An NSF Materials Research Science and Engineering Center (MRSEC)

Center for Complex and Active Materials (CCAM)

Xiaoqing Pan

University of California, Irvine

MRSEC Directors' Meeting (Virtual)

January 28-29, 2021

Center for Complex and Active Materials

UCI MRSEC

National Science Foundation

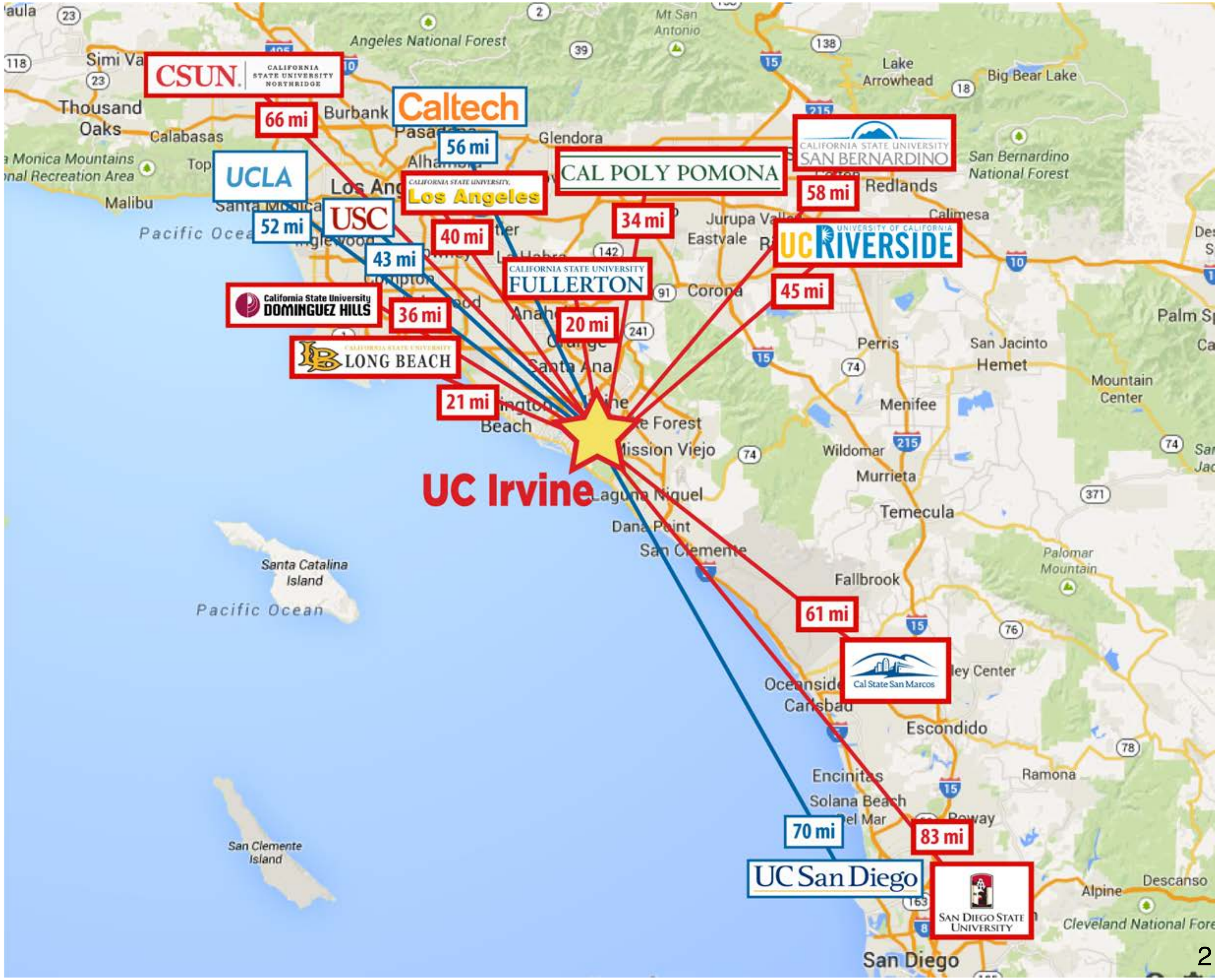
MRSEC

MATERIALS RESEARCH SCIENCE AND ENGINEERING CENTERS

UC Irvine

Center for Complex and Active Materials
UCI MRSEC

- We are in the heart of the booming economy in SoCal, with an ethnically diverse population
- OC is home to many high-tech companies including semiconductor, biotech, aerospace, and advanced manufacturing
- UCI is a powerhouse of research, entrepreneurship, and technology, e.g., UCI has $5 billion annual economic impact, and involves $13 billion of investments for startups over the last 3 years
- **UCI interacts with many higher education Institutions, most of them are minority serving Institutions including UCI.**



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Our Team

Assistant Professor

URM

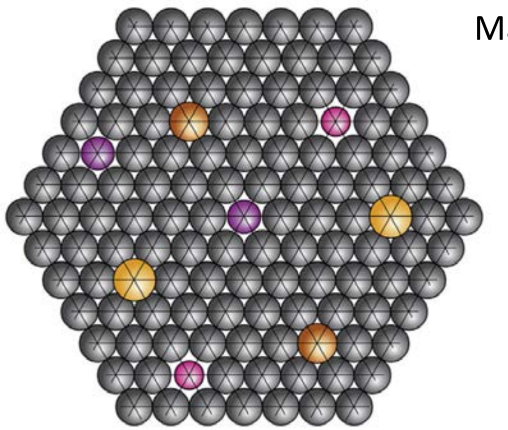
Women

7 URMs (including 5 women)

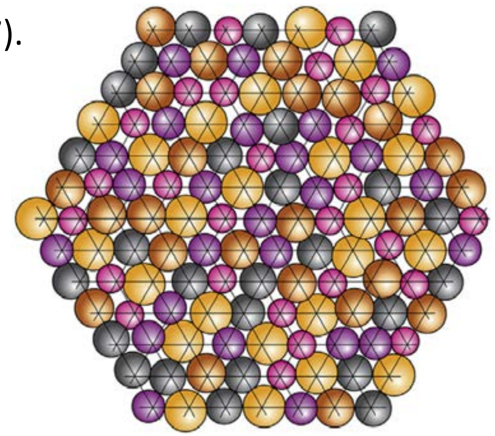
Vision: To establish a major research hub for materials discovery and innovation in the Southern California academe-industry eco-system

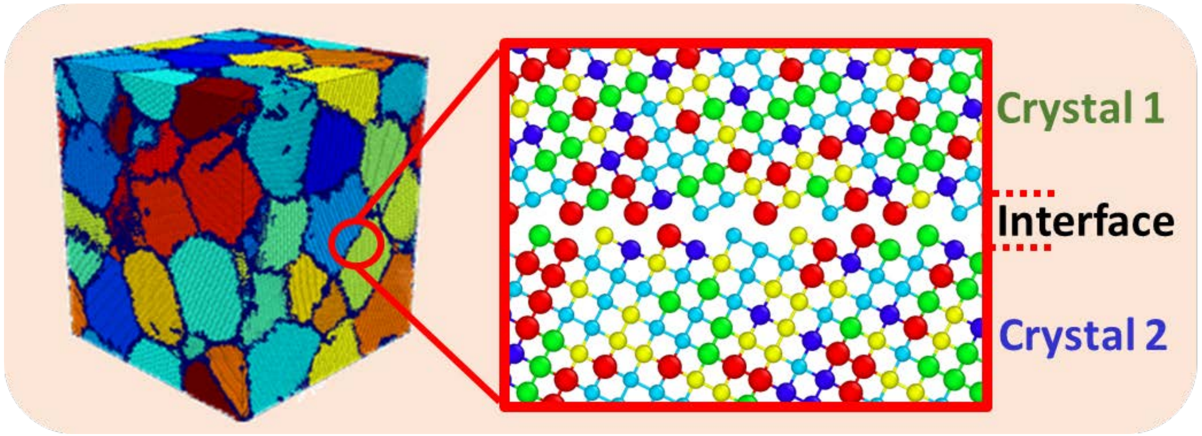
Mission: To develop new classes of new complex and active materials with novel functionalities to address urgent needs for applications in advanced manufacturing and biotechnologies, provide opportunities for workforce training, and technology transfer to industry.

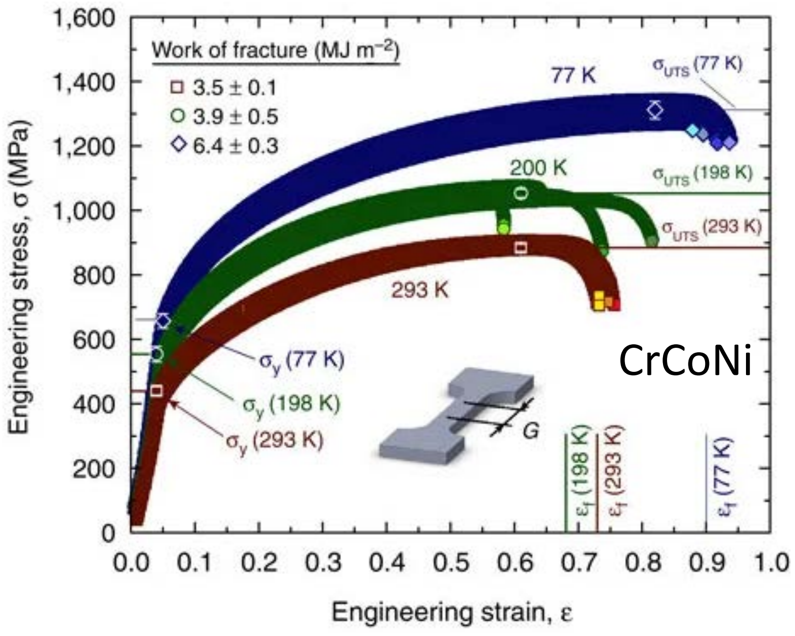
Motivation and Vision



Miracle, Acta Mater (2017).

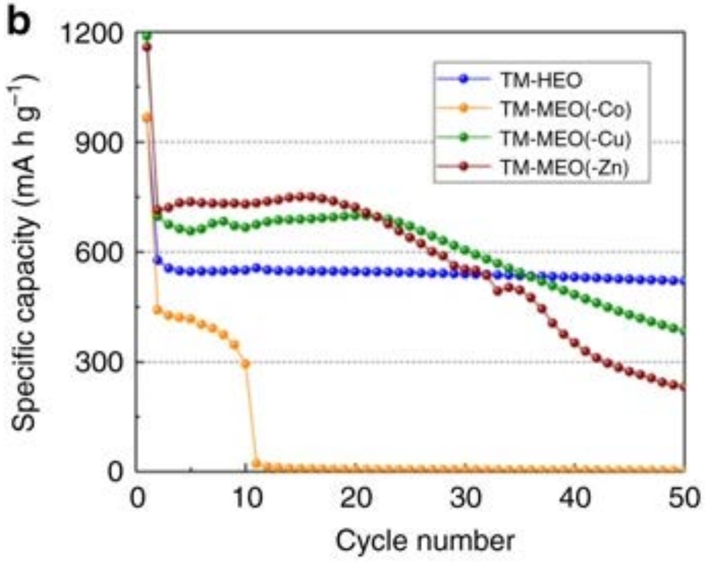






Gludovatz et al., Nature Comm (2016).

$(Co_{0.2}Cu_{0.2}Mg_{0.2}Ni_{0.2}Zn_{0.2})O$



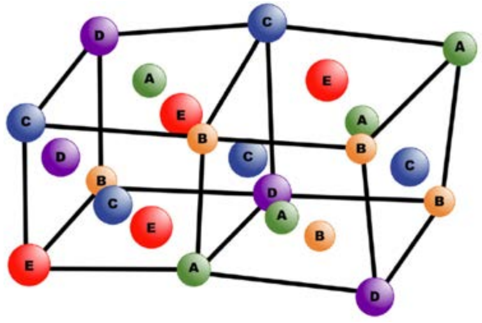
Sarkar et al., Nature Comm (2018).

- Complex concentrated materials have been reported to have outstanding properties such as high strength, tailored band gaps, extremely large dielectric constants, and substantially reduced thermal conductivity, making them the next paradigm shift in structural and functional materials.
- However, microstructural engineering with any predictive capability is missing.

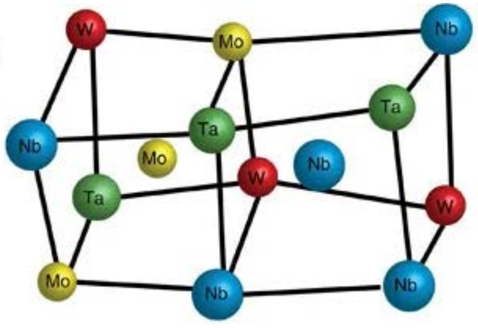
Grand Challenge and Distinguishing Features of IRG-1

Metals

Face centered cubic

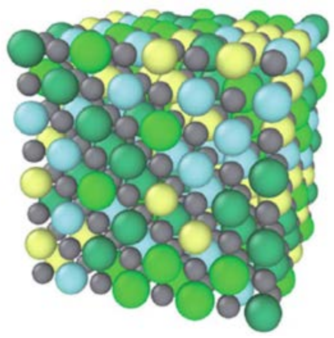


Body centered cubic

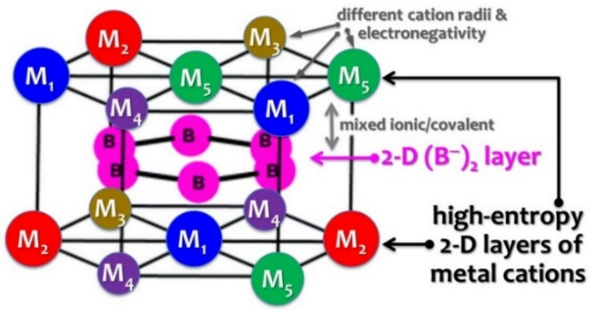


Ceramics

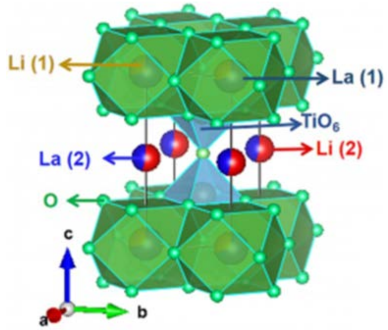
Rocksalt



2D Layered



Layered Perovskite



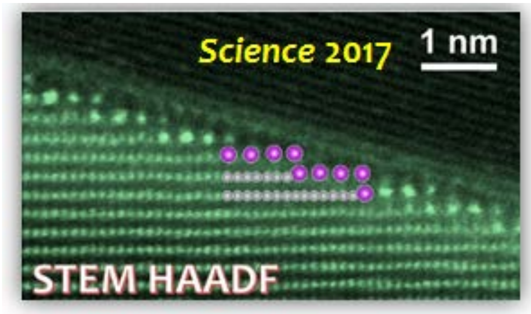
Metals → Build on established theories for simpler alloys

Ceramics → Add the complexity of interfacial charge, more complex crystal structures

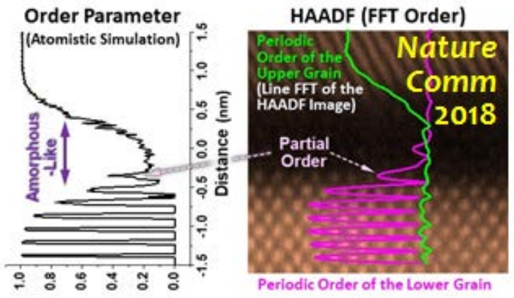
Sample essential properties, relevant for new structural/functional tech.

Chemical complexity →

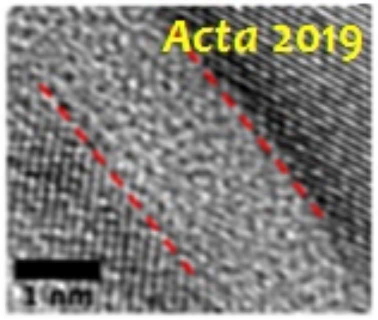
Structural disorder →



Ni-Bi



Ni-S



Cu-Zr-Hf

RA1 RA2 RA3 RA4

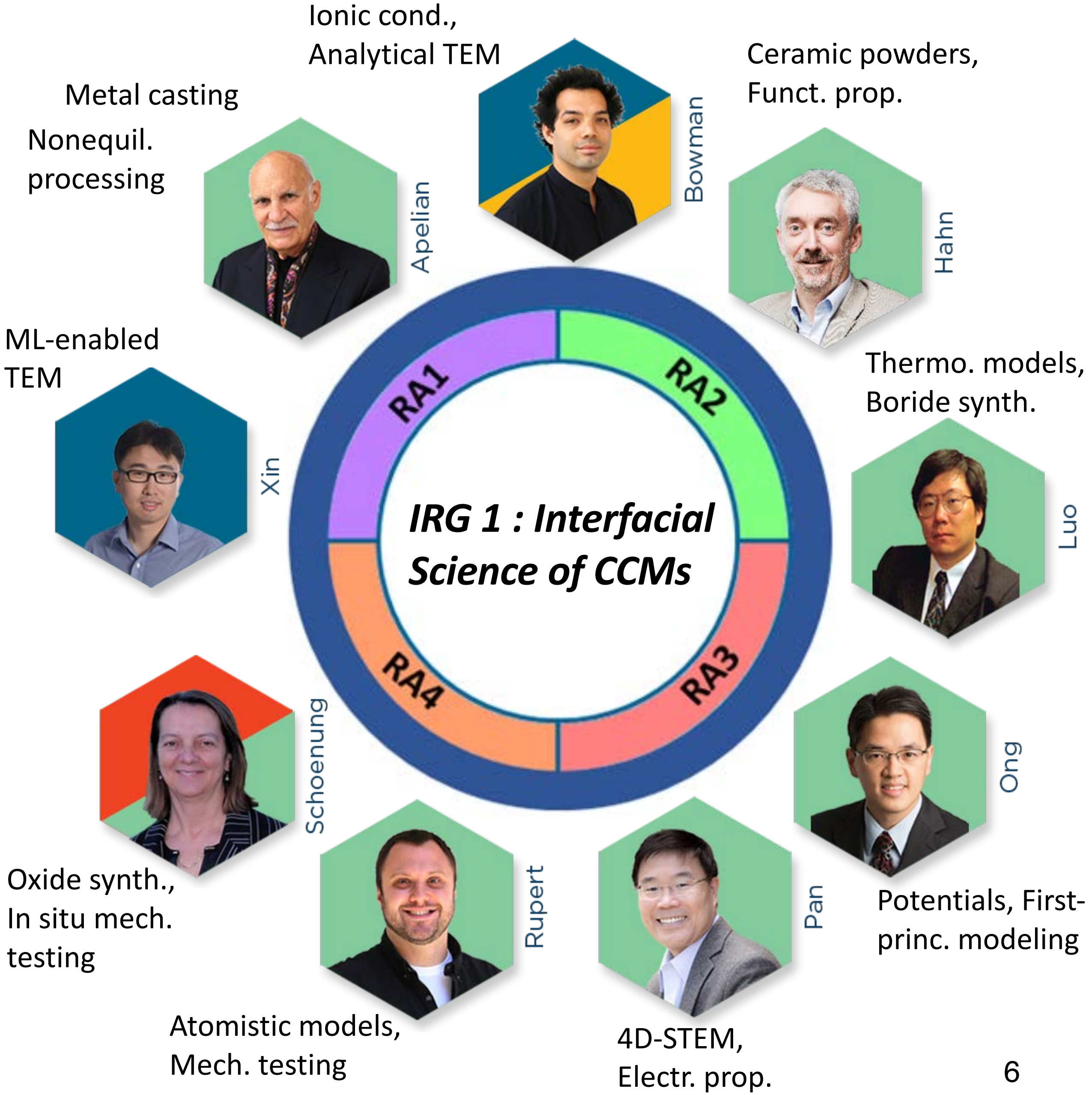
Examples of cross-cutting hypotheses

- Chemical complexity frustrates interfacial ordering
- Processing route determines segregation and nucleation
- Interface structure is modified during electrocatalysis

IRG 1: Goal, Integrated Team and Approach

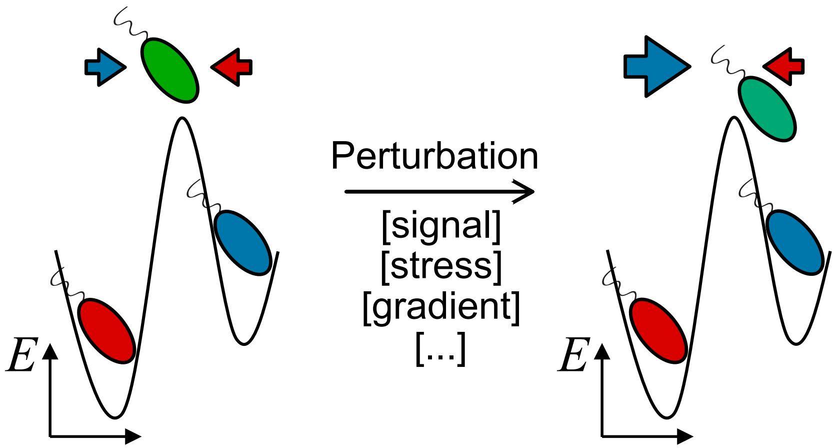
Goal: IRG-1 will establish the foundational science needed to understand, describe, and predict interfacial phenomena in metals and ceramics with multiple principal elements

- Develop the core principles of microstructural engineering for CCMs, including atomic-level structure and chemistry, interfacial thermodynamics, kinetics, and properties
- Design and synthesize materials with desirable microstructures and properties
- The team has complementary expertise in theory, computation/modeling, processing, advanced characterization, property measurement, and AI/machine-learning to enable a comprehensive study of interfacial behavior in CCMs.
- This IRG is expected to transform CCMs from laboratory curiosities into materials that alter our global economy in a variety of essential industries.

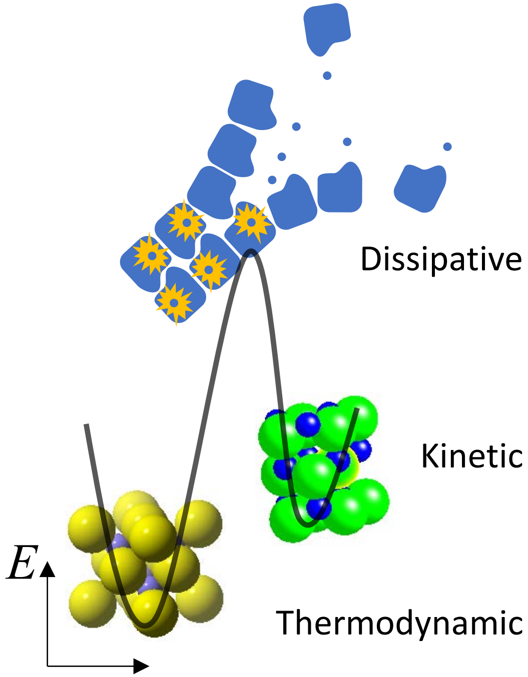


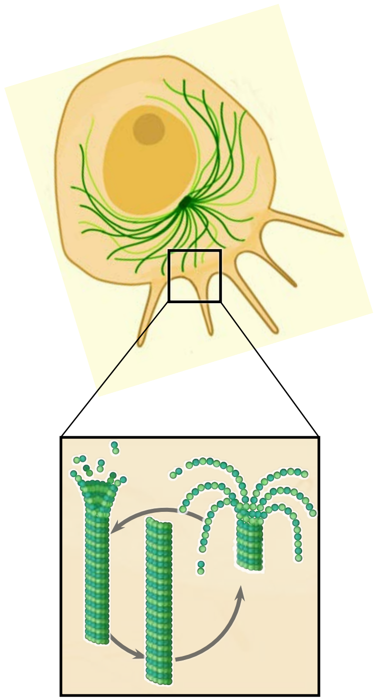
IRG 2 - Bioinspired Supramolecular Materials: Motivation and Vision

- Living systems largely exist far from equilibrium
- In contrast, synthetic materials reside at equilibria defined be composition and processing
- Organisms use constant energy dissipation and dynamic control to drive cellular processes



Out of equilibrium materials in biology:





Because Living systems exist at high energy, out-of-eq states, relatively small perturbation (stress, toxin, food, etc) will result in quick response and action

Synthetic materials mostly are designed to exist in thermodynamic minimal energy state or kinetically trapped state

Illustration of dynamic process for microtubule assembly-disassembly

IRG 2 is to design out-of-equilibrium (*dissipative*) materials to mimic biological function and better interface with biological systems

IRG 2: Dissipative Materials as Reconfigurable Bio-interface Devices

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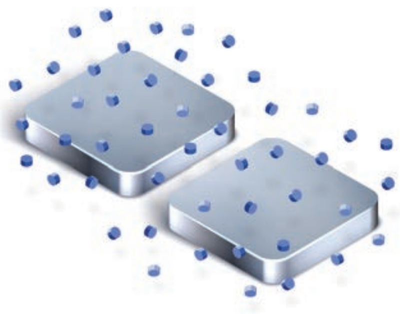
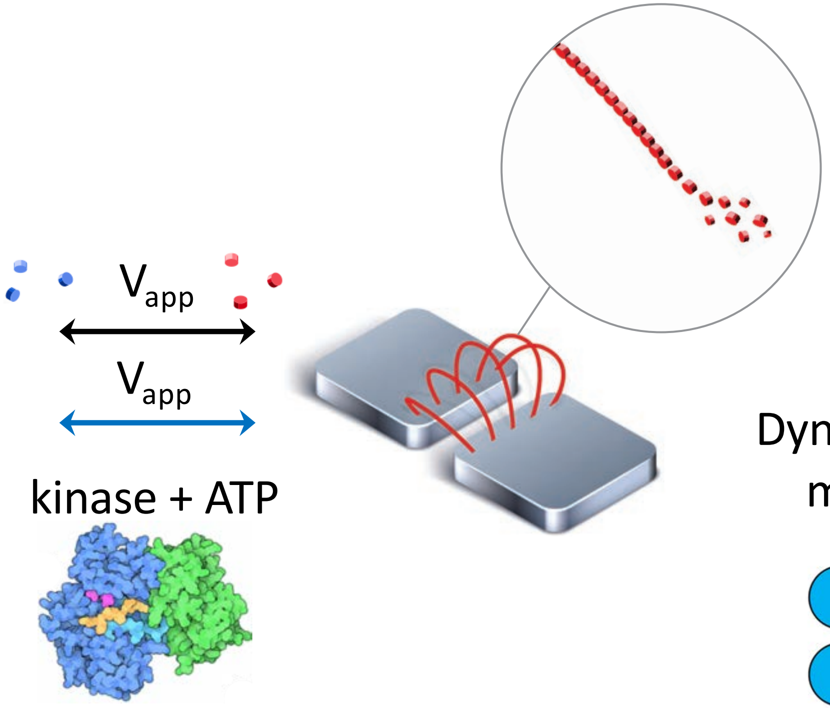
Electrically responsive:

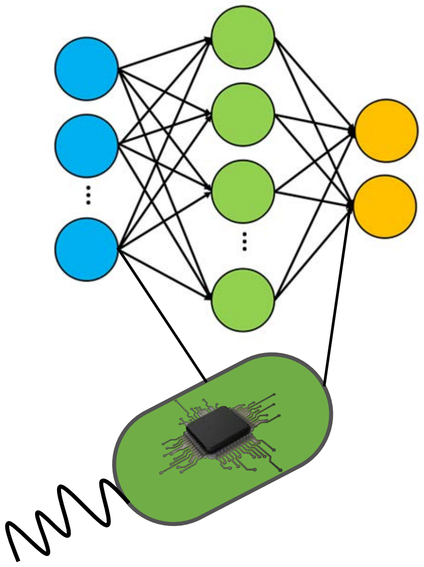


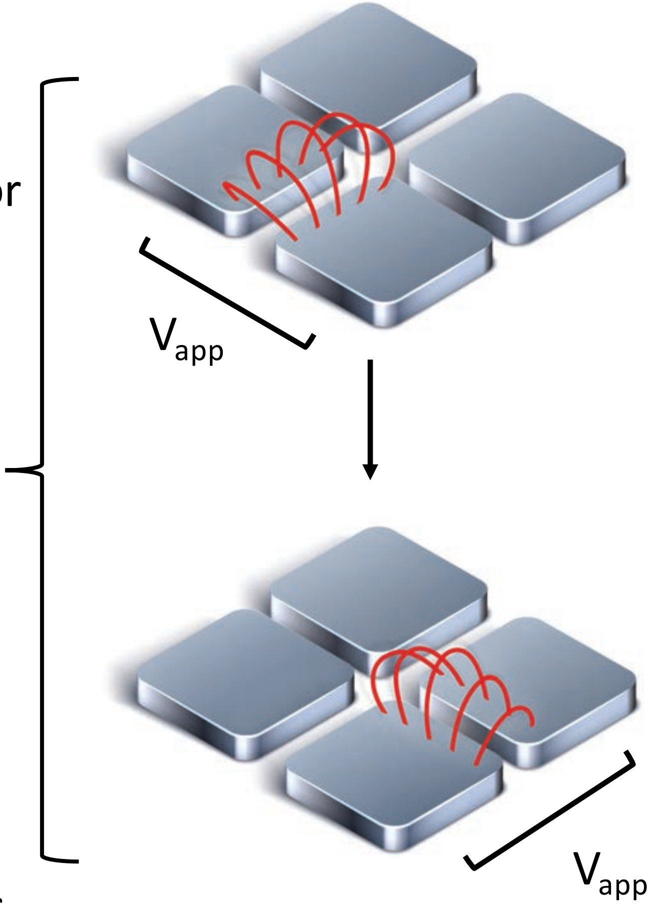


Biochemically responsive:

Resistive switching (neuromorphic computing)

Dynamic hardware for machine learning

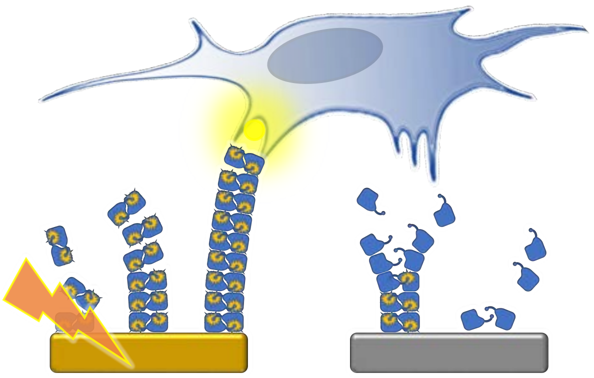




Integrated bio-logic

Transient cell electrical and mechanical stimulation:

(healing, neural interfaces, stimulated differentiation)



IRG 2: Goal, Integrated Team and Approach

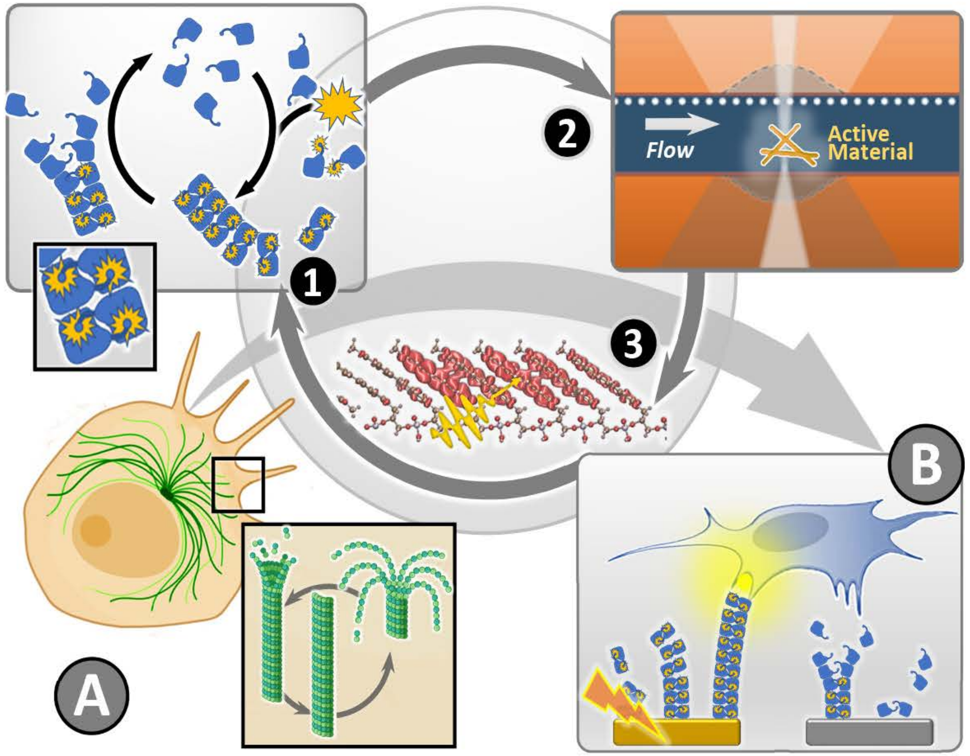
Grand Challenge: Develop a new experimental and theoretical framework for bioinspired dissipative, conductive supramolecular materials that can better interface with living systems.

Three Research Areas addressing three big scientific questions:

RA 1: How to design out-of-equilibrium supramolecular materials that can better interface with biology?

RA2: What processes (deterministic and stochastic) drive dissipative materials assembly and disassembly?

RA3: What features (chemical and structural) determine electronic conductivity in active, supramolecular materials?



Shared Facilities - IMRI

Nion STEM 200 HERMES

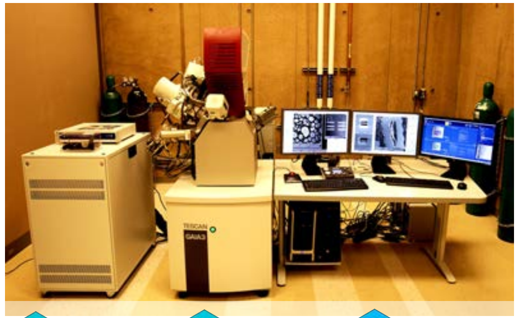
JEOL Grand ARM 300CF

JEOL TEM 2800

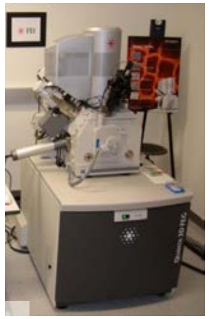
Cryo-TEM Glacios

Kratos AXIS Supera

TESCAN SEM/FIB



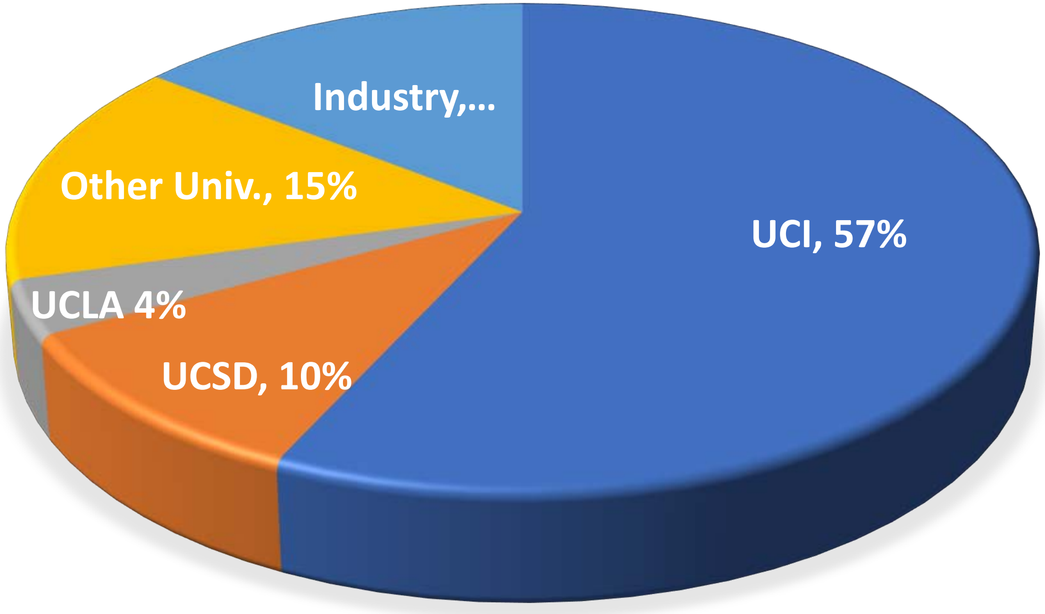
FEI-SEM



Since 2015, UCI invested over $40M on materials characterization facilities at IMRI, and supports many PhD level staff

IMRI operates a cluster of the cutting-edge facilities

IMRI is professionally staffed, affordable, with 24/7 open-access, user-friendly services.



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Instrumentation Innovation

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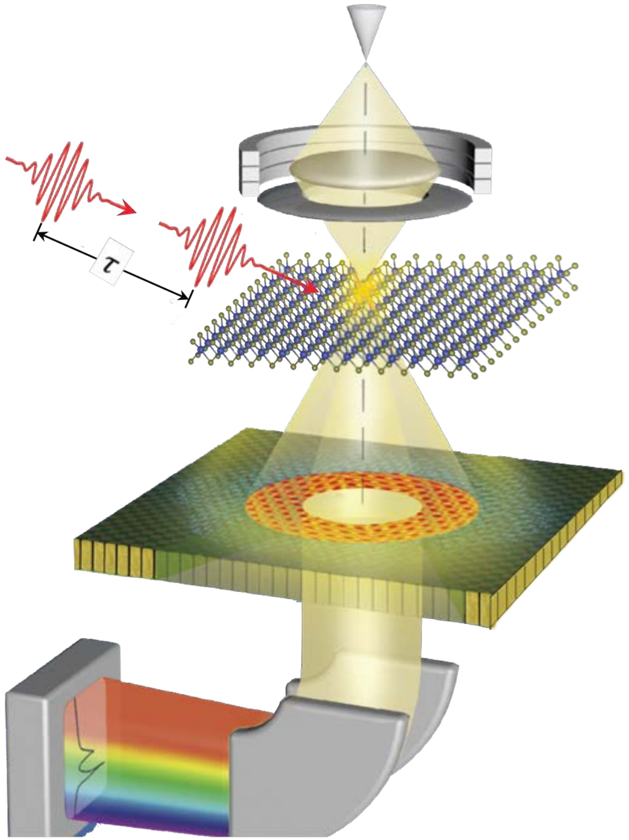
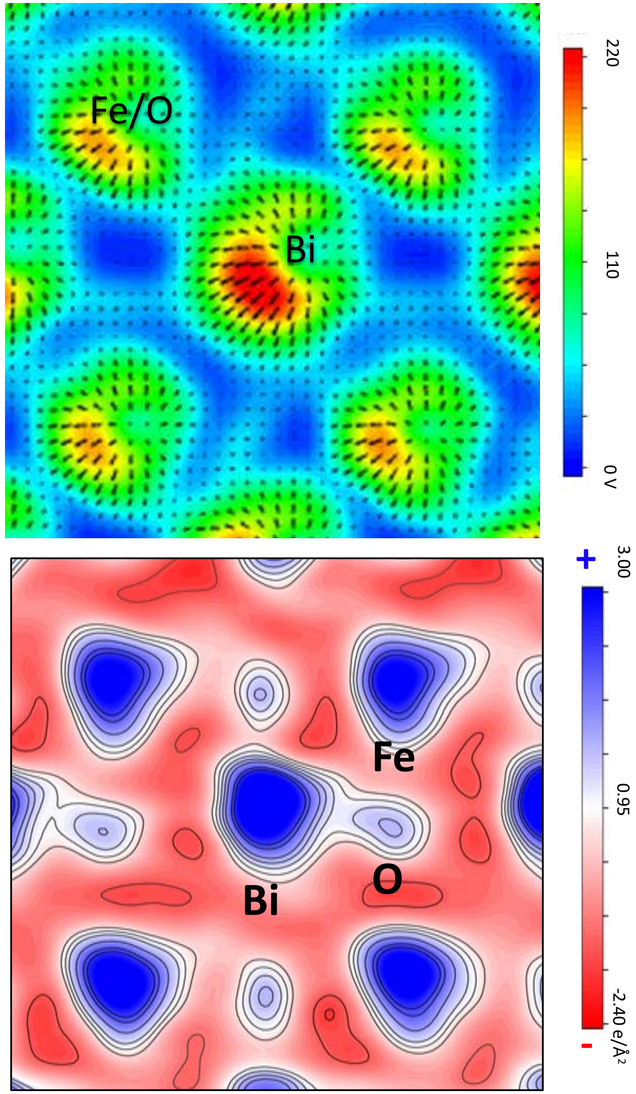
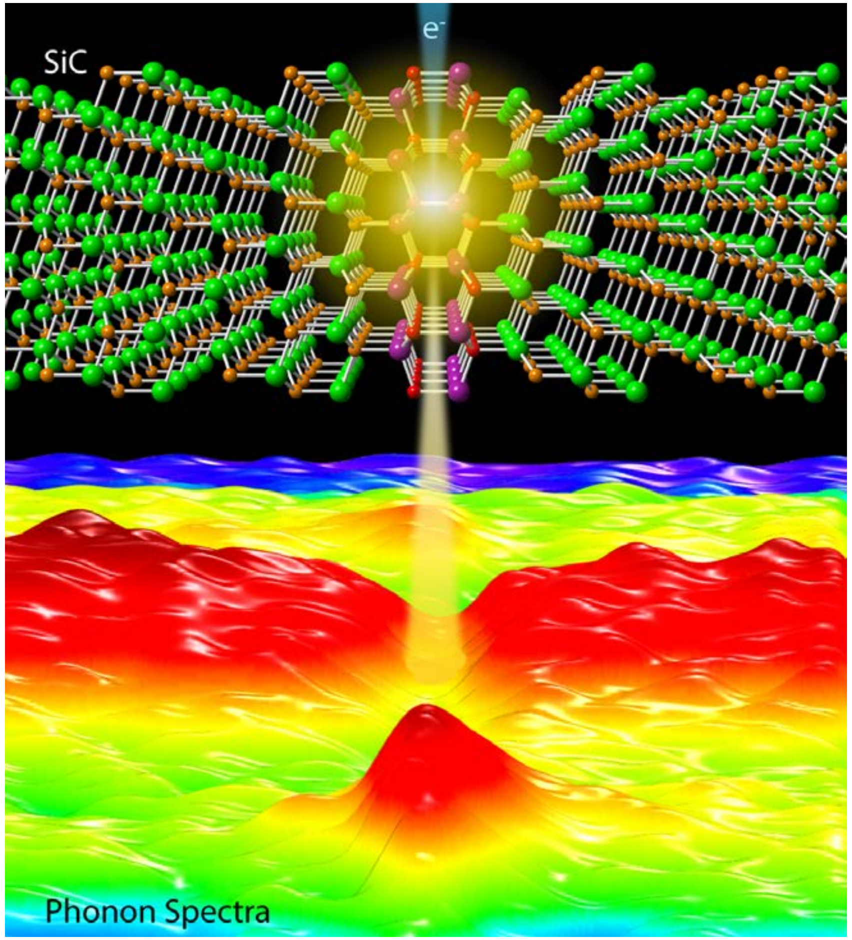


Dynamic S/TEM to probe dynamic responses of materials to THz pulses. Vibrational EELS with spatial and momentum resolutions



Real space mapping of electric field and charge density by 4D STEM

W. P. Gao, et al., *Nature* **575**, 480 (2019)



Upper: Sketch of a stacking fault in cubic SiC.
Lower: 3D plot of phonon spectra mapped by EELS. Note a red shift and intensity changes in acoustic phonon near a single stacking fault. These changes are confined to within a few nm of the stacking fault.

X. X. Yan, et al., *Nature* ***589*, *65 (2021)***

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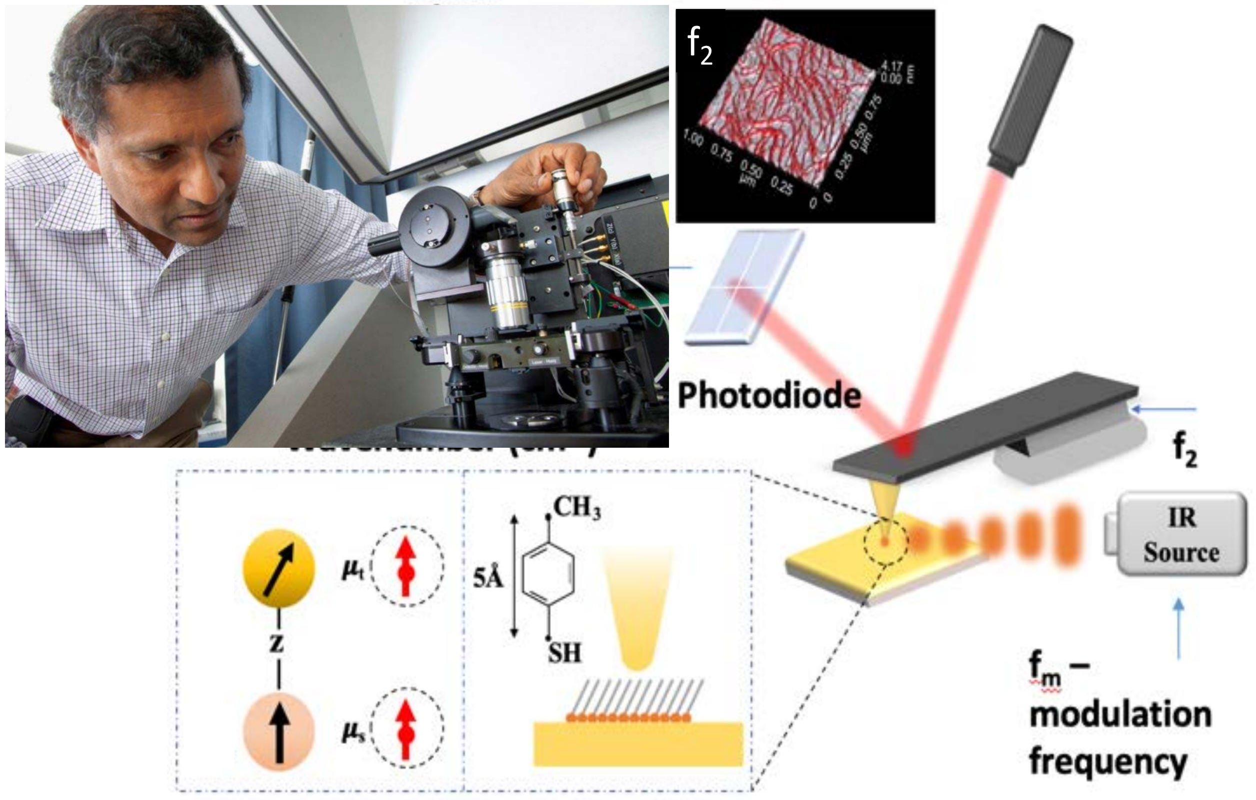
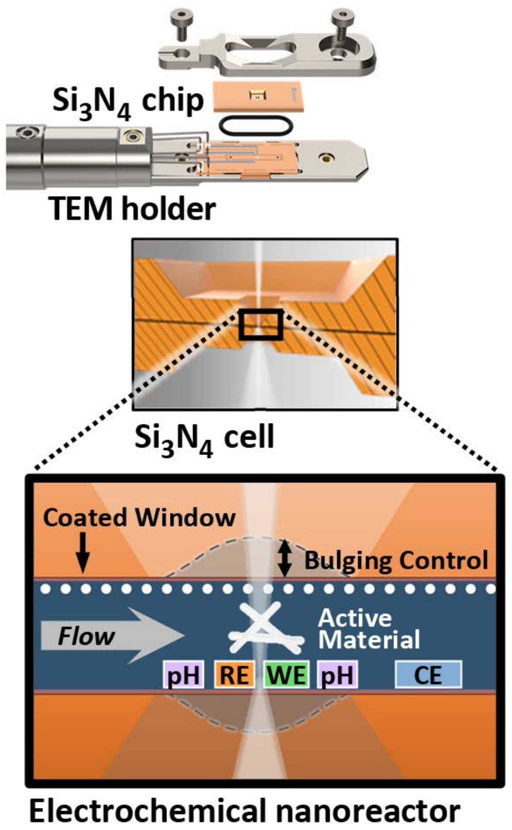
Plans for Developing Instrumentation





in situ **electrochemical TEM holder**

Silicon nitride cell

Nanoreactor configuration.

Photo-induced Force Microscopy (PiFM), developed by Wickramasinghe, a nanotechnology pioneer. To image samples under aqueous conditions, the system will be modified for experiments with liquid.

***In situ* liquid nanoreactor for TEM,** to be developed by Patterson, to enhance the temporal and spatial resolution for reaction kinetic studies of supramolecular materials.

Diversity, Equity, Inclusion and Belonging!

Education Director

Stacey Nicholas Endowed Chair for Diversity in Engineering Education

Co-Director

Assistant Dean for Stacey Nicholas Office for Access and Inclusion

New $5 Million Donation: Stacey Nicholas Office of Access & Inclusion

Director of Academic Innovation, Partnerships

OC STEM
ECOSYSTEM INSTITUTE

Gregory Diggs-Yang
Assistant Director for Stacey Nicholas Office for Access and Inclusion

https://www.latimes.com/socal/daily-pilot/news/story/2020-02-10/foundation-trustee-donates-5-million-to-uc-irvine-for-inclusive-stem-recruitment

https://news.uci.edu/2019/10/04/the-power-of-partnership/

Hypothesis & Goals: Engagement, Capacity and Continuity Trilogy

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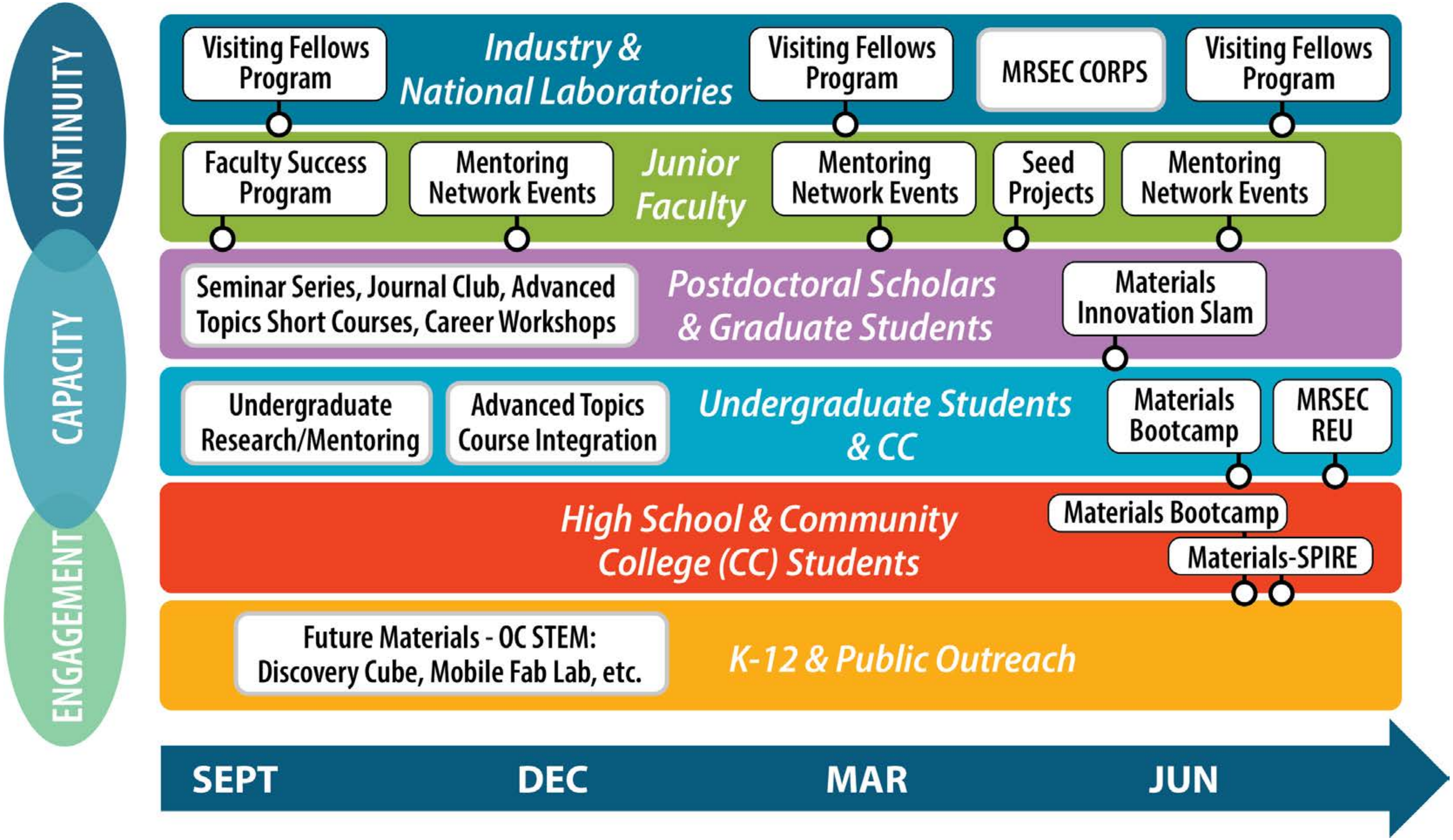
Engagement	Capacity	Continuity
		
Increase awareness, interest and motivation in STEM	**Cultivate skills to advance to rigorous STEM content**	**Continue engagement and tracking to support advancement to and through STEM**

Jolly, E.J., Campbell, P.B., & Perlman, L. 2004. Engagement, Capacity and Continuity: A Trilogy for Student Success. GE Foundation. www.campbell-kibler.com. Accessed April 1, 2016. 10. Campbell, P.B., and Jolly, E.J. Ten Years of Engagement, Capacity and Continuity: Reflections on a Triology for Student Success, http://www.campbellkibler.com/ECC_10_final.pdf. Accessed April 1, 2016.
Campbell, P. B., Jolly, E. J., Hoey L., & Perlman, L. K. (2002). Upping the Numbers: Using Research-Based Decision Making to Increase Diversity in the Quantitative Sciences. Newton, MA: Education Development Center, http://www.campbellkibler.com/upping_the_numbers.pdf. Accessed April 1, 2016.

Comprehensive Education and Outreach Plan



Solution: Define Pathways to STEM Careers

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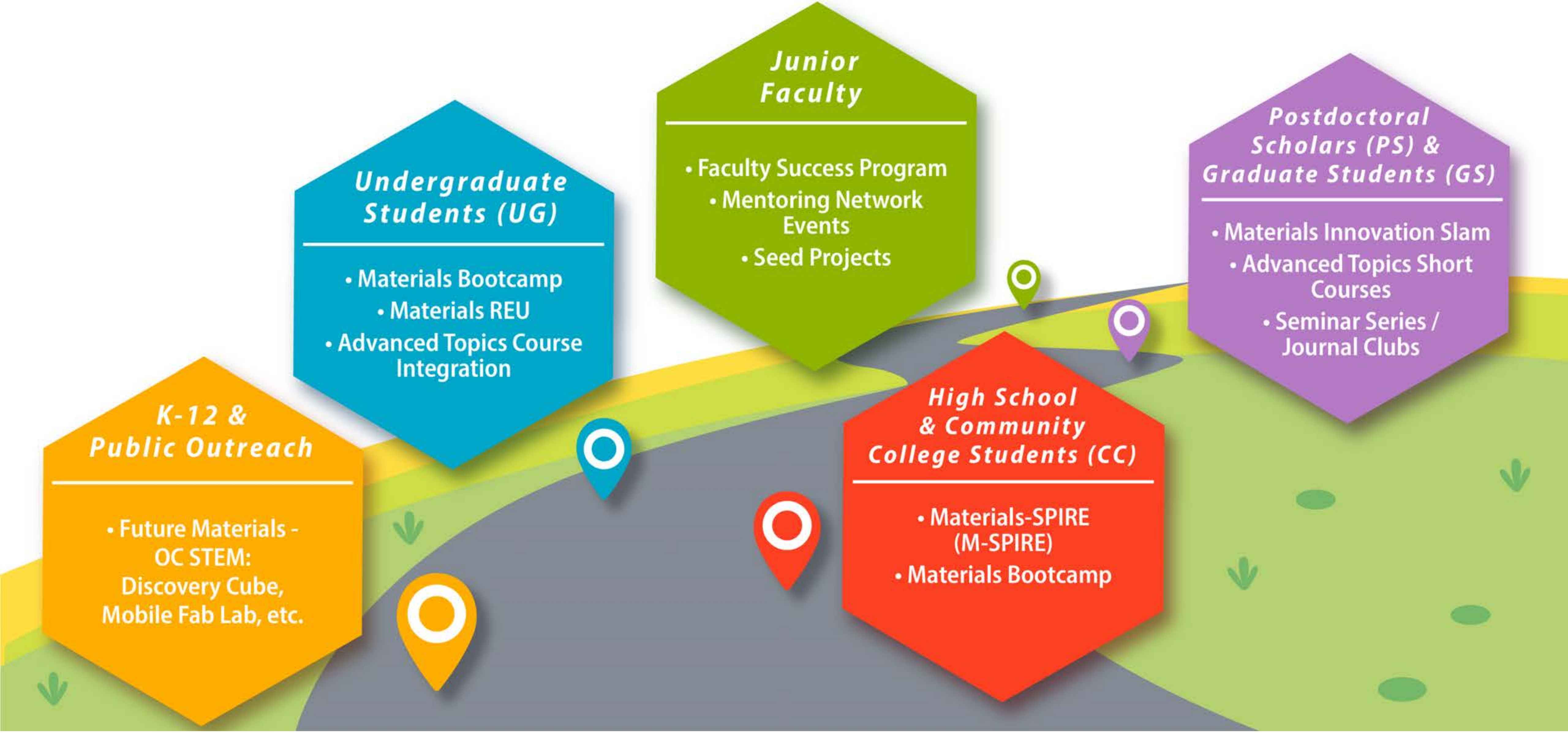
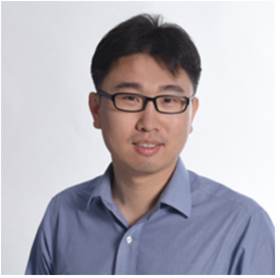


Junior Faculty Leadership Development Committee

Regina Ragan Diran Apelian Doug Tobias. Houlin Xin



https://www.equityinstem.org/networks-metaanalysis/

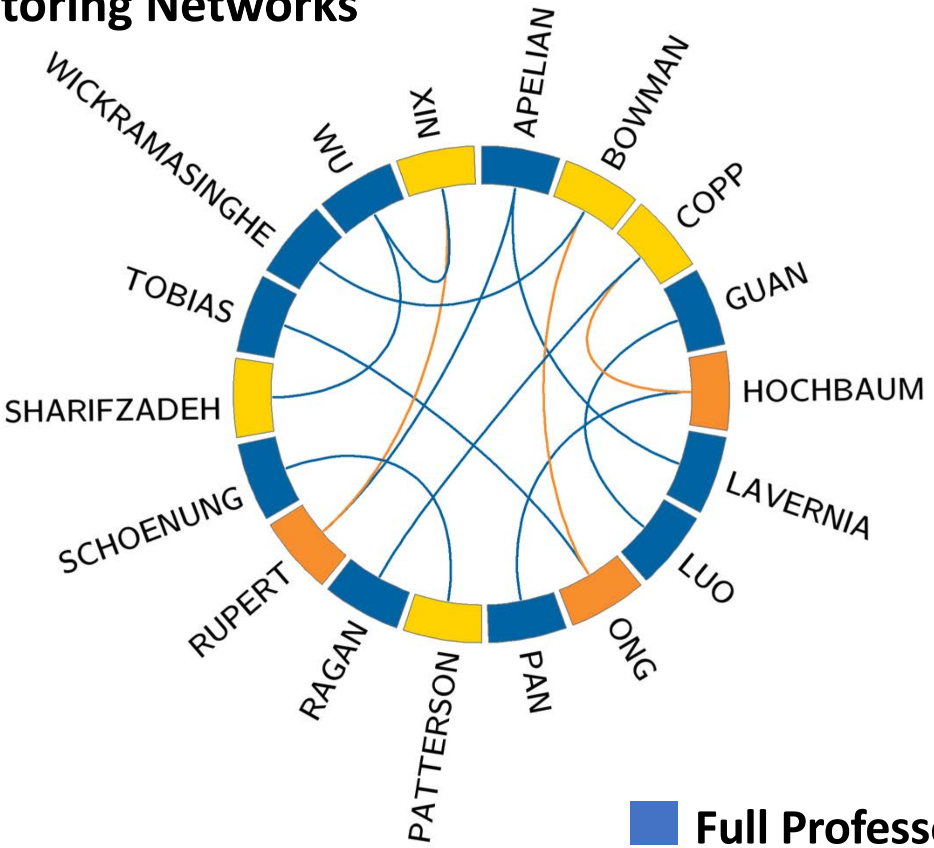
The meta-analysis suggests faculty networks are gendered to disadvantage women in STEM.

-Women have smaller networks than their male counterparts.

-Women STEM faculty also tend to be more disconnected from the most central actors in research networks

-Both men and women scientists tend to have homophilous networks, but for women, their gender-homophilous networks are negatively associated with organizational status, and thus provide them with lesser quality information and resources.

Mentoring Networks



Full Professor
Associate Professor
Assistant Professor

- Co-authored publications
- Collaborative funding
- National awards/ nominations

Faculty Success Program | Mentoring Network Events | *Junior Faculty* | Mentoring Network Events | Seed Projects | Mentoring Network Events

Junior Research Fellows: Materials Innovation Slam

Industrial partners will judge best three-minute research presentations by JRF.

Showcases JRF and provide networking opportunities for JRF.

INTERN
NSF

COVE

Top 2 students from each IRG write quarterly podcasts

THE LOH DOWN ON SCIENCE
npr KPCC
Fuhs Family Foundation
UCI SCI COMM
LDOS Media Lab, Inc.

Seminar Series, Journal Club, Advanced Topics Short Courses, Career Workshops

Postdoctoral Scholars & Graduate Students

Materials Innovation Slam

REU - Active Learning: Materials Bootcamp & Industry Engagement

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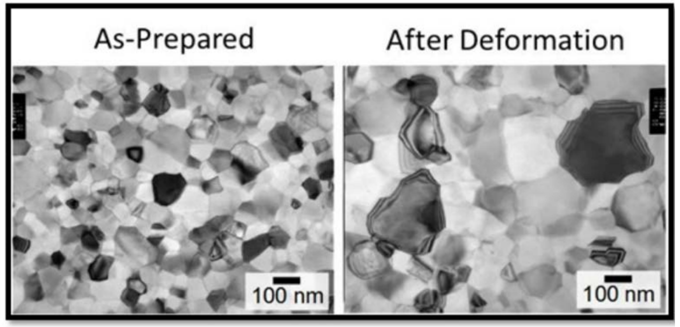

www.pnas.org/cgi/doi/10.1073/pnas.1916903117
Active Learning Narrows Achievement Gap

ACRC Advanced Casting Research Center

Western Digital

IBM

United Technologies

QuesTek Innovations LLC

SHARK TANK

UCI Beall Applied Innovation
COVE

Undergraduate Research/Mentoring | Advanced Topics Course Integration | *Undergraduate Students & CC* | Materials Bootcamp | MRSEC REU

THANK YOU!