange luminescence of CHIPs, as well as single-particle circularly-polarized microscopy (CIRPOM) we find that the chiral emission profile is heavily dependent on the chiral geometry of the microparticle assembly, confirming the action of a strong chiral scattering component on emission characteristics.

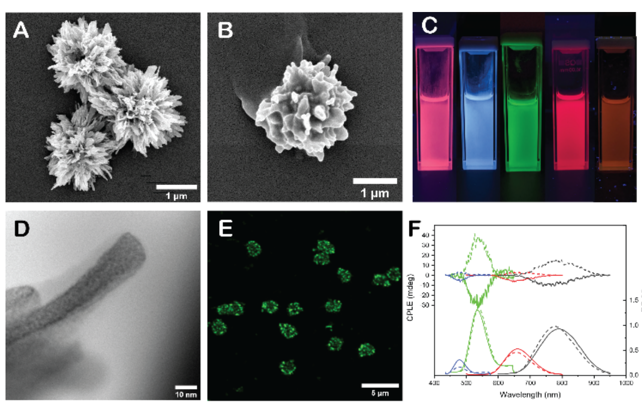

Figure 1. (**A**) SEM image of CHIPs as-synthesized. (**B**) SEM image of CHIPs coated with luminescent perovskite $FAPbBr_3$. (**C**) Photograph of colloidal dispersion of P-CHIPs of varying perovkite composition under UV illumination. (**D**) BF-STEM image of a spike of P-CHIPs. (**E**) Z-stack maximum projection of confocal fluorescence micrograph of $FAPbBr_3$ P-CHIPs. (**F**) CPLE of L- (solid) and D- (dashed) P-CHIPs coated with variable perovskite composition.

1. Veksler, Michael, et al. "Circularly Polarized Light Emission From Single Chiral Hedgehog Particles Coated with Nanofilms of Achiral Perovskites." *Advanced Materials* (2025): e18765.

Unconventional Lattice Reconstruction in Twisted Multilayer CrI_3

Nishkarsh Agarwal[1], Suk Hyun Sung[2], Zeliang Sun[3], Liuyan Zhao[3], and Robert Hovden[1,4,*].

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[2] The Rowland Institute at Harvard, Harvard University, MA, USA.
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Moiré engineering of van der Waals (vdW) magnetic materials could induce tremendous exotic phenomena like non-trivial magnetic states and moiré magnon networks [1, 2]. One such system is twisted double bilayer (tDB-) CrI_3, where spin frustration in individual moiré cells results in coexisting ferromagnetic (FM) and antiferromagnetic (AF) ground states [3-5]. However, the structure of few layer twisted CrI_3 still remains relatively unstudied. Dark-field transmission electron microscopy (DF-TEM) and selected area electron diffraction (SAED) are powerful techniques for characterization of moiré domains in twisted materials providing information on the stacking order, real-space periodicity, and soliton boundaries [6]. These diffraction-based techniques are especially useful for air-sensitive systems like 2D vdW magnets where crystalline capping layers obscure real space signals [7].

Here, we report unconventional torsional lattice relaxation of low-angle twisted two-dimensional magnet CrI_3 using DF-TEM. The moiré pattern of twisted double bilayer (tDB-) CrI_3 results in complicated spatial magnetic structure [5]. Competition between interlayer vdW interaction and intralayer elastic energy induces torsional periodic lattice distortions (PLDs) where lattices get reconstructed into non-trivial domain structures [8]. Using DF-TEM and SAED, we unveil the PLD in tDB-CrI_3 moiré structure arising from 2nd order distortions (Q2 distortion), explaining the underlying lattice relaxation.

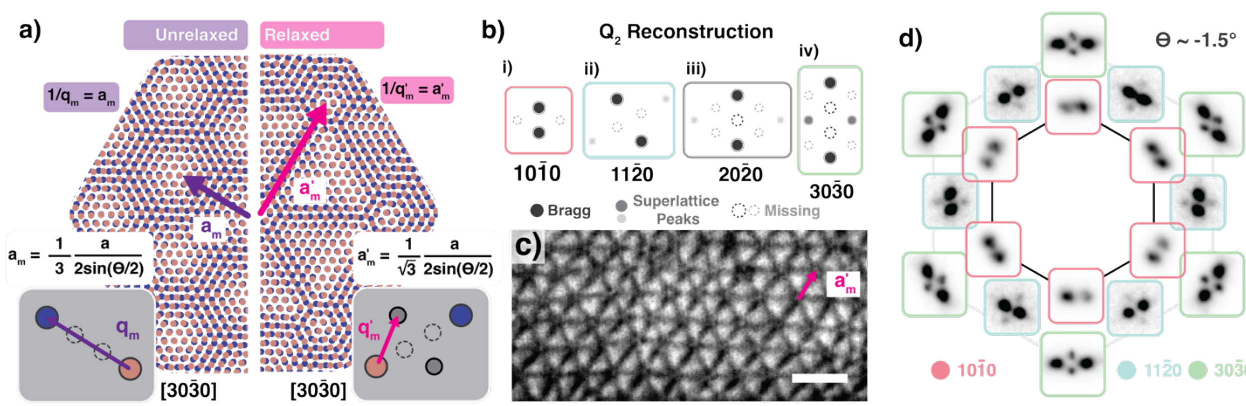

Fig. 1. | Q_2 Reconstruction and relaxation of moiré lattice in twisted CrI_3. a) Real-space diagram of simple twisted hexagonal bilayer, showing before (unrelaxed) and after (relaxed) reconstruction. b) (i–iv) Schematic diagram of potential superlattice peak locations around each Bragg peak. c) Corresponding DF-TEM of tDB CrI_3 showing characteristic triangular moiré domains. Scale bar is 25 nm. d) SAED patterns from -1.5° tDB-CrI_3 device.

References:
[1] C Gong et al., *Nature* **546** (2017); [2] B Huang et al., *Nature* **546** (2017); [3] T Song et al., *Science* **374** (2021); [4] Y Xu et al., *Nat. Nanotechnol.* **17** (2022); [5] H Xie et al., *Nat. Phys.* **18** (2022);

[6] JS Alden et al., *Proc. Natl. Acad. Sci.* **110** (2013); [7] B Yang et al., *Nat. Mater.* **22** (2023);

[8] SH Sung, et al., *Nat. Commun.* **13** (2022).

New Developments in JEOL's Atomic Resolution Field-Free S/TEM (MARS)

Dr. Thomas Isabell,

JEOL USA, Inc. Peabody, MA, USA

The Magnetic field-free Atomic Resolution System (MARS) from JEOL represents a breakthrough in high-resolution scanning/transmission electron microscopy (S/TEM), enabling atomic-scale imaging and analysis in a magnetic field-free environment. Contrary to conventional high-resolution TEMs, wherein the sample sits within the large magnetic field of the objective lens, the MARS utilizes dual oppositely-wound lenses with a resulting magnetic field that is canceled at the sample plane. Employing a higher-order aberration corrector then allows for atomic-level imaging in this field-free environment.

The ability to perform S/TEM without subjecting a specimen to a high magnetic field broadens the characterization prospects for existing classes of materials while also expanding atomically-resolved analytical capabilities to steels and other magnetic materials. The latest analytical data as well as new developments from the MARS system will be discussed.

Driving Biological Imaging Through Core Facility: From 2D to 3D

Alice Liang

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Fengxia.liang@nyulangone.org

With the rapid development of microscopy technologies and methods, centralized research facilities that provide access to state-of-the-art instrumentation and professional expertise have become indispensable to the scientific community. Established in 2005 within a rapidly expanding medical school, the Microscopy Core Laboratory at NYU School of Medicine has evolved from an electron microscopy-focused facility into a comprehensive, school-wide imaging core encompassing both light and electron microscopy. Today, the Core supports not only NYU researchers but also the broader scientific community, including neighboring academic institutions and industry partners.

Modern electron microscopy enables high-resolution examination of the fine structural details of cells and tissues in both two- and three-dimensional modalities. Volume electron microscopy (vEM) has become a powerful approach for addressing biological questions, incorporating TEM-based methods, such as serial section imaging and serial electron tomography, as well as SEM-based platforms including array tomography, focused ion beam-SEM (FIB-SEM), and serial block face-SEM (SBF-SEM). The integration of correlative microscopy has further expanded these capabilities, driven by a resurgence of interest in ultrastructural organization, along with innovations in instrumentation and advances in specimen preparation [1 -3].

As a research-driven microscopy core, we engage in projects spanning a wide spectrum of biological systems. The success of these efforts depends on selecting the most appropriate imaging strategies, careful designing experiment, optimizing sample preparation for ultrastructural preservation [4], and employing methods to localize specific proteins at the subcellular level [5]. Our work ranges from *in vitro* cultured cells to parasites and mammalian tissues, enabling high-resolution imaging and impactful visualization of biological processes from 2D to 3D. Through these approaches, we aim to drive forward discoveries in biomedical research.

References:

1. McDonald KL and Auer M. *Biotechniques* (2006) **41**137-143.https://doi.org/10.2144/000112226
2. Krijnse Locker J and Schmid SL. *PLos Biol*. (2013) **11** e1001639. doi: 10.1371/journal.pbio.1001639
3. Peddie CJ and Collinson LM. *Nat Rev Methods Primers* (2022) **7** 51 doi: 10.1038/s43586-022-00131-9
4. Liang FX. *Microsc. Today* (2021) **29** 18-23. https://doi.org/10.1017/S1551929520001777
5. Liang FX and Delmar M. *Methods Cell Biol.* (2023) **177** 55-81 DOI: 10.1016/bs.mcb.2022.12.020

Dr. Alice Liang is the Director of Microscopy Laboratory at New York University Grossman School of Medicine, and Professor in the Department of Cell Biology. She serves on the Council of the Microscopy Society of America and was the Biology Director (2021- 2024).

She earned her Ph.D. in Cell Biology from Peking University under the joint mentorship with New York University (NYU) School of Medicine, followed by postdoctoral training on urothelial differentiation that led to 28 publications. In 2005, she founded the Electron Microscopy Core at NYU Skirball Institute, expanding it from two TEMs into a school-wide imaging facility now serving over 190 laboratories and 50 external institutions.

In addition to advancing imaging technologies, Dr. Liang is deeply committed to education - teaching graduate courses at NYU and the American Museum of Natural History, and leading EM courses at CUNY Hunter College. She has organized three volumeEM symposiums at the Microscopy and Microscopy Analysis annual meeting (M&M), conducted workshops and training at local and national meetings to promote the local applications of EM technologies.

Under her leadership, the NYU Microscopy Laboratory has contributed to more than 400 publications, with images cited in textbooks and featured in *New York Times*. She has received multiple awards, including M&M Diatome Prizes, NIH/Chan Zuckerberg Imaging funding, and the Core is a major share resource in the awarded Cancer Center Grant. With more than 30 years of microscopy experience, Dr. Liang has established the Microscopy Core as a vital resource supporting research across NYU Langone Health and beyond.

Don’t Call It A Comeback: High Pressure Freezing Has Been Here For Years!

Jotham R. Austin II

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High-pressure freezing (HPF) emerged as a transformative technique in biological electron microscopy, offering unparalleled preservation of ultrastructure in cells and tissues by vitrifying samples up to 600 µm thick without ice crystal damage. Unlike conventional chemical fixation, which selectively cross-links macromolecules and risks introducing artifacts, HPF reduces the rate of ice nucleation under pressures of ~2100 bar, effectively maintaining the “live state” of biological material. This approach enables high-resolution, quantitative imaging of complex systems, from macromolecular assemblies to whole tissues.

In this lecture, I will review the principles of HPF and freeze substitution (FS), discuss best practices for preparing healthy and representative specimens, and highlight how fillers, cryo-carriers, and sample handling strategies critically influence outcomes. When combined with CLEM or cryo-focused ion beam (cryo-FIB) milling, HPF expands into a robust pipeline for 3D tomography, bridging molecular and tissue-level perspectives. Case studies will include chloroplast thylakoid membranes, airway smooth muscle, yeast, cyanobacteria, bacterial colonies, and a new project studying cytoneme formation during embryonic development. These projects underscore HPF’s role not only as a preservation method but also as a gateway to multiscale “Google Earth”-style exploration of biological systems linking molecules, cells, and tissues within the same experimental framework.

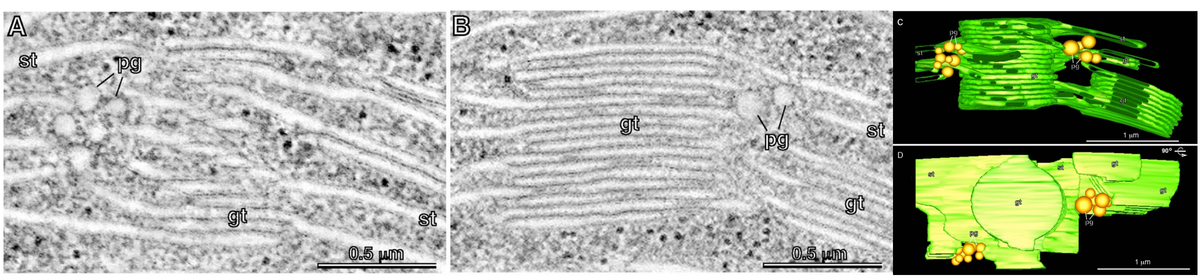

Fig. 1. A, B) HPF/FS tomographic slices of thylakoid membranes. C, D) 3D tomographic models. st: stroma; gt: grana; pg: plastoglobules

References:

1. Austin JR, Staehelin LA. Three-dimensional architecture of grana and stroma thylakoids of higher plants as determined by electron tomography. *Plant Phys.* 2011, 155: 1601-1611. DOI: https://doi.org/10.1104/pp.110.170647
2. Graham B, Austin JR, Kaech A, Heuser JE. Freezing techniques: History, Comparisons, and Applications. *Microscopy Today*. 2008, 16:12-17. DOI: https://doi.org/10.1017/S1551929500061708
3. Austin JR. High-Pressure Freezing and Freeze Substitution of Arabidopsis for Electron Microscopy. In: Arabidopsis Protocols, Methods in Molecular Biology (Methods and Protocols), vol 1062. Eds: Sanchez-Serrano JJ, Salinas J. Humana Press, Totowa, NJ. 2014, Pg: 473-486. DOI: https://doi.org/10.1007/978-1-62703-580-4_25

Jotham R. Austin II, Ph.D. is a Research Associate Professor in the Department of Molecular Genetics and Cell Biology and Director of the Advanced Electron Microscopy Facility at the University of Chicago. Trained at Arizona State University and the University of Colorado–Boulder, he has built a career advancing methods in electron microscopy, from high-pressure freezing to 3D electron tomography. Since 2005, he has led the development of vEM, cryo-SPA, and cryo-ET, at UChicago, guiding researchers in visualizing cellular architecture across resolution scales. Beyond the lab, Jotham is also an author and science communicator, blending his expertise in imaging with storytelling through fiction and his podcast, Rabbit Hole of Research.

Exploration of Sex-Based Differences in Pulmonary Fibrosis

Batoul Chalhoub[1*], Dr. Caymen Novak[2],

[1]Mechanical Engineering Department, University of Michigan-Dearborn, Dearborn, Michigan, USA
* Corresponding author: batoulch@umich.edu

Idiopathic pulmonary fibrosis (IPF) is a long-term and progressive lung disease that causes scar tissue buildup in the lungs. It is more prevalent in males than in females, indicating sex-based differences in incident rate and progression of the disease. This research focuses on studying the morphological differences in male and female fibroblasts in 3D matrices under control and treated conditions, in addition to comparing sex-based fibrotic progression.

Pulmonary fibroblasts derived from male and female porcine lungs were encapsulated in 3D collagen matrices. The cultures were maintained under both control and profibrotic conditions. Cellular morphology was assessed at various timepoints from day 0 to day 3. Transforming growth factor beta (TGF-β) was used to induce the activation of fibroblasts and extracellular matrix deposition. Confocal laser scanning microscopy (Olympus FV1200) was used to capture both the cells as well as the gel matrix surrounding them, giving insight into the interactions between the cells and their environment. The images were then analyzed using ImageJ software, providing the morphological quantification of the cellular area, aspect ratio, and circularity.

Results revealed distinct morphological responses between male and female fibroblasts under TGF-β treated conditions. Male fibroblasts showed an increase in cell area and spreading, and circularity in female fibroblasts was significantly decreased. This indicated elongation, which is linked to remodeling and migratory behavior in fibroblasts.

These findings indicate that male and female fibroblasts differ in response to profibrotic stimulus. Future directions include expanding to additional cell lines, as well as quantifying extracellular matrix remodeling. These findings will provide insight into how the cells interact with their environment, which will aid in better understanding of sex-based differences in IPF progression.

1.

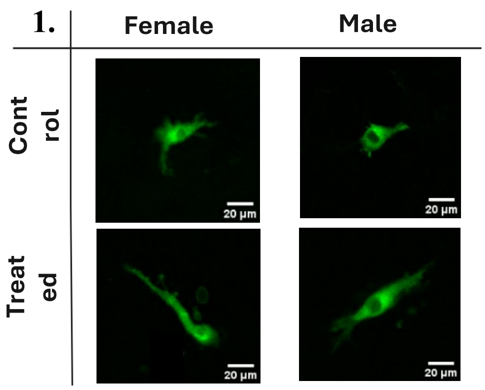

Figure 1: Representative images of cellular morphology in male and female pulmonary fibroblasts cultured in 3D.

2.

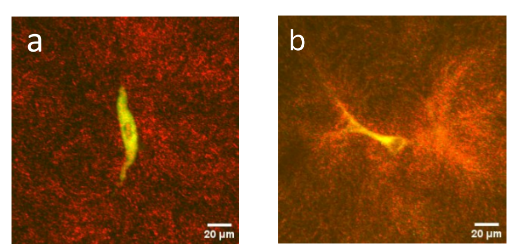

Figure 2: Representative images of pulmonary fibroblasts highlighting the matrix remodeling under a) control and b) profibrotic conditions.

Endothelialization of Deep Vein Stents by Scanning Electron Microscopy

Oscar Moreno[1*], Trevin Eggleston[1], Catherine Luke[1], Amber Clay[1], Sabrina Rocco[1], Kevin Hughes[2], David Gordon[3], Daniel D. Myers[1, 4], Thomas Wakefield[1], Peter Henke[1], Andrea Obi[1].

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Introduction: Venous stenting treats deep vein thrombosis (DVT) by relieving symptoms. Still, it carries a risk of thrombosis after implantation, which decreases after the stent is fully covered by endothelium—a process not previously studied in human veins. Before using new stents in patients, their safety and effectiveness must be tested in animal models. Traditionally, large animals have been used and are often expensive. Our new rodent models offer a more efficient and accessible way to study how venous stents function and how they respond over time.

Methods: In this study, we developed a new microsurgery rodent model to implant nitinol venous stents (3x5 mm) in the inferior vena cava (IVC) of *Sprague-Dawley* rats. (**Fig. 1A-B**). After stent implantation, the rats were anticoagulated with enoxaparin. We monitored stent openness (patency) using ultrasound and examined how the stents were covered by endothelial cells after 7-, 14-, and 21-days using scanning electron microscopy (SEM). Stent coverage measurements were performed on QuPath 0.6.0.

Results: Our findings revealed that all stents stayed open, and endothelial coverage improved over time. (**Fig. 1C**). Following stent placement, we saw extracellular matrix deposition (ECM) that endothelial cells use as a scaffold to attach to. At 7 days, 66% of the stent surface was covered by endothelial cells. At 14 days, coverage increased to 87%, and by 21 days, it reached 91%. (**Fig. 2**). These findings are significant because a fully restored endothelial surface helps maintain stent openness and prevents new clot formation.

Conclusion: In summary, this work introduces a new and practical rodent system for studying venous stent performance, providing a reliable and cost-effective option for preclinical testing. These models can help accelerate the evaluation and improvement of future stent designs before clinical use, providing a promising new platform for preclinical testing of venous stent

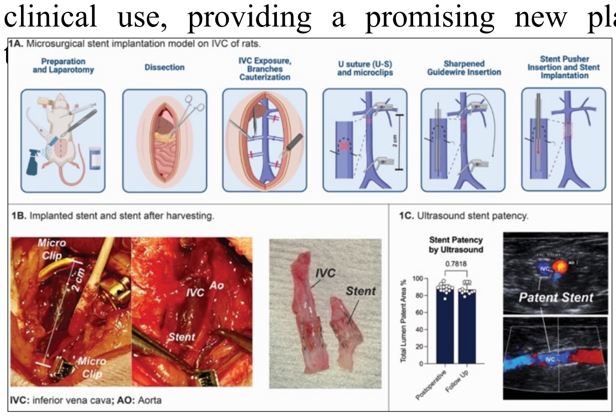

*Fig. 1. **A.** In vivo inferior vena cava (IVC) stent deployment model in rodents. **B.** Rat IVC with a stent implanted. **C.** Stent patency by ultrasound.*

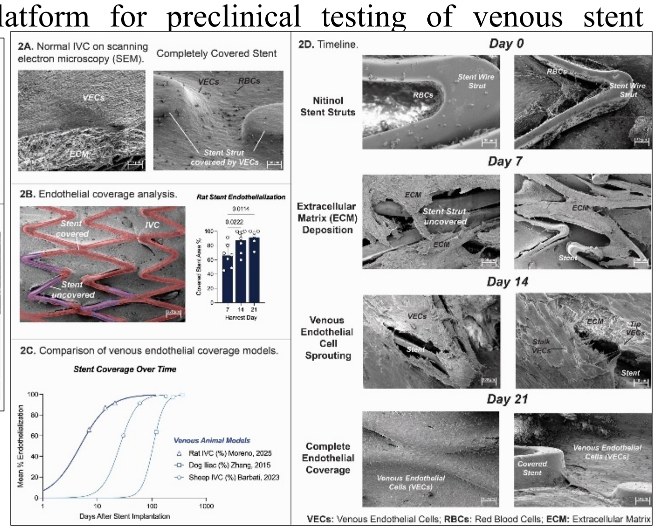

*Fig 2. **A.** Normal IVC by SEM and a completely endothelium-covered stent. **B.** Stent coverage quantification on QuPath; **C.** Comparison of venous endothelization with other animal models. **D.** Timeline of stent coverage.*

Pharmacological Inhibition of Protein Kinase CK2 Rescues Neuron-Glia Dysfunction and Alleviates Striatal Pathology and Motor Deficits in a Mouse Model of Huntington's Disease.

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Huntington's disease (HD) is an autosomal dominant neurodegenerative disease caused by a CAG triplet-repeat expansion in the huntingtin gene (*HTT*), resulting in cognitive, psychological and motor impairments. Pathological hallmarks of the disease include aggregation of mutant HTT protein (mHTT), selective degeneration of striatal medium-spiny neurons (MSNs) and striatal astrogliosis, resulting in the robust striatal degeneration characteristic of human HD. To date, effective therapeutic treatments for HD have not been identified. Protein kinase CK2, a serine/ threonine kinase involved in a large variety of cellular functions including neuroinflammation and protein quality control regulation has been investigated in a wide variety of diseases including other neurodegenerative disorders and cancer. CK2 possesses two catalytic subunits alpha (CK2a) and alpha prime (CK2a') with distinct expression distribution and substrate specificity. We found that CK2a' is pathologically induced in the striatum of HD patients and mouse models and CK2a' haploinsufficiency reduced mHTT aggregation, restored RNA signatures associated with neuronal and astrocytic functions, and ameliorated motor deficits in a knock-in mouse model of HD (zQ175). To determine the therapeutic potential of CK2a' in the treatment of HD we utilized an FDA designated orphan drug, and CK2 inhibitor CX4945 (Silmitasertib), currently in clinical trials for treatment of various cancers. We showed CX4945 was well tolerated in mice and effectively inhibited phosphorylation of key CK2 targets in the striatum demonstrating effective target engagement in the brain. Importantly, zQ175 HD mice treated with CX4945 showed ameliorated motor deficits compared to vehicle treated mice, decreased mHTT aggregation and neuropathology. CX4945 also had a profound effect in ameliorating astrocyte dysfunction in HD mice. Using high resolution confocal and live cell 2-photon imaging, we found astrocytes in the striatum increased uptake of mHTT aggregates due to increased phagocytosis, rescued calcium signaling dynamics and presented increased spatial and subtype distribution. These results suggest novel cell and non-cell autonomous processes in both neurons and astrocyte in HD and establish CX4945 as a promising therapeutic agent for HD.

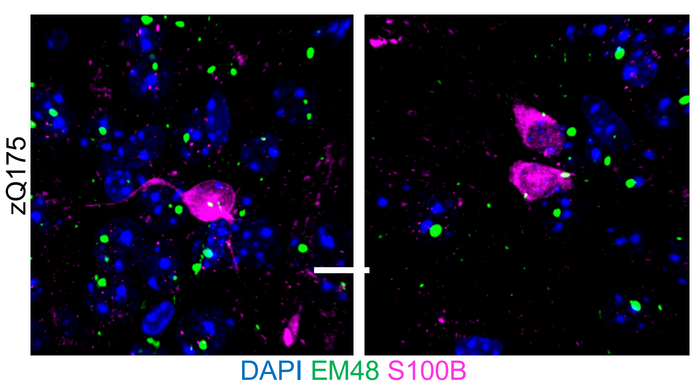

Figure 1. CX4945 treatment increases uptake of mHtt aggregates by astrocytes and spares neurons. Scale bar = 3uM

Large-Format Direct Detection Camera for 80-200 keV Cryo-EM Imaging

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Single-particle cryo-electron microscopy (Cryo-EM) has emerged as a leading technique in structural biology for elucidating the structures of dynamic macromolecules. High-resolution cryo-EM typically requires high-voltage cryo-transmission electron microscopes (cryo-TEMs) equipped with coherent field emission gun (FEG) sources, stable columns, autoloader systems, and counting direct detection cameras, all of which are expensive. Recently, the use of 100-keV cryo-TEMs has been proposed to increase accessibility to cryo-EM and reduce its operational costs. Advancements in direct detection technology have led to the development of the Alpine camera, exhibiting an entirely new pixel design and significant improvements in detective quantum efficiency (DQE) at lower voltages (≤200 keV). The Alpine detector has achieved sub-2Å reconstructions of apoferritin (Figure 1) and ~3.2Å for the LKB1 complex at 120 keV on a TFS Glacios microscope [1]. Detailed analysis showed that Alpine reconstructions are comparable to K3 reconstructions at 200 keV. Remarkably, the Alpine LKB1 reconstructions at 120 keV outperformed the 200 keV data obtained using either the Alpine or K3 detectors. These findings suggest that lower-voltage TEMs, when paired with advanced detectors, could leverage the advantages of lower accelerating voltages and expand the scope of cryo-EM to include small proteins.

Additionally, upgrading a standard 120-keV LaB6 TEM with the Alpine camera achieved 2.65Å resolution for apoferritin (Figure 2), 4.33Å for 64 kDa hemoglobin, and 4.4Å for the 153 kDa GPCR (M4 muscarinic acid receptor) [2]. Such a configuration offers a cost-effective solution for obtaining high-quality cryo-EM structures without needing FEG sources, further lowering the economic barrier for advanced cryo-EM studies.

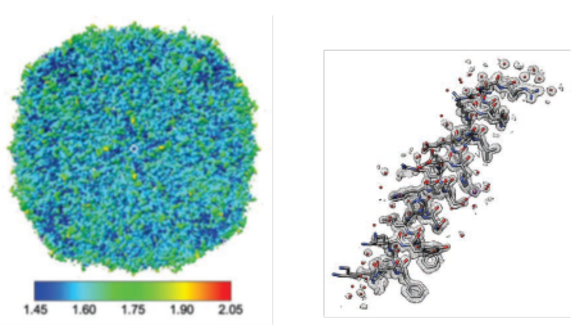

Figure 1. 1.76Å reconstruction of Apoferritin using Alpine on a Glacios at 200keV.

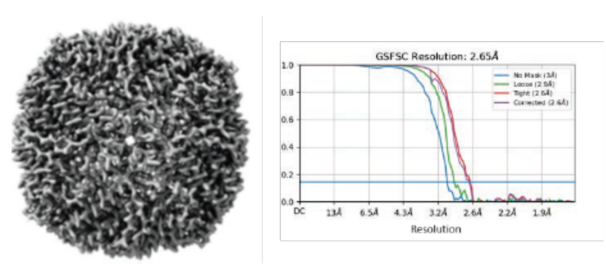

Figure 2. 2.65Å reconstruction of Apoferritin using Alpine on a Tecnai 120-keV LaB6 G2 Spirit TWIN.

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PS.1: **Hierarchical Self-Assembly of Structurally Complex Chiral Hedgehog Particles**

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Abstract: Hierarchically organized particles are so named because they exhibit multiscale structural organization, incorporating both molecular and nanoscale elements. The design of complex supramolecular architectures from simple inorganic components remains a central challenge in nanoscience.[1] Here, we report the hierarchical self-assembly of Gold–Penicillamine (Au-pen) complexes into spiked, hedgehog-like supraparticles. These assemblies arise from controlled coordination between gold ions and the ligand penicillamine, which introduces both steric and chiral constraints during particle growth. The tendency for random agglomeration was reduced by the introduction of cetyltrimethylammonium bromide due to the strong electrostatic repulsion. The resulting structures exhibit high anisotropy and multiscale organization, reminiscent of biomineralized composites, despite being formed from polydisperse precursors. Morphological characterization was analyzed using scanning electron microscopy, while chiroptical properties were examined through circular dichroism and Raman optical activity spectroscopy. Confocal microscopy and fluorescence spectroscopy were employed specifically to investigate liposome trapping, highlighting the functional capabilities of the Au-pen hedgehogs. Their complex organization arises from competing chirality-driven assembly constraints, making the assembly pathways more reliant on nanoparticle symmetry than on particle size. Our findings highlight how subtle variations in temperature, pH and coordination chemistry can guide the emergence of shape complexity and surface roughness at the nanoscale. These Au-pen hedgehogs represent a new class of supramolecular particles with potential for chiroptical sensing, pH-responsive behavior, and tunable surface interactions in biomedical applications.

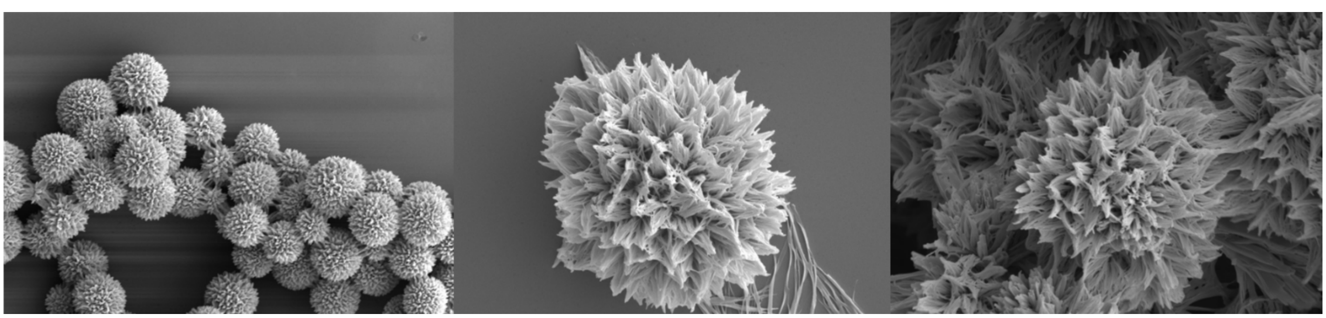

Fig. 1. SEM images of Au-L-Pen chiral Hedgehog particles

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PS.2: **Liquid Mediated Reaction Pathway in the Formation of High Entropy Oxides**

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Abstract: High entropy oxides (HEOs) are materials that emerge when contributions from configurational entropy become large enough to overcome unfavorable enthalpic conditions. The theory their discovery has relied on calculation of the stability of precursors and the final product, which neglects intermediate phase evolution. We report a surprising liquid copper phase intermediate in the otherwise solid-state synthesis of (MgCoNiCuZn)O. Using a multimodal, *in-situ* approach, identify two-fold CuO reduction followed by the emergence of a Cu melt that facilitates the rapid homogenization of the cationic elements and subsequent recrystallization under reducing environments. Modifying the composition and phase of reaction constituents to promote (eliminate) this liquid intermediate will facilitate (prevent) formation of the single phase in multiple high entropy systems. Liquid phase reaction intermediates will enhance our ability to realize compositionally complex materials that would otherwise not be expected to be achieved and will need to be considered in the prediction of synthesizable solid-state reactions.

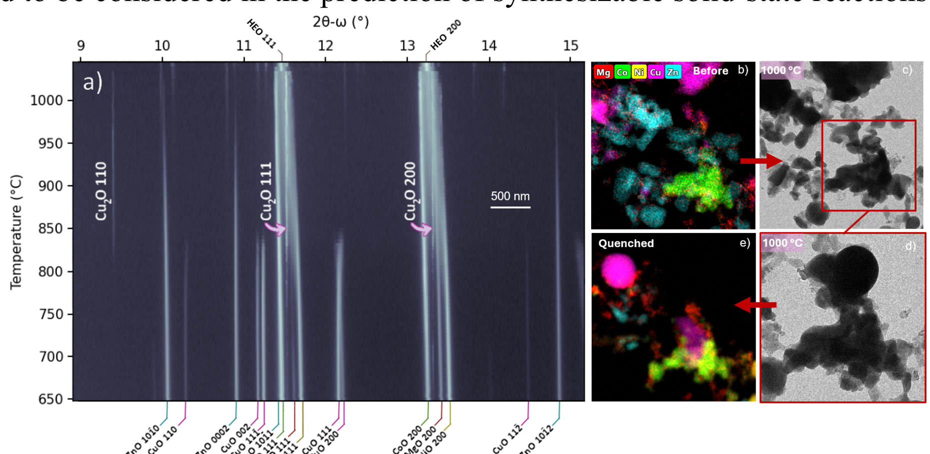

Fig. 1: HEO synthetic pathway. A) Shows XRD during reaction from binary components to HEO. b-e showcase formation of the liquid intermediate at 1000 °C

PS.3: **A Novel STEM-EDX Tomography Approach for 3D Phase and Morphology Reconstruction in Z-Contrast Challenged Nano-systems**

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The conventional high-angle annular dark-field (HAADF) STEM tomography, which relies on Z-contrast for phase differentiation, is ineffective for materials with closely matched effective atomic numbers (Zeff). Furthermore, diffraction-based contrast mechanisms in bright-field (BF) and low-angle annular dark-field (ADF) STEM are susceptible to crystalline artifacts and orientation-dependent intensity variations, which severely compromise the signal-to-noise ratio and limit phase visibility across the required tilt range. Using a nanoscale Al–Si eutectic as a model system, we demonstrate these inherent limitations, highlighting the failure of traditional fine-scale characterization techniques to resolve the true 3D morphology and phase distribution. To circumvent these challenges, we have developed a novel approach based on STEM-energy-dispersive X-ray spectroscopy (EDX) tomography. We will present the optimized experimental parameters, including beam current, dwell time, and tilt increment, and discuss a specialized post-processing workflow. This methodology enables the acquisition of reliable 3D reconstructions with high spatial resolution and chemical specificity, providing an accurate representation of the intricate eutectic morphology and interfacial phase relationships that are otherwise inaccessible with conventional techniques.

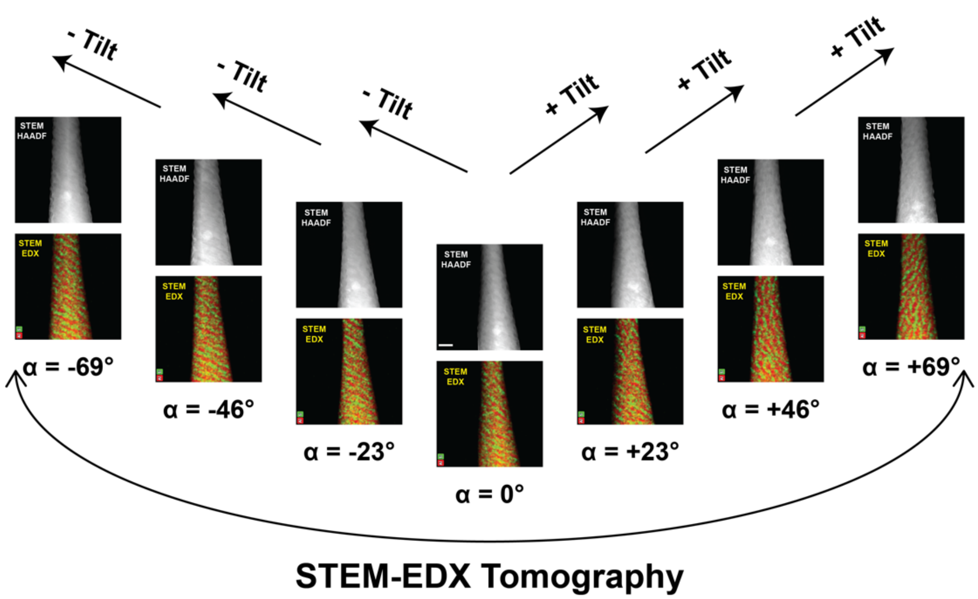

Fig. 1. Series of STEM-EDX micrographs in between the tilting range from -70° to +70° used for the tomography reconstruction (In actual experiment, we took the micrographs at every 3° interval, but a few tilt angles are presented here for space constraint).

PS.4: **High-Throughput Characterization of Particle Assemblies by Stochastic Trapping in Micropatterns**

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Spiky and twisted morphologies of organic-inorganic particles found in living systems often perform specific functions that simple spherical particles cannot achieve. These structures result from hierarchical assemblies of molecular and nanoscale units and are characterized by their structural complexity. Due to the nature of stochasticity and coexistence of order and disorder, utilizing these particles as functional materials precise quantification of the property distribution for individual particles. Herein, we present a high-throughput analysis method for single "hedgehog" particles, which exhibit rapid attachment to and isolation of exosomes. We have developed a methodology to effectively isolate each particle and collect multi-dimensional data. Our results demonstrate the effective capture of exosomes by the hedgehog particles and provide precise quantification of their interaction kinetics. Our methodology offers a guideline for characterizing functional complex nanoassemblies. (Preference: Poster presentation)

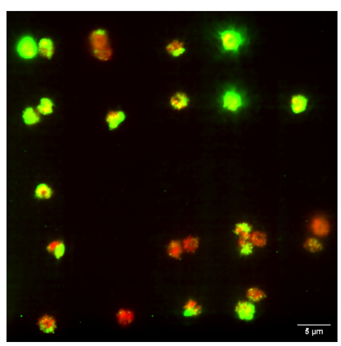

Fig. 1. Laser scanning confocal microscopic image of hedgehogs (red) and captured liposomes (green). (Scale bar: 5 μm)

PS.5: **Operando Visualization of Rate Capability Improvements in 3-D Composite Solid-State Battery Electrodes**

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Solid-state batteries (SSBs) offer improved safety and energy density (>400 Wh/kg). In SSB electrodes, point contacts exist between active material (AM) and solid electrolyte (SE) phases. Therefore, ionic and electronic transport is strongly influenced by AM and SE contents and electrode microstructure (i.e., tortuosity), which often results in rate limitations. Furthermore, their rate capability is strongly dependent on the thickness (or electrode capacity), composition, and microstructure of the electrode. As a result, tradeoffs between energy and power density have been noticed, which exacerbate at high charging rates [1]. Therefore, it warrants underlining the factors, probing the rate limitation mechanisms, and proposing new approaches to improve the rate capability of composite SSB electrodes. Herein, graphite/Li6PS5Cl composite electrodes of varying composition and capacity were chosen as a model electrode system [2]. Leveraging the color change ability of graphite with respect to the state of charge (i.e., LixC phase; SOC), operando optical microscopy was performed to investigate the rate limitation mechanisms in composite SSB electrodes. Operando optical microscopy established the occurrence of global and local SOC heterogeneity across the electrode thickness and within the AM particle domains, respectively. An electrostatic potential drop is seen within the SE phase, while solid-state diffusion exists within the AM domains. Moreover, these local SOC heterogeneities appear stronger for thick and high-capacity electrodes. Combining ex-situ electrochemical results, operando visualization, and simulation predictions, we fabricated 3-D composite SSB electrodes having optimum composition-cum-microstructure by a facile templated method. The 3-D SSB electrodes showed improved homogeneity in the local SOCs throughout the electrode thickness and high-rate capability. Overall, the insights presented in this study will enable new strategies to overcome power/energy tradeoffs in SSBs with composite electrodes.

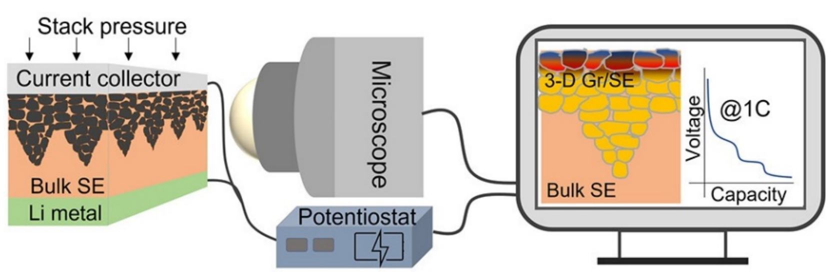

***Fig. 1.** Operando visualization platform to study SOC heterogeneity in composite SSB electrodes.*

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PS.6: **Microscopy Extracted Graphs for Complex Material Structure-Property Relations**

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Advancements in synthesis capabilities often make it impossible to test all available materials, thus motivating methods that relate synthesis conditions, structure, and properties. A crucial ingredient to these methods is a quantitative representation of the material under study, which is especially challenging for materials with complex structures. In many disciplines, complex systems are represented using graph theory (GT). However, despite its unique capabilities, the application of GT to complex materials is relatively new. Here, we summarize our recent works in using microscopy extracted graphs for complex material structure-property relations, including charge transport properties of conductive films,[1] stress pathways in acrylic strut lattices,[2] and chiroptical properties of plasmonic nanodendrimers.[3] We then give an overview of our recently released open-source Python package, StructuralGT, that will allow researchers to extend the present work to structure-property relations for their own complex materials.[4] We expect that widespread adoption of the present methods will accelerate the development of structure-property relations for rapid complex material design.

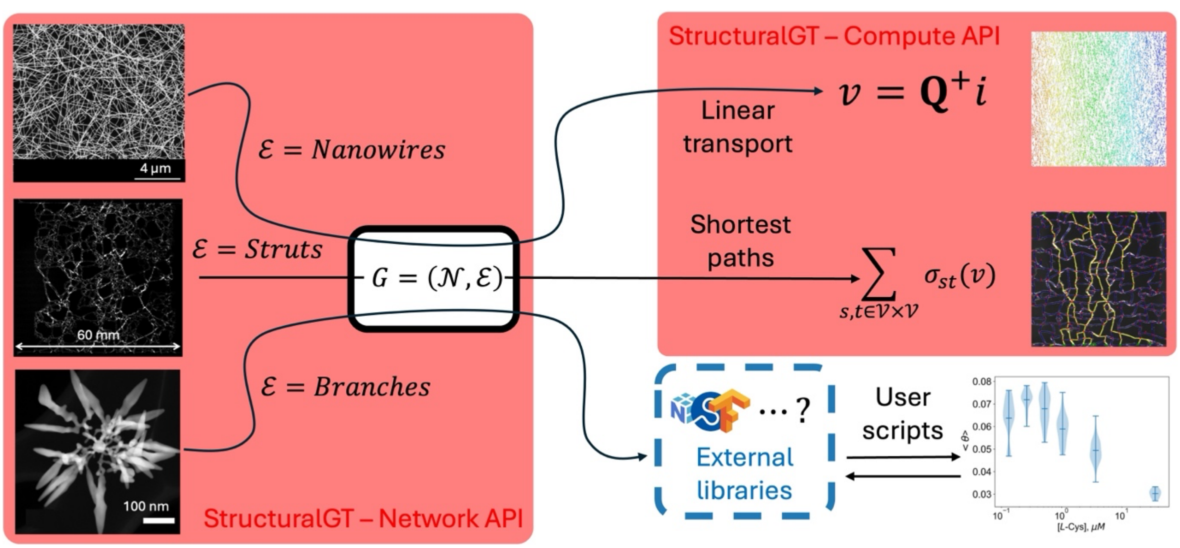

Fig. 1. *Left: Microscopy images for graph-based extraction. Right: Combination of graphs with computational tools for property predictions.*

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PS.7: **Investigation of Cracks in Early Cycled Polycrystalline NMC Cathode Particles**

Maalini Krishna[1], Nishkarsh Agarwal[1], Jinhong Min[1], Won Joon Suk[1], Juhwan Lim[1], Yiyang Li[1], Robert Hovden[1,2]

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Lithium-ion batteries have become increasingly important in the development of electric vehicles. A popular choice of cathode material is polycrystalline NMC ($Li(Ni,Mn,Co)O_2$) secondary particles. NMC secondary particles (3~10 μm) are an agglomerate of primary nanoparticles [1]. The secondary particles are cycled by applying a current in the opposite direction to charge and by applying a current in the opposite direction to discharge. While charging, Li+ ions inside the NMC particles move into the liquid electrolyte. While discharging, Li+ ions reenter the particle. It has been proposed that cracks form in the NMC particles during cycling, which increase the surface area exposed to electrolyte and allow for higher Li+ ion transport, which causes the impedance of NMC polycrystalline particles to decrease after the first cycle [1-3]. However, the capacity of the NMC particles decreases over time, partly due to structural reconstruction leading to the original layered structure transitioning to a cubic spinel and/or rock-salt structure [4-6]. Recently, a multi-electrode array from Min et al. has allowed for the study of individual particle cycling with particles of various diameters [1].

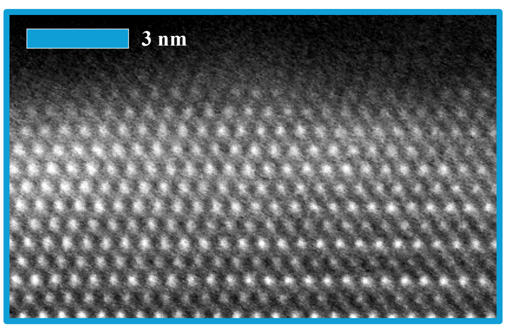

Fig. 1. Cubic spinel and/or rock-salt structure surface reconstruction at an intergranular crack surface

We utilize cross-sectional focused ion beam (FIB) milling to investigate cracks of individual NMC 532 particles that were cycled a few times. Cross-section images of a highly cycled particle and a pristine uncycled particle were also obtained using a scanning electron microscope (SEM). These images enable characterization of the extent of cracking, which correlates with the degree of cycling and the size of the secondary particles. We then utilize scanning transmission electron microscopy (STEM) to observe crack interfaces at an atomic scale (Fig. 1.). Overall, our explorations can help improve the production of lithium-ion batteries for energy-efficient applications.

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   Chem. Mater. 2025, 37, 5, 1788–1797

PS.8: **Real-Time Dynamic Reconstruction of In_2O_3 Nanoparticles in an NH_3 Environment**

Hailey Dover Lovelace McKenna[1], Xiaobo Chen[2], Zhucong Xi[1], Meng Li[3], Dmitri N. Zakharov[3], Judith C. Yang[2,3], Liang Qi[1], Rachel S. Goldman[1*]

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In_2O_3 nanoparticles (NPs) experience changes in resistivity in the presence of dilute amounts of NH_3, allowing for NH_3 gas sensing. While conductivity due to oxygen vacancies has been predicted as the primary mechanism for these resistance changes, In_2O_3 particles undergoing CO_2 hydrogenation have demonstrated transformation into an amorphous/molten phase followed by In_2O_3 reconstruction [1]. We hypothesize that this transformation and reconstruction could also impact resistance during the sensing of reductive gases.

In this work, we investigate In_2O_3 NP diffusivity at different temperatures in NH_3 gas using environmental transmission electron microscopy (ETEM). Indium droplets were deposited by molecular beam epitaxy (MBE) on DENS Wildfire chips with SiN_x windows using a specialized-TEM chip holder [2]. Indium droplet arrays were then loaded and oxidized in an FEI Titan 80-300 ETEM.

In_2O_3 NPs were observed at 100, 200, and 300°C in 100 mTorr NH_3. As temperature increases, In_2O_3 begins to experience increased diffusivity over the SiN_x membrane. The root-mean-squared velocity is determined, along with particle size as a function of time. Mechanisms of In_2O_3 diffusivity will be discussed, along with plans for future In_2O_3 diffusivity experiments in other reductive gases, such as H_2 and CO.

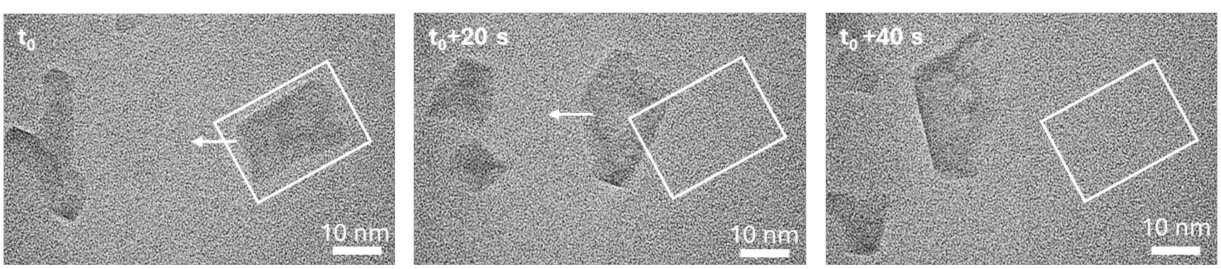

Fig. 1. *In_2O_3 particle (white box) undergoing dynamic reconstruction over 40 s at 300°C. At t_0, the particle came into the field of view.*

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PS.9: **Characterization of the structural, physical, and chemical characteristics of photo(electro)chemical systems for solar hydrogen production**

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The urgent need for sustainable chemical conversion technologies has intensified efforts to develop clean energy solutions that address the global energy and climate crisis. Photo(electro)catalytic water splitting offers one promising pathway to clean and renewable hydrogen production, which can be used directly as a fuel and feedstock. A widely studied system approach for this couples metal nanoparticle electrocatalysts (np-ECs) with semiconductor (SC) light absorbers, where the SC harvests solar energy to generate charge carriers, which are separated and move to np-ECs to drive the hydrogen (HER) and oxygen (OER) evolution half-reactions of water splitting. However, despite significant progress, the fundamental mechanisms governing charge transfer efficiencies (i.e., photovoltage) at these nanoscale EC/SC interfaces remain poorly understood, especially under dynamic reaction conditions. In addition, classical theories, such as the Schottky model for metal/semiconductor contacts, fall far short of accurately describing and explaining the performance of these systems. As a result, even well-studied, prototypical model systems lack physical frameworks that fully explain their significant performance gap when compared to their buried junction analogues.

In this presentation, I will showcase our recent efforts to develop structure-function relationships in these photo(electro)chemical systems through the rigorous use of material characterization techniques such as electron microscopy (e.g., SEM, STEM) and surface sensitive spectroscopies (e.g., XPS). The insight obtained through these methods inform physical models that describe interfacial mechanisms governing the performance and help guide the rational design of interfaces in practical photo(electro)chemical systems and are broadly applicable to photovoltaic devices.

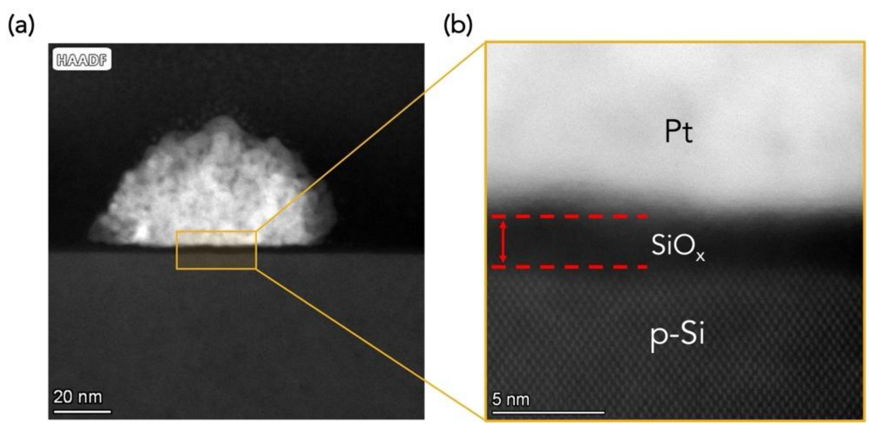

Fig. 1. (a) Low-magnification cross-sectional HAADF-STEM image of Pt nanoparticles supported on a p-Si light absorber. (b) High-resolution cross-sectional HAADF-STEM image of the Pt/p-Si interface. Red dashed line marks the boundaries of the interfacial SiO_x layer.

PS.10: **Size Modulation and Loading of Palladium Nanocomposites for Lightweight Charged Particle Shielding**

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The applications of nanoparticles (NPs) are frequently seen with research surrounding catalysis, hydrogen storage, medical devices, electronics, and even nuclear reactions. This is largely due to the inherently usable properties of NPs: improved chemical reactivity, biocompatibility, high surface area-to-volume ratio, quantum confinement (notably affecting optical, electronic, and magnetic qualities), phonon density-of-states control, among others. For enhanced technology development, control of the NP size is essential to the manipulation of NP properties and therefore applications for a vast array of industries.

This study presents a recipe for synthesizing palladium NPs which allows for NP size modulation between 2-70 nm. The NPs are synthesized in an aqueous solution containing tannic acid, trisodium citrate dihydrate, and potassium tetrachloropalladate before being deposited onto a polymer matrix. Moreover, for the technological applications of this research, the NPs are bonded onto an aramid nanofiber (ANF) matrix where the composite weight fraction, NP size, and annealment parameters are controllable factors. The Pd-ANF composites have shown to increase scattering of charged particles, making them a novel lightweight material for shielding cosmic rays. Additionally, because NPs are hypothesized to create a large hydrogen to metal ratio when loaded with H_2, the composites can also be used for shielding neutrons.

The Thermo Fisher Talos F200X TEM is utilized in this study to characterize NP size (Figure 1) and collect scattering information from the diffraction patterns (Figure 2) of nanoscaled materials compared to bulk counterparts. The JEOL IT500 SEM is used for elemental composition and microstructure analysis of the NP composites. While much research has been done on enhanced shielding via nanostructures, more discoveries on the underlying mechanisms is still necessary. In the future, this study will utilize 4D STEM to analyze changing diffraction patterns at different NP boundaries while altering NP size, NP layer thickness, and accelerating voltage.

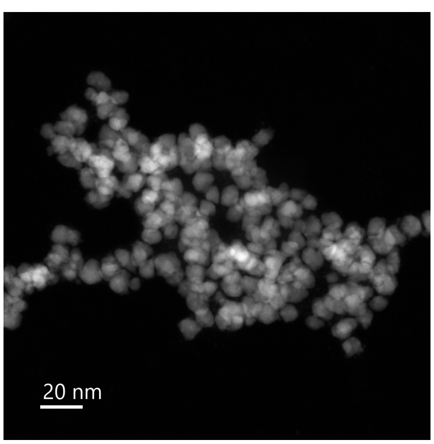

Fig. 1. STEM image of Pd NP

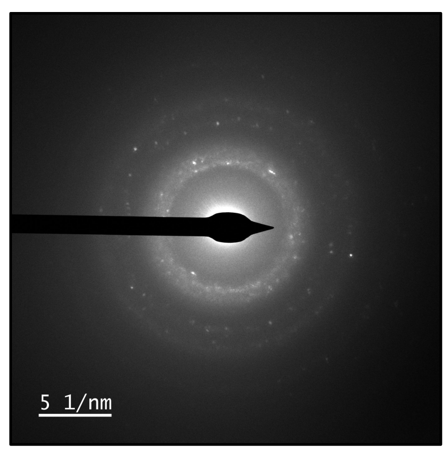

Fig. 2. Diffraction Pattern of Pd Np

PS.11: **Stabilization of 2D 1T-TaS_2 Charge Density Waves via In-Situ Current Biasing**

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1T-TaS_2 is a layered, two-dimensional material which hosts several charge density wave (CDW) states with three distinct phases: an insulating commensurate (C) phase and the metallic nearly-commensurate (NC) and incommensurate (IC) phases [1,2]. CDW phase selection can be achieved via biasing, making 1T-TaS_2 an attractive candidate for device applications [3,4]. The insulating C phase, however, only forms below ~180 K [1, 5] for 1T-TaS_2 and even lower for thin flakes [4], leaving the metal-insulator transition unreachable for room temperature devices.

Recent work has shown endotaxial heterostructures of 2H-TaS_2/1T-TaS_2 can stabilize 2D C-CDW states in the twinned commensurate (tC) phase at room temperature by heating 1T-TaS_2 past its polytype transition and annealing back to room temperature. This new tC-CDW phase hosts a single metal-insulator transition at ~350 K [2], paving the way for devices operable at room temperature.

Here, we show that the tC-CDW state can be synthesized electronically via current. Using an in-house built transmission electron microscopy (TEM) biasing holder, we can source current through exfoliated 1T-TaS_2 flakes in-situ. For sufficiently thin flakes, a current of 210 $\mu A/\mu m^2$ is enough to switch between the NC and IC phases (Fig. 1b). Upon sourcing a large current of 750 $\mu A/\mu m^2$, layer-by-layer polytype conversion occurs (Fig. 1a). Holding at this current for 60 seconds is enough to stabilize the tC-CDW phase. Similarly to the NC-IC transition, we can switch between the tC and IC phases of this new endotaxial structure by sourcing current through the sample (Fig. 1c). Using in-situ TEM we can correlate a polytype transition and the associated tC-CDW formation through electrical signatures.

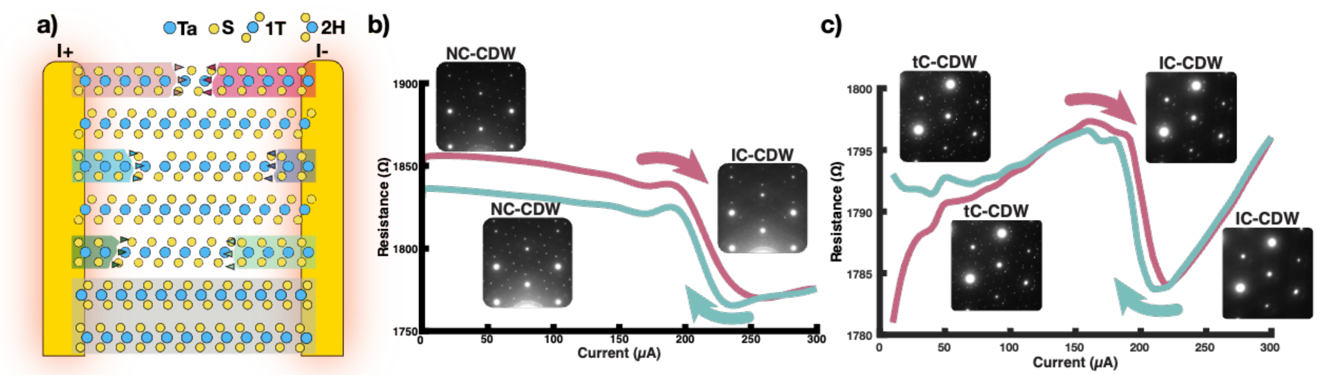

Fig. 1 | Electronic Endotaxy and Switching. a) Schematic diagram showing layer-by-layer conversion of individual 1T-TaS_2 layers to the 2H polytype under an applied current. 2-point in-plane resistance measurements as a function of applied current for **(b)** bulk 1T-TaS_2 and **(c)** mixed polytype 1T/2H-TaS_2.

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PS.12: **Multiscale Design of Chiral Semiconductor Helices**

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Helical geometry is utilized by a broad range of biological structures that span from the double helix data storage structure of DNA to the mechanical propulsion mechanism of a bacterium or a biomimetic nanobot. The combination of a continuous helical geometry with charge transport and storage properties of semiconductor materials however has recently served as a focus in the development of optoelectronics, photocatalysts, and biomimetics. Notably the self-assembly behavior of chiral cadmium telluride (CdTe) nanoparticles into continuous semiconductor helices has shown the strong tunable chiroptical activity in the near infrared (NIR) segment of the electromagnetic spectrum that is necessary for emerging applications.[1] Circularly polarized luminescence (CPL)-active materials, those capable of emitting light that is circularly polarized, in particular have gained increasing interest due to their potential applications in 3D displays, optoelectronic devices, optical sensors, and optical information storage. CPL in the NIR has been found to have advantages over visible light for the areas of bioimaging and telecommunications, resulting from the low absorption of NIR light in biological samples allowing for high-quality imaging with minimal sample damage and low attenuation of NIR light in optical fibers which is ideal for long-distance communication.[2] Few cases of NIR-CPL active materials along with limited characterization equipment for CPL detection in the NIR has however made the expansion of this material library challenging. This work seeks to address these challenges through morphological and compositional assembly tuning of semiconductor helices yielding strong chiroptical activity in the NIR.

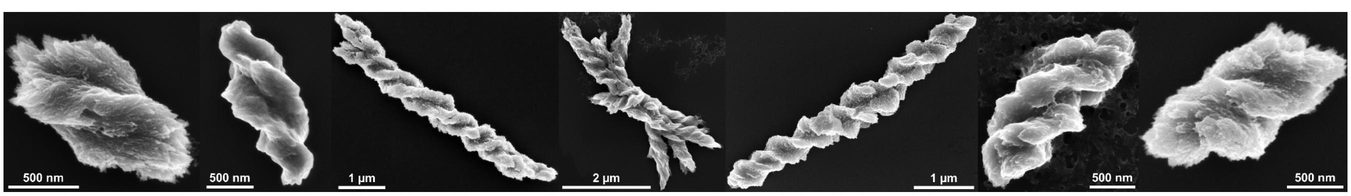

Fig. 1. SEM images of left- and right-handed cadmium telluride helices of different lengths and morphologies.

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PS.13: **Characterization of Epitaxial Nb, Mo, and Chemically Complex VNbTa Thin Films Deposited by Magnetron Sputtering on MgO(100)**

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Thin film microstructure strongly influences strength and plasticity, making microstructural control and characterization critical starting points for experiments investigating how composition affects mechanical behavior. Here, refractory metal thin films are grown epitaxially to achieve near-single crystal microstructures and facilitate microcantilever beam bending experiments to study the influence of refractory alloy composition on crack tip plasticity. Scanning electron microscopy (SEM), selected area electron diffraction (SAED), and x-ray diffraction (XRD) were used in combination to characterize the epitaxial growth quality of these thin films.

Previous studies have identified MgO (100) as a suitable substrate for growing epitaxial Nb films [1]. It was hypothesized that other refractory metals could also grow epitaxially on MgO (100), given their similar lattice mismatch. In this work, refractory metal thin films with compositions of Nb, Mo, VNbTa, Nb-Mo, and VNbTa-Mo were grown at 800 °C. XRD characterization identified the out-of-plane orientation relationships between the films and MgO, as shown in Figure 1(a). Nb grew in a (110) //MgO(100) orientation, VNbTa adopted a (100)//MgO(100) orientation, and Nb-Mo displayed both.

SEM and SAED analyses further supported these findings. In the (110)//(100) out-of-plane orientation, two distinct in-plane alignments were observed. These are evident in the SEM micrograph, where surface features show vertical alignment, and in the SAED pattern, which displays three single-crystal diffraction patterns (Figure 1b,e). The Nb-Mo sample exhibited less defined columnar grains, and SAED indicated a polycrystalline film with no specific in-plane orientation (Figure 1c,f). The VNbTa film demonstrated a strong in-plane orientation relationship, (011)//MgO(001), corresponding to a 45-degree rotation about the surface normal (Figure 1d,g). From these results, VNbTa and VNbTa-Mo are identified as ideal systems for studying the effect of adding a group VI element to a group V alloy on crack tip plasticity because they maintain a consistent epitaxial orientation, regardless of Mo content.

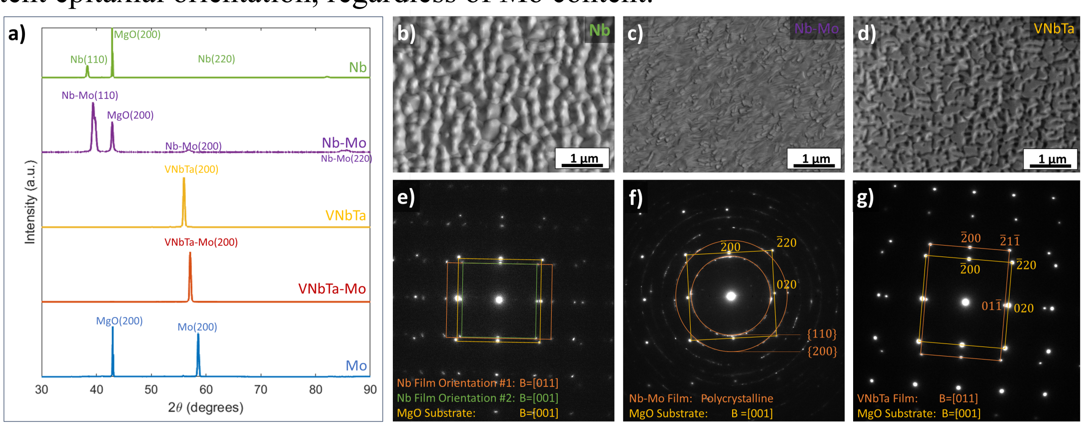

Fig. 1. Epitaxial growth orientation and quality is characterized by (a)XRD, (b) SEM, and (c) SAED.

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PS.14: **In-Situ SEM Tensile Testing with High-Resolution Electron Back Scatter Diffraction and Digital Image Correlation in Polycrystalline MgY alloys**

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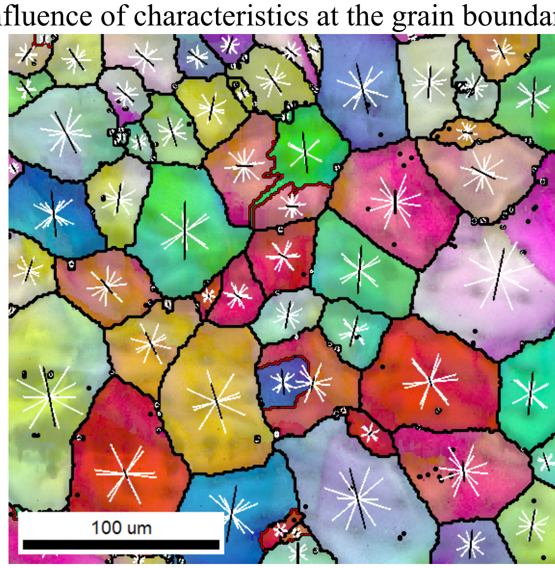
Magnesium and its alloys offer attractive applications in aerospace, automotive and defense industries. While lightweight and dense, widescale commercial utilization of Mg alloys is limited due to its low ductility and formability at room temperature.[1] Due to basal slip systems containing a limited number of available slip directions, researchers have improved the activation of non-basal slip by alloying magnesium with trace amounts of Rare Earth metals such as Yttrium. [2] It was reported that MgY alloys displayed <c+a> slip activation and exhibited superior ductility, but the mechanism to explain remains unclear. Non-Basal Pyramidal slip is required to accommodate slip motion in the c-axis and explains the increased ductility of Mg alloys. [3] Additionally, the activation of Pyramidal slip must overcome a higher critical resolved shear stress (CRSS) as compared to basal slip. Previous work suggests that Yttrium segregation at the grain boundaries prevents dislocation motion onto neighboring grains, however, this explanation cannot account for the anisotropy in the microstructure leading to variations in strain hardening rates respective to each grain.

We perform an in-situ tensile test inside a Tescan Mira 3 on Mg-1 (wt%) Y while coupling two techniques: High Resolution Electron Back Scattered Diffraction (HREBSD) and Digital Image Correlation (DIC). Together these techniques 1) quantify the evolution of Geometrically Necessary Dislocations and 2) characterize the complexities in the stress state in polycrystals under plastic deformation. We investigate the activation of Pyramidal slip at higher strains (>2%) and propose the influence of characteristics at the grain boundary such strain gradient and misorientation.



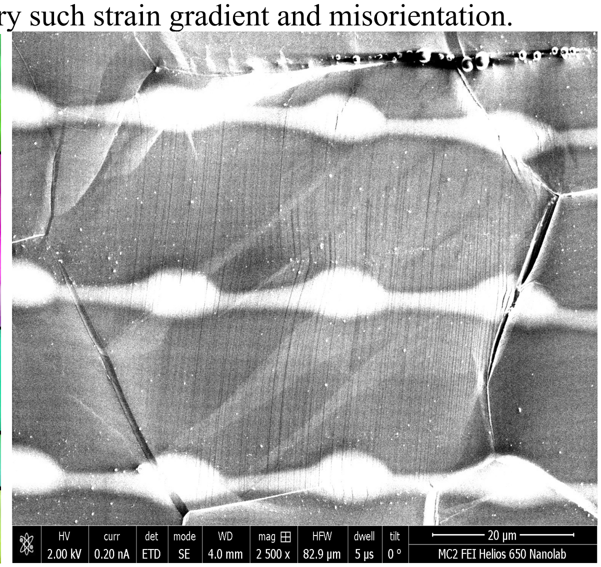


Fig. 1.a Electron Back Scattered Diffraction of Mg-1%Y post tensile test with slip traces for Basal and Pyramidal slip.
Fig. 1.b Pyramidal slip traces present on the surface of the sample post tensile test

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PS.15: **Elemental Mapping and Depth Profiling of Battery Materials via LALI-TOF-MS**

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To meet the increasing demand for battery and energy storage solutions, scientists and engineers are researching novel chemistries, developing innovative electrode geometries, and recycling end-of-life batteries. Characterizing lithium distribution in battery materials is critical for applications ranging from traditional lithium-ion battery technology to new electrode chemistries like lithium metal. Despite its importance, reliably measuring lithium can be challenging for traditional analytical techniques, especially in air- and moisture-sensitive materials.

Addressing the limitations of conventional techniques, a new analytical approach combines Laser Ablation Laser Ionization (LALI) with Time of Flight Mass Spectrometry (TOF-MS). LALI-TOF-MS involves a dual-laser system that directly analyzes solid or powder battery materials and ionizes neutral particles. The TOF mass analyzer creates a full mass spectrum at each laser spot, detecting low-mass elements (e.g., Li, C) to high-mass metallic elements. This capability supports multi-element quantification, detailed elemental mapping, and high-resolution depth profiling. By operating under vacuum, it allows accurate characterization of air- and moisture-sensitive battery electrodes.

Progressing advanced battery technology from research to commercial scales involves understanding lithium's interactions with the electrolyte and formation of the solid electrolyte interface (SEI) layer, which significantly impacts a battery's performance and lifespan. Lithium measurements also allow early detection of potential degradation mechanisms like lithium plating. Further down the lifecycle, characterizing lithium distribution in black mass can provide important insights for optimizing recycling processes.

This study presents results acquired by LALI-TOF-MS on a variety of battery materials showing the distribution of lithium along with compounds formed by lithium in combination with the electrode's active elements.

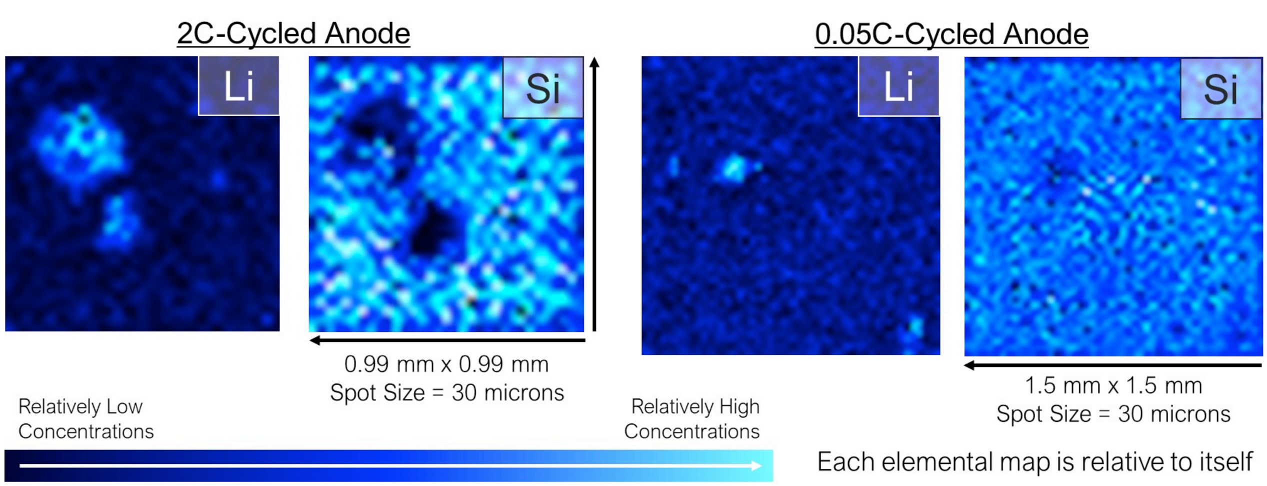

Fig. 1. Elemental maps of cycled battery anode acquired using benchtop Exum Massbox system.

PS.16: **Cross-Platform Ultra-Cold Liquid Helium TEM Sample Holder with High Stability**

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Here, we introduce a novel ultra-cold transmission electron microscope sample holder cooled with liquid helium capable of atomic resolution stability. This custom holder can reach any temperature between room and base cryogenic temperatures (≥23 K) in scanning transmission electron microscopes (S/TEM) with ±2 mK thermal stability over a period of 10+ hours [1].

Despite recent advancements in cryogenic TEM techniques and successes in atomic-resolution STEM studies at liquid nitrogen (LN_2) temperatures [2,3] and near liquid helium (LHe) temperatures [4,5], current tools are insufficient for materials characterization. Many radiation-sensitive materials and quantum phase transitions remain out of reach due to a lack of sufficiently stable ultra-cold capabilities. Additionally, severe thermal drift and mechanical vibrations caused by cryogen excitation yield low-quality images and short experimental windows for low-temperature side-entry sample holders [6]. Furthermore, LHe is orders of magnitude more volatile than LN_2, resulting in the exacerbation of current issues faced by side-entry holders at lower temperatures.

We have developed an ultra-cold specimen holder compatible with modern aberration-corrected TEMs to enable imaging of low-temperature phases of materials. This design incorporates vibration-damping equipment and a liquid-flow heat exchanger to reduce mechanical and thermal instability. These advancements enable atomic resolution imaging (≥0.8 Å) at ultra-cold temperatures (≥23 K). Precise temperature control is achievable with ±2 mK stability or better over long experiment windows (10+ hours), facilitating nanometer per minute (0.37 Å/s) sample drift. The holder design has been expanded to be compatible with JEOL, Thermo Fisher Scientific, and Bruker Nion microscopes.

In summary, our cryogenic TEM sample holder represents a significant advancement that addresses a longstanding desire to access ultra-cold temperatures within a modern aberration-corrected electron microscope, offering new opportunities for characterizing biological and quantum materials [7].

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[7] This work was supported by The Rowland Institute at Harvard and the University of Michigan. The authors are grateful for technical support from the Michigan Center for Materials Characterization.

PS.17: **Dynamic Self-Assembly of Complex Chiral Supraparticles**

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Biological nano- and microstructures can dynamically reconfigure across families of complex asymmetric morphologies, modulating their physiological functions at multiple scales. In contrast, conventional chiral nanomaterials remain structurally static, drastically limiting control over binding interfaces essential for selective biomolecular binding. Here we show that atomically thin covellite-like CuS nanosheets functionalized with amino acid ligands reversibly self-assemble into complex chiral supraparticles with controllable asymmetry from subnanometer to micron scales. By tuning attractive and repulsive forces through pH, temperature, and chemical additives, the system accesses multiple progressively reconfigurable isomorphs with distinct morphology, chirality, and optical activity.

The dynamic disassembly and reassembly into distinct superstructures can be traced using electron and fluorescence microscopy, revealing chemical and spatial reconfigurations of various nanoscale isomorphs forming hierarchically organized materials from nanoclusters to micron-scale liquid crystalline phases. We show that biocompatible nanosurfaces of these materials enable rapid, non-denaturing protein isolation from biological fluids reaching ~1,000-fold single-step enrichment of low-abundance targets and 99% depletion of abundant nonspecific targets such as albumin and glycoproteins. Captured proteins are released by disassembling the superstructures in benign buffers, establishing a dynamic platform for selective bioseparation with straightforward translation to diagnostics and bioprocessing.

Fig. 1. *SEM image of hierarchically organized supraparticles self-assembled from covellite nanosheets.*

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LS.1: **Using Multiple Microscopy Methods to Study Cilia and Flagella Phenotypes in *CFAP221* Mutants**

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Cilia and flagella are motile hair-like organelles essential to biological processes including fluid movement and sperm motility [1]. Uniquely, mormyrid fish lack sperm flagella [2] and a large portion of a gene necessary for cilia/flagella formation, *Cilia- and Flagella-Associated Protein 221* (*CFAP221*). In mammals, *CFAP221* knockout leads to aflagellate sperm and cilia that beat slowly in an aberrant pattern [3,4]. The state of mormyrid cilia, if the *CFAP221* deletion causes sperm aflagellism, and if mormyrid *CFAP221* is translated into a functional protein are unknown. To study *CFAP221* mutation and cilia/flagella phenotypes, we use multiple microscopy methods including electron microscopy, dark field microscopy, light microscopy, and fluorescence microscopy to image cilia/flagella in mormyrids and two *CFAP221* zebrafish CRISPR mutant lines: *CFAP221*$^{del/del}$ mimics the mormyrid deletion and *CFAP221*$^{KO/KO}$ will be a knockout. In mormyrids we confirm the aflagellate sperm phenotype in three species and found in one species that the egg surface is covered in tiny hair-like structures. We also found that mormyrid cilia beat significantly slower than wildtype zebrafish cilia. In the *CFAP221*$^{del/del}$ line we found F0 individuals produce a mix of flagellated and aflagellate sperm, but homozygous mutants produce flagellated sperm. Furthermore, the internal structure of *CFAP221*$^{del/del}$ flagella and cilia and the beat frequency of somatic cilia are indistinguishable from wildtype. Finally, we are using fluorescence microscopy to examine CFAP221 protein localization in flagella and cilia using antibodies for zebrafish and mormyrid CFAP221 protein. This work is ongoing, but thus far we have visualized CFAP221 protein in wildtype zebrafish olfactory cilia and sperm. As this project continues we will perform the above analyses for *CFAP221*$^{KO/KO}$ which may be a better proxy for the molecular mechanisms occurring in mormyrids if our antibody work reveals that mormyrid *CFAP221* is not translated into a functional protein.

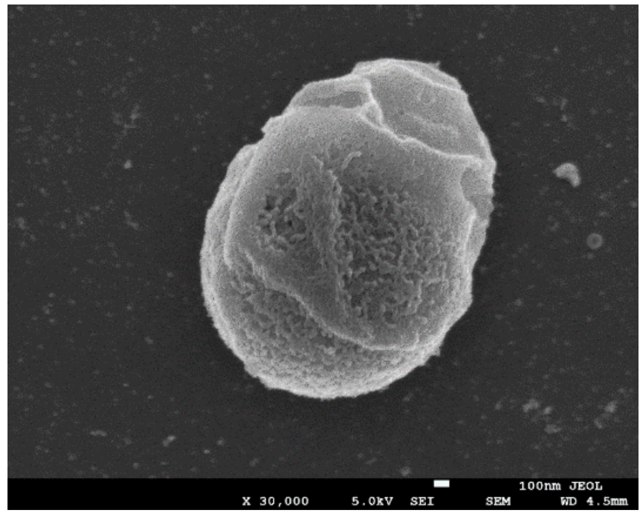

Fig. 1. *A scanning electron microscope image of aflagellate sperm from a mormyrid fish species.*

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LS.2: **Electron Microscope Studies of the Self-Assembly of Complex Extracellular Matrix Structures Through an Intervening "Glass House" Fully Encapsulating the Protoplast in Diatoms**

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The self-assembly process of extracellular matrix polymers (ECM) extruded through nanopores and slits in the silica "shoe box" frustule of diatoms (single celled algae) has been investigated using a combination of cryo-field emission SEM (cryo-FE-SEM), high pressure freezing/freeze substitution (HPF/FS-TEM), colloidal gold-EM immunocytochemistry, and video microscopy. Cryopreservation required due to the high level of hydration and fragility of the ECM polymers was accomplished through fast-freezing, freeze fracture, freeze sublimation, cryo-coating, cryotransfer and cryo-FESEM observation. High-resolution, time lapse video microscopy revealed that production of a highly organized ECM "stalk" was correlated with vesicle transport and deposition to a certain region of the plasma membrane underlying the major slit in the frustule, the raphe. TEM observations of the ECM preserved by HPF/FS showed detailed structure of mucilaginous polymers in vesicles and post-assembly. Cryo-FESEM and HPF/FS TEM demonstrated that secreted adhesives, appearing as fine fibrils, were passed through the diatotepum, a continuous, multi-layered intervening layer, located between the plasma membrane and the silicon frustule. These fine fibrils were then extruded through frustule slits and pores. Monoclonal antibody-colloidal gold conjugates labeled intracellular vesicles near the perinuclear Golgi apparatus, and differentiated fibrils secreted through the diatotepum and the raphe. Distinct and unique antibody labeling patterns appeared on the stalk during the self-assembly process external to the frustule where fibrillar materials were organized into four distinct layers of the mature stalks, each with a unique chemistry.

LS.3: **Actin Focal Rings in Focal Adhesions of Cultured Epithelial Cells**

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Cancer cells have weaker adhesiveness than normal cells, so there is considerable interest in the structure of focal adhesion (FA) plaques that attach cells to their substrates. Actin filaments are anchored in the FA and form columns in the cytoplasm by binding to accessory proteins. Another structure has an osmiophilic core with actin filaments radiating away at 30° angles and is found deep in the interior of nerve cell protrusions called growth cones [1]. In epithelial cells, 10-15% of FAs have a similar structure. As imaged by electron tomography (Figure 1), the focal rings are oblate spheroids 23 nm in breadth and 11 nm in thickness. The structures are observed in sections through the cell-substrate interface, where 3-6 filaments radiate away from each core. The average angle between adjacent filaments is 56°, but they can extend outward at angles as small as 20°. The most complete structure observed to date has filaments spaced 60° apart (Figure 2). In this respect, the structure differs from the actin rings of the growth cone, which have 12 filaments spaced at 30° apart. Measurements of the filaments' diameter suggests a mean width of 9.9 nm, which is considerably greater than the diameter of a single filament. Here, the cell cytoplasm was depleted before fixation, a procedure designed to retain the most stable actin structures [2]. The cells were permeabilized with 50µg/ml of digitonin in cytoskeletal buffer containing 10 µM /ml of phalloidin. Although the composition of the core and the polarity of the actin remain unknown, the results suggest that this is a structure stabilized by an actin accessory protein, and it plays a role in cell adhesion.

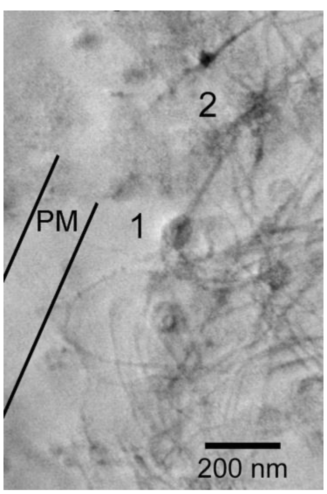

Figure 1. Site of FA integration with the plasma membrane (PM). The substrate is at the left with the PM adjacent to it. A spider-shaped figure is formed by filaments radiating from a central core at area 1. One filament emerges to the northeast, and two are emerging on the opposite side. Area 2 has filaments in a radial arrangement.

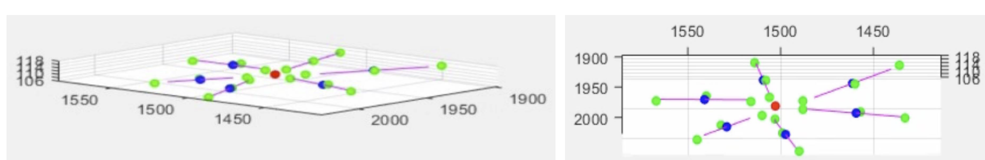

Figure 2. Trajectories of filaments radiating from the core (center in red) of an actin focal ring. (Left) viewed from the side. (Right) viewed from

References
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2. Varghese M: To Be or Not To Be a Protrusion: Unraveling the Determinants of Protrusion Formation. Bowling Green State University: 2012, dissertation. http://rave.ohiolink.edu/etdc/view?acc_num=bgsu1332989801

LS.4: **Single-Particle Characterization of Aerosol Physicochemical Mixing State in the Southeastern United States**

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The climate and air quality impacts of atmospheric aerosol particles are directly tied to their individual physicochemical properties, including size, chemical composition, and morphology. Another critical variable is aerosol mixing state, which describes the distribution of chemical species across a particle population and is influenced by the proximity of particle emission sources and chemical evolution (i.e., aging). These properties influence key atmospheric processes such as cloud formation, radiative forcing, and chemical reactivity. Single-particle analysis enables unique characterization of aerosol physicochemical mixing state, including the role of particle size and morphology, and its relationship with aerosol-driven atmospheric processes. This study focuses on the southeastern United States, a complex and dynamic region with diverse, seasonally variable emission sources, including secondary organic aerosol (SOA), biomass burning (BB), fly ash, soot, mineral dust, sea spray, and primary biological particles (PBAPs). In this study, online measurements (aerosol size distributions, cloud condensation nuclei number, hygroscopicity, etc.) are combined with offline single-particle analysis to investigate aerosol physicochemical mixing state. Aerosol samples in northwestern Alabama at Bankhead National Forest, using a miniature micro-orifice uniform deposit impactor (mini-MOUDI) as part of the ARM Mobile Facility 3 (AMF3) deployment. Samples were analyzed using single-particle analysis techniques, including optical-photothermal infrared (O-PTIR) spectroscopy, Raman microspectroscopy, and computer-controlled scanning electron microscopy with energy dispersive X-ray (CC-SEM-EDX) spectroscopy. This suite of analyses provides functional group, elemental, and morphological information at the individual particle level. Changes in single-particle physicochemical properties are compared under different meteorological conditions. This work contributes to a more complete understanding of aerosol complexity in the southeast U.S., with implications for aerosol-cloud interactions, air quality, and climate modeling.

LS.5: **Live-Cell Super-Resolution Imaging Reveals that Dps Binds and Protects DNA in Bacteria without Impacting Chromosome Accessibility, Dynamics, or Organization**

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Dps is a highly conserved and abundant DNA-binding protein in starved bacteria that facilitates survival in harsh environments. Electron microscopy images of Dps-DNA complexes show striking crystalline arrays, leading to the widely accepted model that Dps reorganizes DNA into a compact liquid crystal, slowing chromosome dynamics, and limiting access of other proteins to DNA. In this work, we directly tested this model using live-cell super-resolution microscopy and genomic analysis in *E. coli*. We found that after 96 h of starvation, Dps compacts the nucleoid and increases short-range DNA-DNA interactions, but does not affect chromosome accessibility to large protein nanocages or small DNA-binding proteins. We also report that chromosome dynamics and organization are primarily impacted by the bacterial growth phase; the effect of Dps is relatively minor. Our work clarifies the role of Dps in modulating chromosome properties, and we propose an updated model for Dps-DNA interactions in which Dps binds, protects, and compacts DNA largely without influencing chromosome access, dynamics, and organization. Additionally, this work provides a general framework for using super-resolution microscopy to assess the impact of DNA-binding proteins on key aspects of chromosome function in living cells.

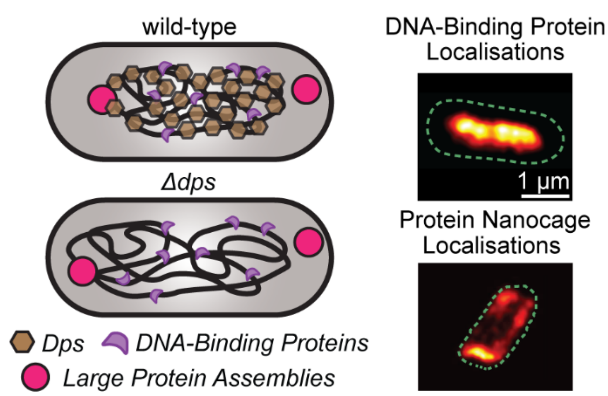

Fig. 1. Using super-resolution microscopy, we quantify the nucleoid accessibility of DNA-binding proteins and protein nanocages with and without Dps (*Δdps*) to determine how Dps modulates access to DNA in live cells.

LS.6: **Simple Automated Biological Specimen Prep for TEM and Volume EM**

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Specimen preparation procedures for life science transmission electron microscopy (TEM) and Volume EM (vEM) include multiple contrast enhancing steps making them some of the longest and most complex tissue processing protocols performed for EM. Additionally, 4 of the steps for vEM need heating or cooling. These specimen preparation workflows call for use of noxious, hazardous and often carcinogenic chemicals including uranium salts, arsenic, heavy metals, cyanide, lead and osmium tetroxide. These long and complex workflows provide ample opportunity for human error and are currently performed manually in most cases.

The Prepmaster™ 5100 Automated Workflow System automatically prepared optimally sized (cubic millimeter) tissue specimens for TEM and vEM from fix rinse through embedding. Operationally, the technician simply placed the $1mm^3$ specimens in the specimen plate with 50 microliters of buffer, then placed the specimen plate on the temperature-controlled specimen dock and pressed “Start”. The unattended Prepmaster then expertly completed the hundreds of individual liquid handling steps required to prepare the specimen for ultramicrotomy and imaging.

A protocol[2] was designed by Thomas J. Deerinck, Eric A. Bushong, Andrea Thor and Mark H. Ellisman in the Ellisman Lab at USCD to enhance signal for backscatter electron imaging of epoxy embedded mammalian tissue at low accelerating voltages (1-3 keV)”. This protocol was programmed into the Prepmaster and then muscle and liver specimens were processed and imaged.

The Prepmaster efficiently, reliably and consistently prepares tissue, cells-seeded-on-coverslips, grids and most other samples, such as organoids or retinas, procured for life science research or diagnosis.

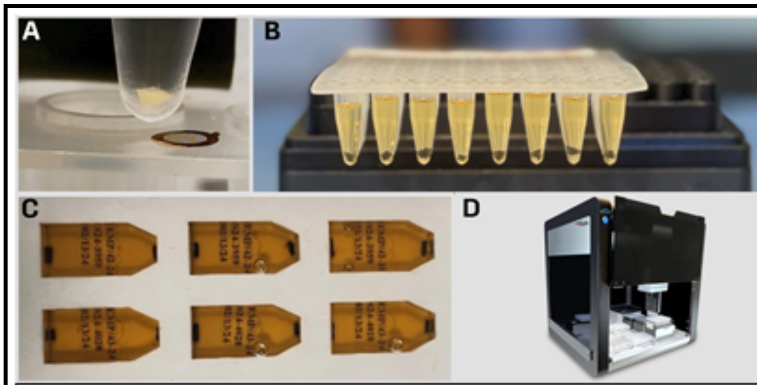

Fig 1. A) Approximately $1mm^3$ renal biopsy next to 3mm dia. Grid. B) Specimens embedded at RT in 100% resin ready to be transferred to a flat mold for curing. C) Cured blocks ready for microtomy. D) The Prepmaster 5100 automated specimen processor.

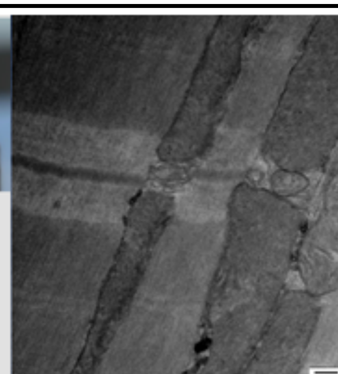

Figure 2. Cardiac muscle, FEI CM120 STEM at 40,000X Note intercalated disc running horizontally.

[1] J. J. Bozzola and L.D. Russel. Electron Microscopy: Principles & Techniques for Biologists p.50
[2] https://ncmir.ucsd.edu/sbem-protocol

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