

**University of Washington**

# **Molecular Engineering Materials Center**

**Daniel R. Gamelin**  
**Center Director**

MRSEC Directors Meeting  
January 28/29, 2021

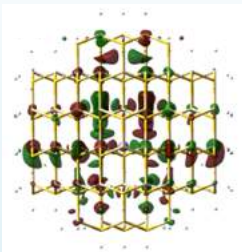


# MEM-C Research Components

## IRG-1:

### Defects in Nanostructures

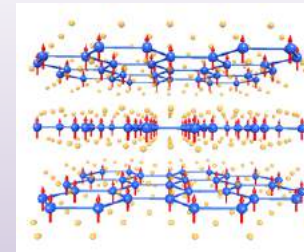
Harnessing defects to control the physical properties of crystalline nanostructures



## IRG-2:

### Layered Quantum Materials

Discovering new forms of quantum matter in atomically layered materials



## Superseed (2018)

Data-Enabled Microscopies and Spectroscopies

## Shared Facilities

Unique capabilities and workhorse instrumentation

## Seeds

Emerging areas, new directions, new investigators

## Partnerships

Collaborations, technology translation

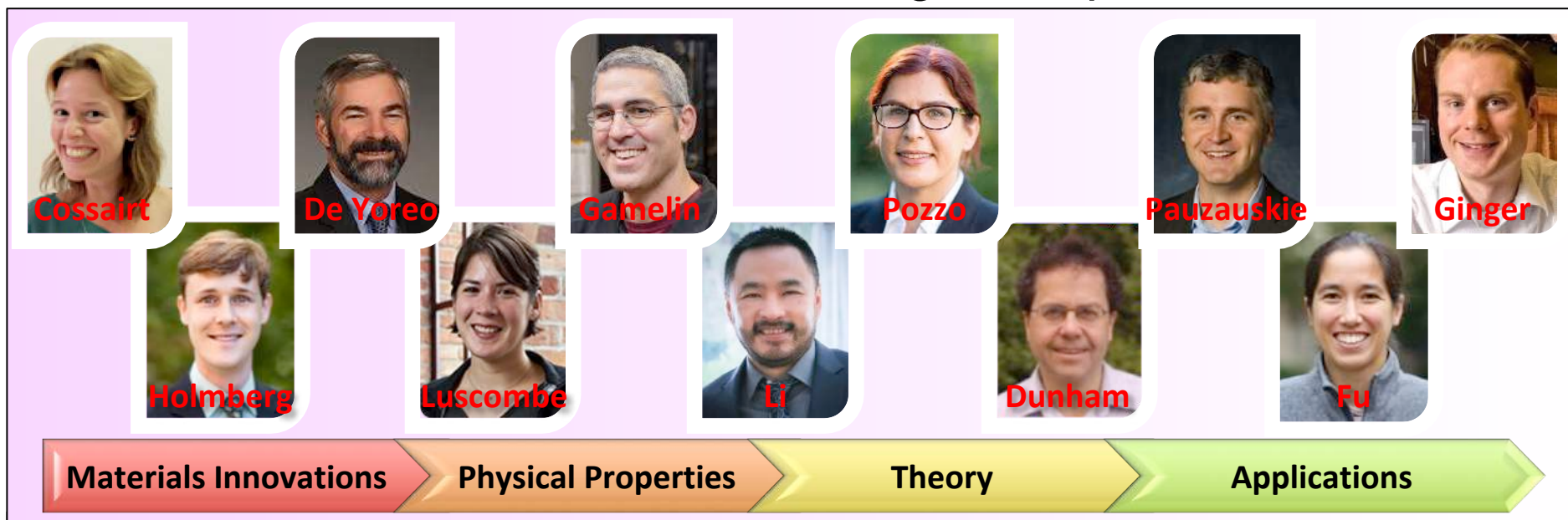
## REU/RET/REM

Broadening participation, impact

### Primary NSF Big Ideas

- Quantum Leap
- Harnessing the Data Revolution

Defect-engineered nanostructures with unique physical properties  
that define future technological capabilities



4 departments  
+ PNNL

**Thrust A:**  
**New Materials**  
synthesis

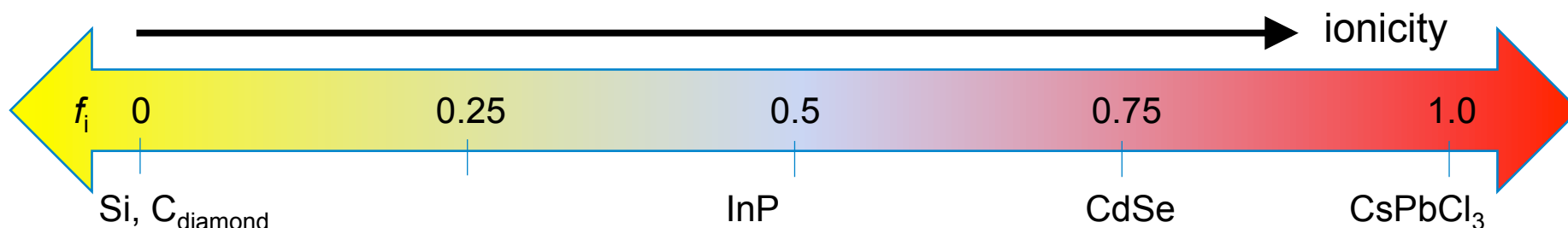
post-synthetic transformations  
defect characterization  
electronic-structure studies

**Thrust B:**  
**New Functionality**  
photophysics  
magneto-optics  
sensing  
spectral conversion  
laser cooling

# Defect Engineering Challenges

## Defect Chemistry Along a Spectrum of Covalency, Dimensionality, and Anisotropy

### Key Fundamental Challenges:



**Kinetic control:** How do impurities/defects impact nanocrystal nucleation, growth, oriented attachment, Ostwald ripening?

**Thermodynamic control:** How do impurities/defects diffuse in nanocrystals? What are the roles of dimensionality, ionicity, faceting, vacancies? Do Fick's Laws of macroscopic diffusion still apply?

**General:** How to overcome impurity/lattice incompatibilities:  
size, shape, charge, ionicity, lattice inertness?

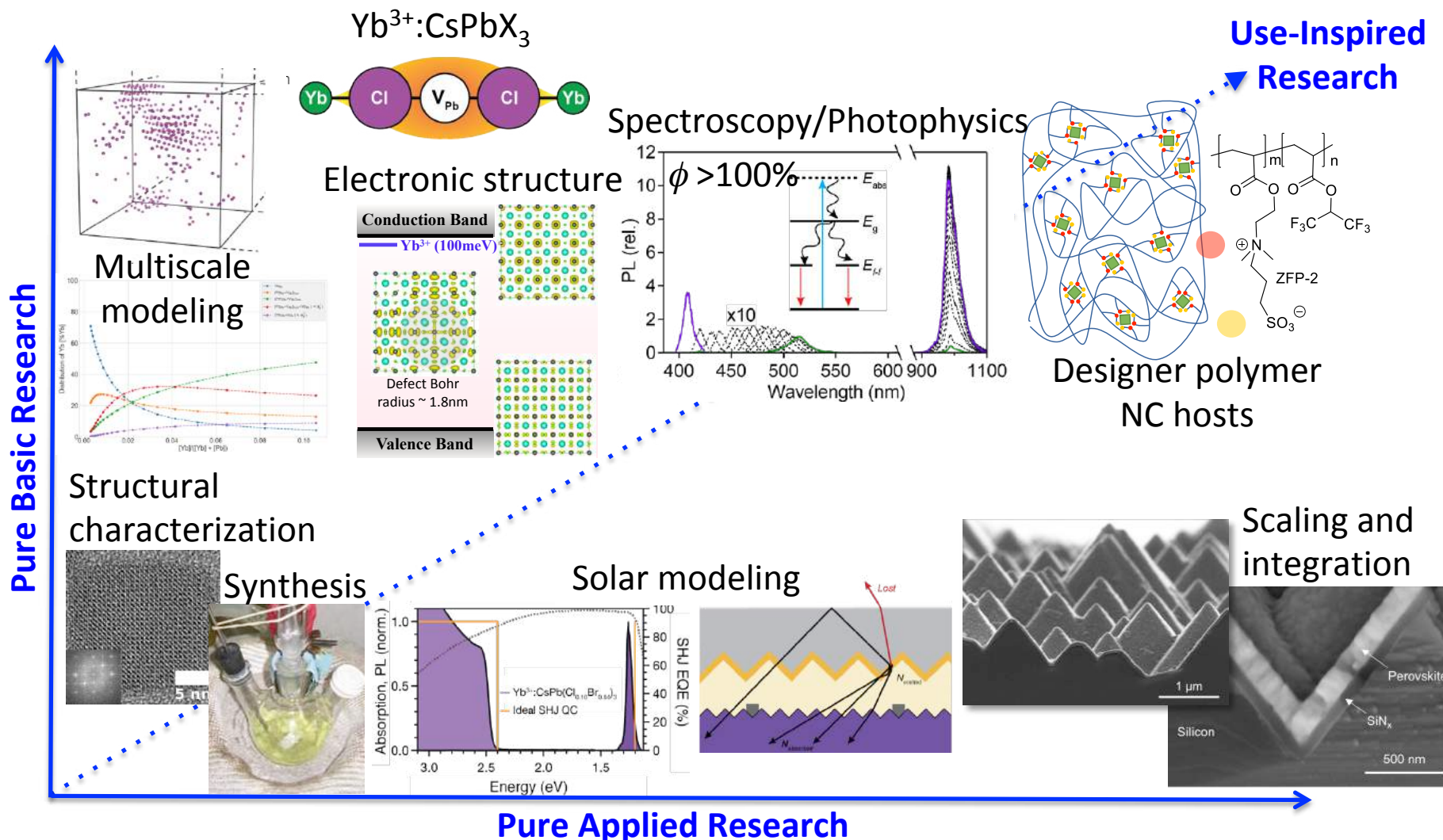
Beyond specific new materials, Thrust A is yielding  
Broad Enabling Capabilities



# IRG-1 Synergy Example

## Opportunity: Quantum-Cutting $\text{Yb}^{3+}$ -Doped Haloperovskites

Use-Inspired  
Research



Gamelin, Dunham, Luscombe, De Yoreo, Li, Mackenzie

**Xiaodong Xu**  
Physics & MSE (IRG Lead)  
*semiconductor optics*  
*2D heterostructures*  
*spin/pseudospin*  
*magnetism*  
*correlated physics*



**Anton Andreev**  
Physics  
*mesoscopic transport*  
*superconductivity*  
*topological physics*



**Xiaosong Li**  
Chemistry  
*theory, ab initio*  
*electronic structure*



**Kai-Mei Fu**  
Physics & EE  
(IRG co-Lead)  
*quantum optics*  
*spin defects*  
*quantum information*



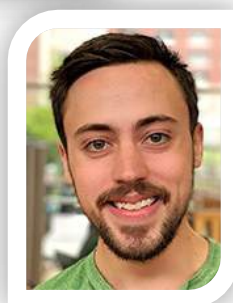
**Mo Li**  
EE & Physics  
*optoelectronics/*  
*mechanics, NEMS/*  
*MEMS,*



**David Cobden**  
Physics  
*quantum transport*  
*device engineering*  
*superconductivity*  
*topological physics*  
*correlated physics*



**Matt Yankowitz**  
Physics & MSE  
*topology, transport,*  
*scanning probe*  
*microscopy*



**Arka Majumdar**  
EE & Physics  
*nanophotonics*  
*quantum optics*

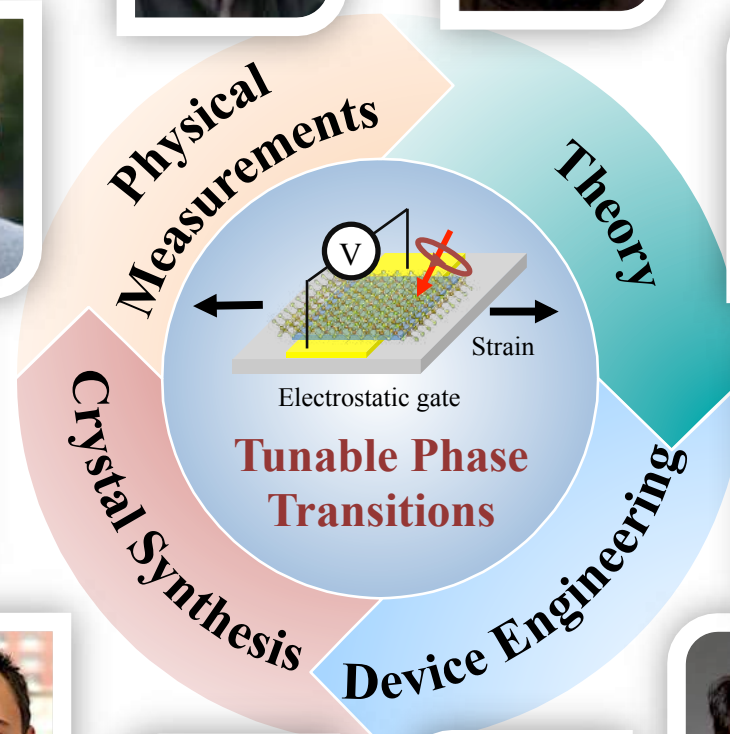


4 departments

**Jiun-Haw Chu, Physics**  
*crystal growth*  
*topological physics, transport*



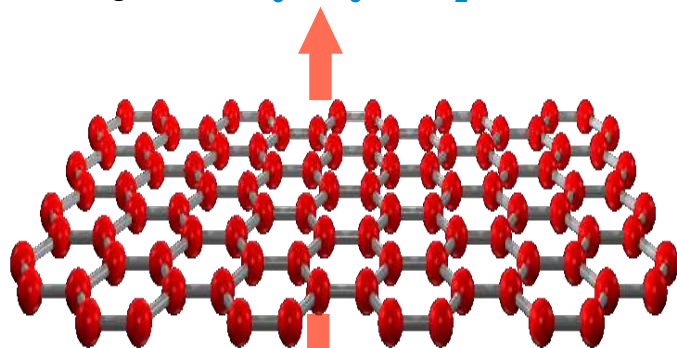
**Jihui Yang, MSE**  
*crystal growth, thermal transport*



# 2D Materials are Uniquely Suited for Controllable Electronic Phase Transitions

## Portfolio of properties

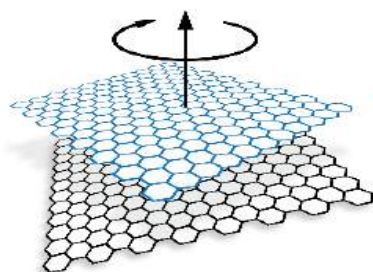
2D metals: Graphene ...  
 2D Semiconductors:  $\text{MoS}_2$ ,  $\text{WSe}_2$ ,  $\text{MoSe}_2$  ...  
 2D Superconductors:  $\text{FeSe}$ ,  $\text{NbSe}_2$ ,  $\text{WTe}_2$  ...  
 2D Ferroelectrics:  $\text{CuInP}_2\text{S}_6$ , **Bilayer  $\text{WTe}_2$**  ...  
 2D Topological Insulators:  $\text{WTe}_2$  ...  
 2D Magnets:  $\text{CrI}_3$ ,  $\text{Fe}_3\text{GeTe}_2$



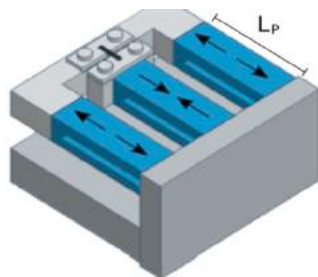
Atomically thin  
 Van der Waals materials

## Nano-mechanical tuning

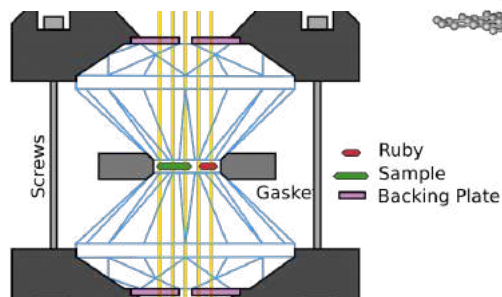
Twist angle control



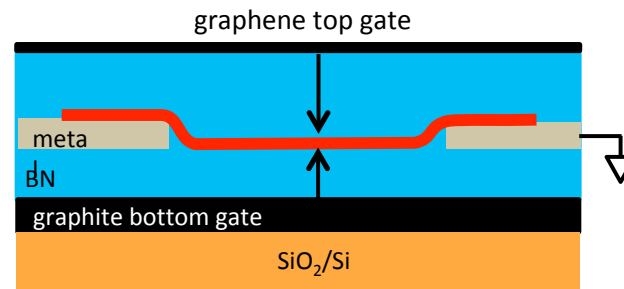
Strain



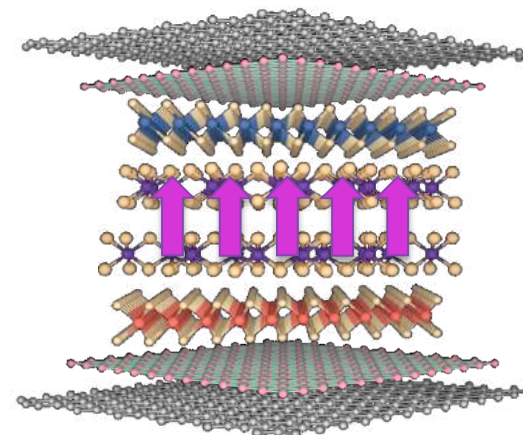
Pressure



## Electrostatic gating



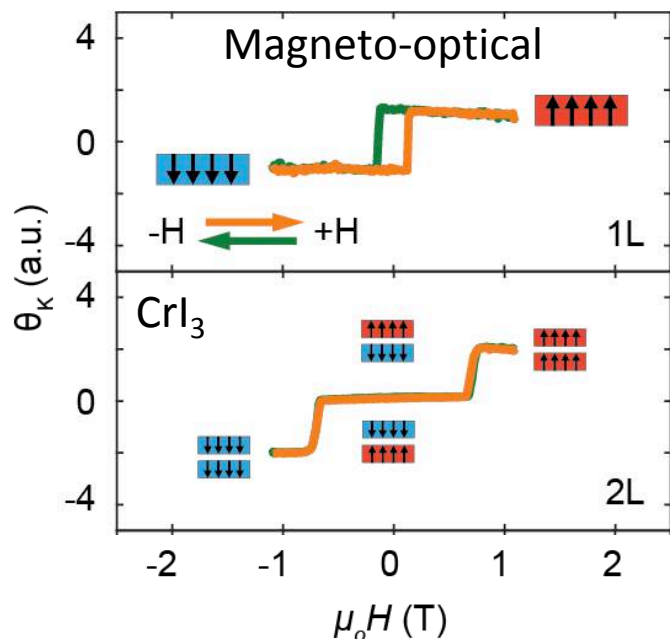
## Interface engineering



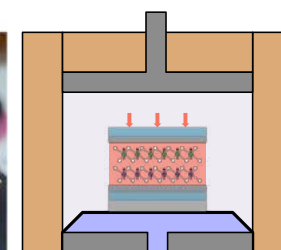
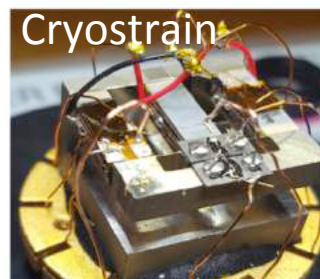
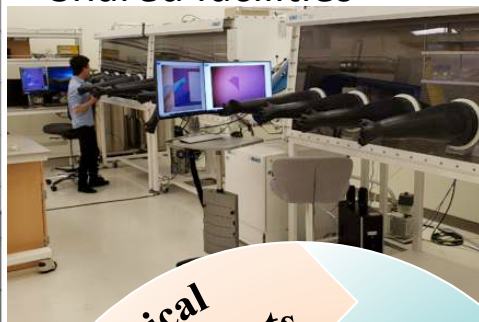


# IRG-2 Synergy Example

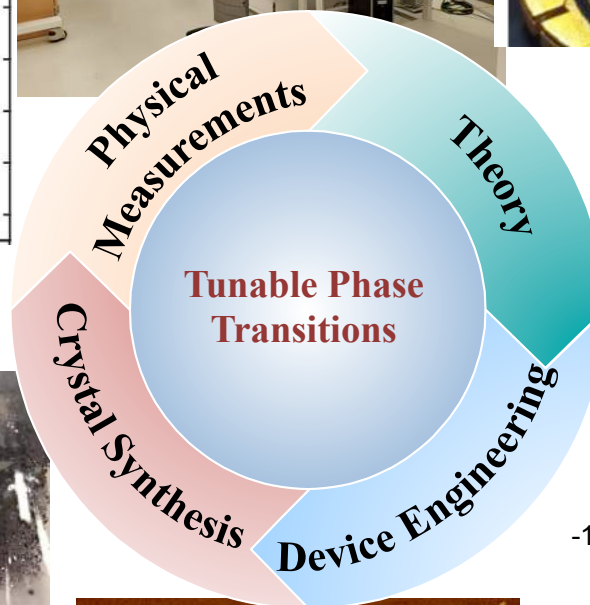
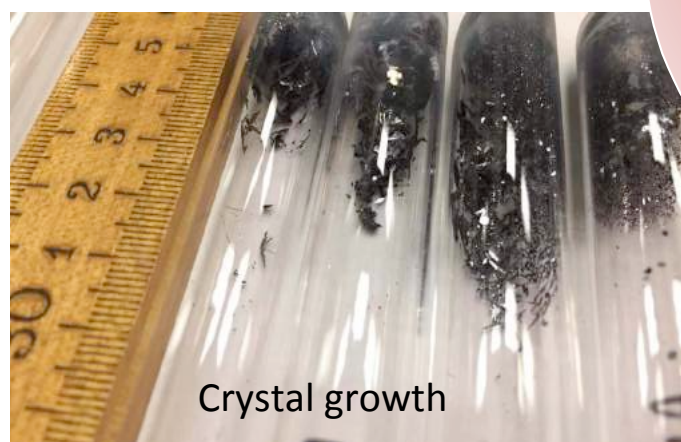
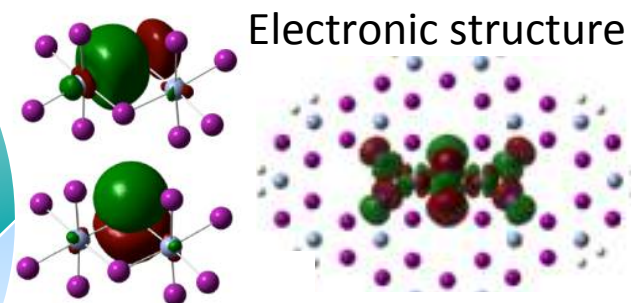
## Opportunity: 2D Ferromagnets, $\text{CrX}_3$



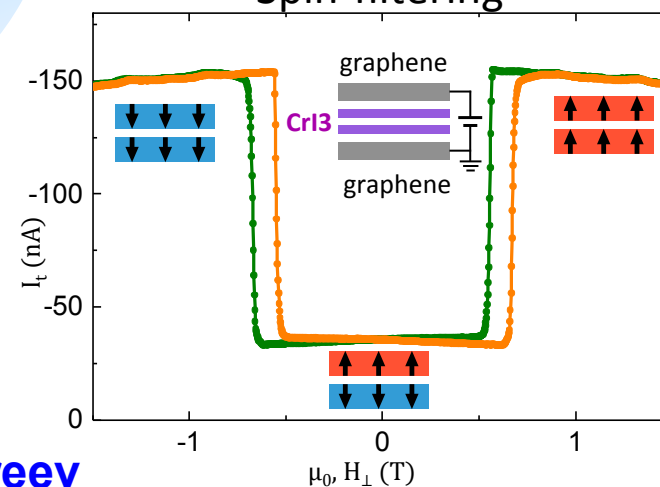
Shared facilities



Pressure



**Spin-filtering**



Xu, Cobden, Chu, Li, Andreev



## Accelerating Materials Discoveries by Data-Enabled Microscopies and Spectroscopies



**Jiangyu Li**  
(MechE)  
Electrochemical  
scanning-probe  
methods



**David Ginger**  
(Chemistry, IRG-2)  
Scanning-probe  
techniques



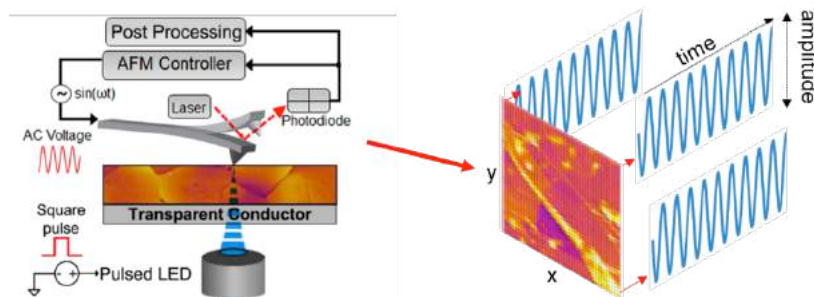
**Nathan Kutz**  
(Applied Math)  
Machine learning and  
big-data analysis



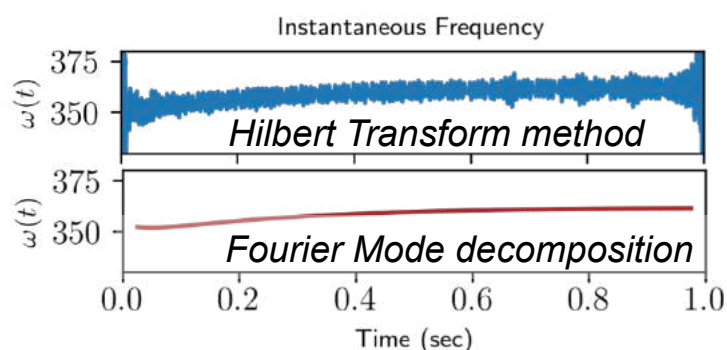
Unfunded  
Collaborator:  
**Xiaodong Xu**  
(Physics, IRG-2)  
2D materials

## New Mathematical Methods Enabling Data-Rich Microscopy

Kutz, Ginger



- AFM yields large, multidimensional datasets
- Need to process dynamic data to extract hidden information

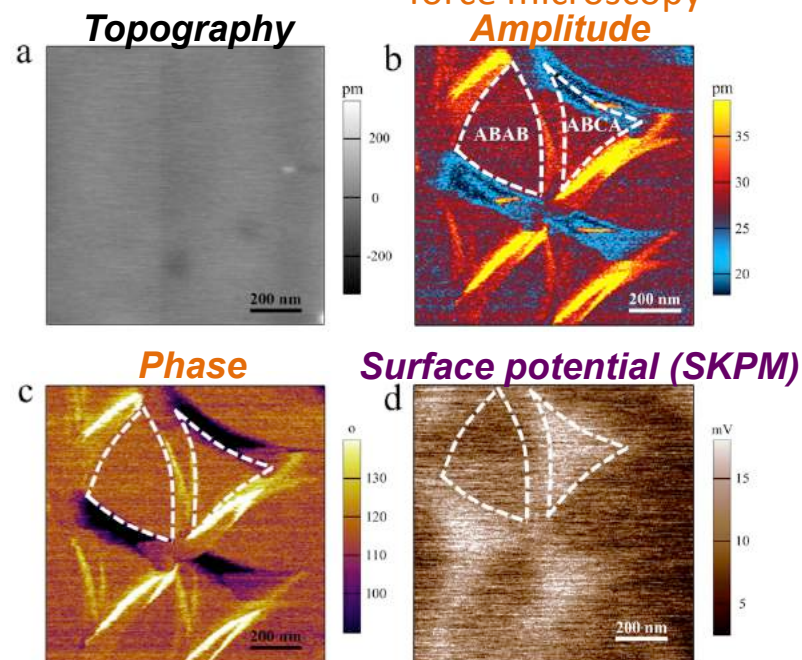


Machine Learning methods (Fourier mode decomposition) to extract frequencies  
→ **significant signal:noise benefits**

## Multimodal SPM Correlates Surface Potential with Stacking in Twisted Double Bilayer Graphene

Ginger, Li, Xu, Cao

Lateral piezoresponse  
force microscopy  
**Amplitude**



- Correlating stacking configurations with piezoresponse amplitude/phase and surface potential
- Electronically imaged Moiré patterns, completely non-contact

# Seed Program

Absorbed into  
IRGs:



**Lilo Pozzo**  
Prof.  
ChemE



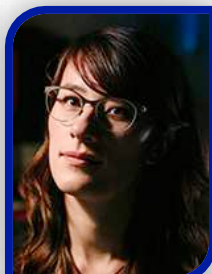
**Mo Li**  
Assoc Prof.  
EE/Phys Fall '18



**Matt Yankowitz**  
Asst Prof.  
Phys/MSE Fall '19



**Ting Cao**  
Asst Prof.  
MSE Fall '19



Superseed

Superseed

- 10  
departments  
- Majority  
assistant profs







# 2019 NANOCRYSTALS NORTHWEST

Pack Forest Conference Center, August 13-15, 2019



New biennial regional conference/workshop  
54 participants from 11 Pacific Northwest institutions  
incl. 6 PUIs, 2 R1 universities (+UW), PNNL, an industry partner (OSRAM), MEM-C REUs

## National Laboratory Partnerships

### Northwest Institute for Materials Physics, Chemistry, and Technology (NW IMPACT)

Founding Co-Directors:

Launched in 2018



**De Yoreo**

(PNNL, IRG-1)



**Ginger**

(Chem, IRG-1)

#### Mission

- create at least 20 new joint UW/PNNL appointments among existing senior researchers
- streamline access to research facilities at both campuses for collaborations
- involve at least 20 new UW graduate students in UW/PNNL collaborations
- competitive seed grants to new UW/PNNL teams

### NW IMPACT seeds of new UW/PNNL collaborations:

New Quantum Phenomena by Combining 2D Materials with Complex Oxides

**Xu, Chambers, Li, Sushko, Cobden, Chu, Gamelin**

*Integrating MEM-C materials with epitaxial oxides for new quantum materials*

Scalable Engineered Chalcogenide Quantum Materials

**Pauzauskie, Perea, Holmberg, Spurgeon, Gamelin, Li**

*Integrating MEM-C materials into optical microcavities for quantum optics*



# UW QuantumX Initiative

Launched in 2019



**Fu**

Chair

(IRGs 1&2)



**Majumdar**

Co-chair

(IRG-2)

Campus initiative aimed at accelerating quantum discoveries, technologies, workforce development

- strategic hires
- infrastructure investments
- education and training
- regional partnerships

**MEM-C anchors the materials-research efforts of QuantumX**

## Northwest Quantum Nexus

**Fu** represented UW in founding Northwest Quantum Nexus (NQN), a coalition of research and industrial organizations in the Pacific Northwest for **Quantum Information Sciences** research and workforce development.

**Keystone partners:**



Inaugural NQN Summit (3/19) featured presentations from regional industry and academic leaders, a U.S. Senator, two U.S. Congressional Representatives, and UW administration leaders.

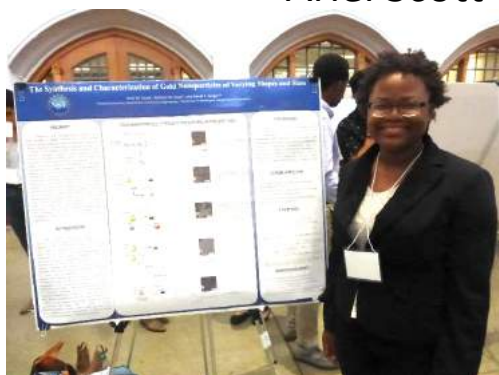


- National recruitment
- >300 applicants annually
- Targeting veteran recruitment
- Emphasis on gateway colleges
- Targeting freshmen/sophomores



Martin Reed

Ariel Scott



## 2018 REU

Ho Lun	Chan	Materials Science and Engineering		California State Polytechnic Univ., Pomona
Kaviraj	Krsnadas	Chem. Engineering		Dartmouth College
Ariel	Scott	Chemistry		Howard University
Stuart	Balaban	Physics	veteran	University of Texas at Arlington
Reed	Martin	Physics	veteran	Olympic College
Todd	Eliason	Chemistry	veteran	University of North Georgia
Eric	Riesel	Chemistry		Columbia University

## 2019 REU

Sawyer	Lichon	Physics	veteran	Pacific Lutheran University
Megan	Bui	Electrical Engineering		Bellevue College
Emmanuel	Valencia	Mechanical Engineering	veteran	Whatcom Community College
Kaitlyn	Fong	Physics and Visual Arts		Carnegie Mellon University
Christopher	Mechling	Chemistry	veteran	Bellevue College
Alejandro	Franco	Chem. Engineering	veteran	Lee College

## 2020 REU (Remote)

Zachary	Alvidrez	Chemistry	veteran	Rio Hondo College
Logan	McCarthy	Biomedical Engineering, Computer Science, Cyber Engineering	veteran	Louisiana Tech University
Sofia	Edgar	Physics, Engineering		Bates College
Shaelyn	Iyer	Chemical Engineering		Northwestern University



## Alejandro Franco

- Flight Chief in the US Air Force for 6 years
- Enrolled at a community college (Lee College, Baytown, TX)
- Came to UW as a 2019 MEM-C REU student, worked with Holmberg
- Attended Nanocrystals Northwest  
(he thought this was super cool, had never experienced a scientific conference before)
- Nominated for the CURS national symposium, selected, traveled to DC for the national event
- Transferred to Texas A&M, ChemE major, class of 2022, hopes to go to grad school