CENTER FOR EMERGENT MATERIALS

NATIONAL SCIENCE FOUNDATION

MATERIALS RESEARCH SCIENCE & ENGINEERING CENTER

DIVISION OF MATERIALS RESEARCH

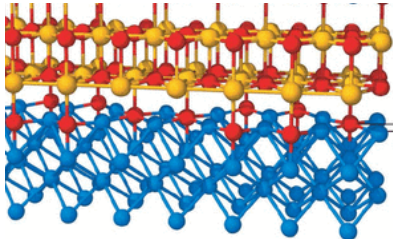
JANUARY 29, 2021

Chris Hammel, Director

La'Tonia Stiner-Jones, Associate Director

cem.osu.edu

Center for Emergent Materials



IRG-1

Creation and Control of Metal/Magnetic-Insulator Interfaces

IRG-2

Topology and Fractionalization in Magnetic Materials

Future scientific community
Diversity Action Plan
Rigorous education research to enhance STEM pathways
Outreach K-undergrad

Foundational research and innovation toward emergent materials and phenomena

Seed Science & Faculty Leadership
Rigorous external review
Reaches broad OSU Mat'ls community
Leadership Institute

Partner with Industry
MRSEC Consortium industry day
Alumni Career Series
Professional Development Class

Shared User Facilities
Characterization, fabrication and growth
Training, education & collaboration
Equipment investments by OSU, NSF MRI, He liq.

International Collaborations
Center-center: Univ. Regensburg, Germany,
Collaborative Research Center SFB 1277
Max Planck Institute, IIT Madras, Leibniz Institute

CEM Leadership Team

- Chris Hammel, Director

- La'Tonia Stiner-Jones, Assoc. Director

- Jinwoo Hwang, IRG-1 co-leader

- Fengyuan Yang, IRG-1 co-leader

- Maryam Ghazisaeidi, IRG-1

- Yuan-Ming Lu, IRG-2 co-leader

- Jos Heremans, IRG-2 co-leader

- Vicky Doan-Nguyen, IRG-2

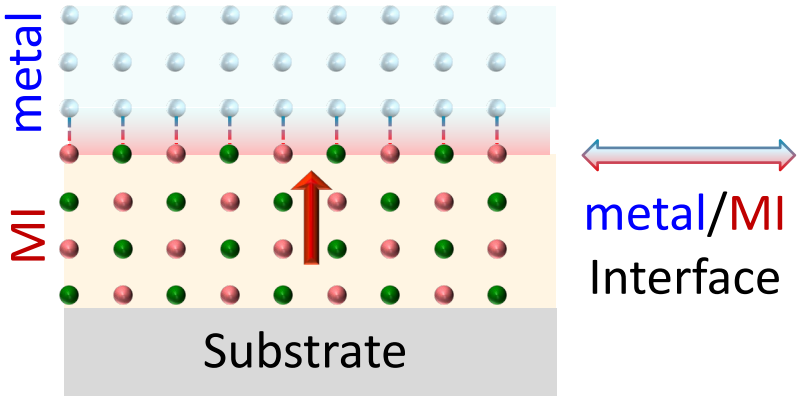
- Mohit Randeria, Chair, Evaluation Committee

- Michelle Richard, Director, EHRD

Creation and Understanding of Emergent Magnetism at Metal/MI Interfaces

Theme

- Interfacial interactions dominate magnetism in metal/MI systems & induce emergent magnetic phenomena



Key questions for metal/MI interfaces

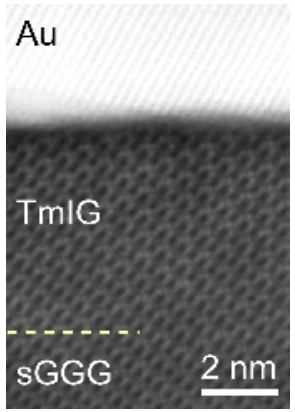
1. *What determines magnetic behaviors of metal/MI interfaces?*
2. *What are the manifestations of fundamental interfacial interactions?*
3. *How does magnetism depend on atomic structure and symmetry at interface?*
4. *What is the nature of spin-orbit coupling at metal/MI interface?*

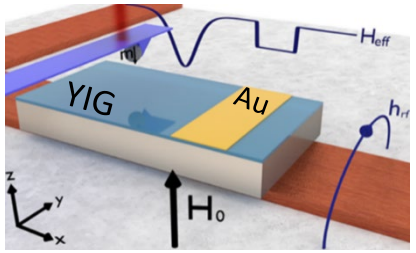
Tunable Interfacial Magnetic Anisotropy in Metal/FMI Interfaces

Single-crystal $Tm_3Fe_5O_{12}$ films

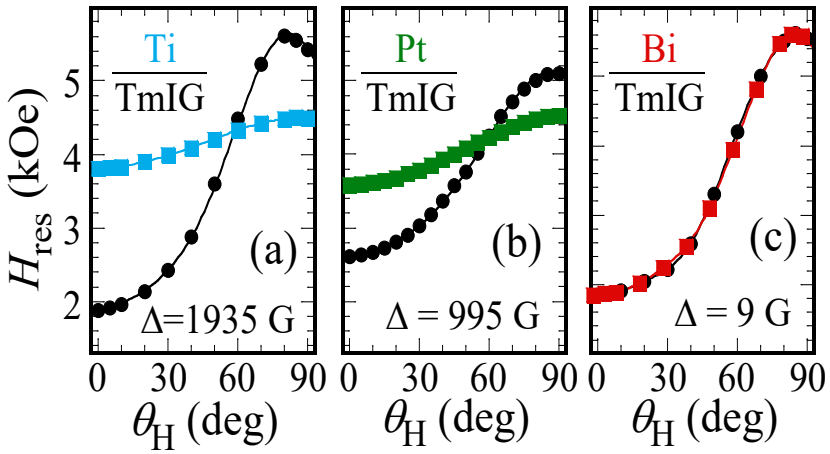
- ➢ *down to 1.5 nm; no "dead layer"*

- **15** elements on TmIG: interfacial magnetic anisotropy → **orbitals**
  - ➢ *d-block vs. p-block; BCC vs. FCC*
- *Microscopy: TEM, FMR imaging*

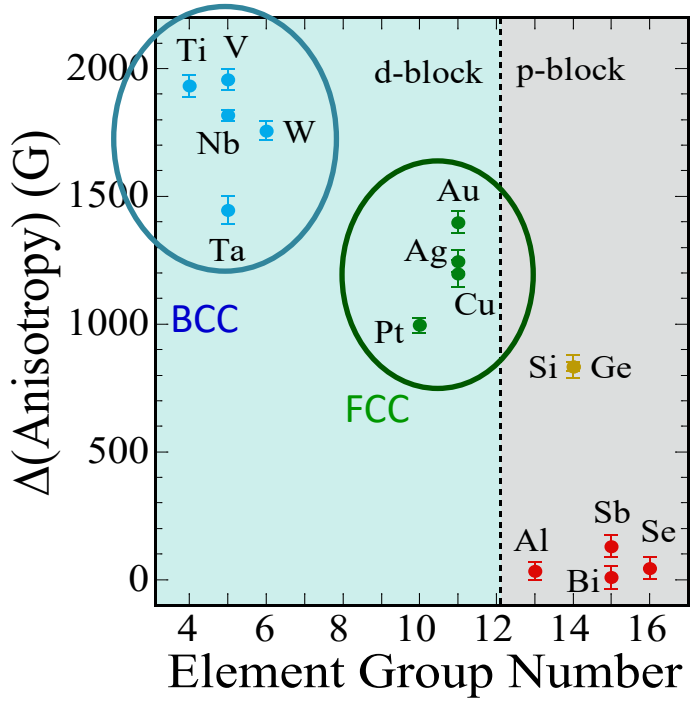




FMR → Magnetic Anisotropy



- Magnetic anisotropy:
  - ➢ *Magneto-crystalline*
  - ➢ *Dipolar ($4\pi M_s$)*
  - ➢ ***Interfacial***



- Proposed origin: Interfacial SOC due to broken inversion symmetry
  - ➢ *Interfacial orbital deformation, crystal & bonding symmetry, etc.*

IRG-1: Creation and Control of Metal/Magnetic-Insulator Interfaces


Ghazisaeidi


Landsman


Randeria


Kawakami


Woodward


Yang


Baker


Hammel


Hwang


Katoch

Bridging Disciplinary & Time-Scale Gaps

Growth of Metal/Magnetic-Insulator interfaces
Off-axis sputtering
MBE
Bulk synthesis
Kawakami
Woodward
Yang

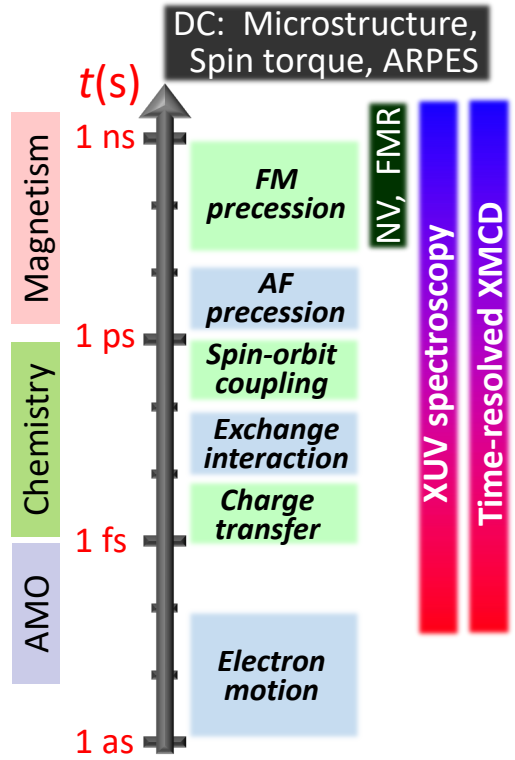
Equilibrium to Ultrafast Theory, DFT
Ghazisaeidi, Landsman, Randeria

Spatial & Temporal Probes
4D/DPC-STEM
fs-XUV, XMCD
NV Microscopy
Nano-ARPES
Pulse switching
Baker, Hammel
Hwang, Katoch
Kawakami, Yang

Novel Metal/MI Interfacial Systems
Create
Control

Thrust 1: Create material foundations and understanding to enable emergent interface-driven magnetism

Thrust 2: Electrical & ultrafast optical control of magnetism opening new opportunities for magnetic switching

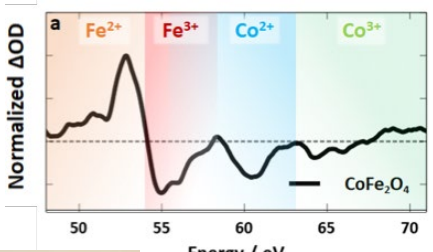


- *Different disciplines focus on different time scales*
- *IRG-1 bridges disciplines and time scales*

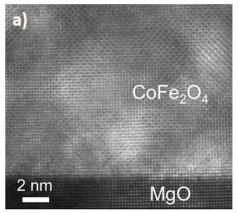
IRG1, Thrust 2

Transient Spin Crossover: Ultrafast Optical Probe of Charge Transfer & Spin States

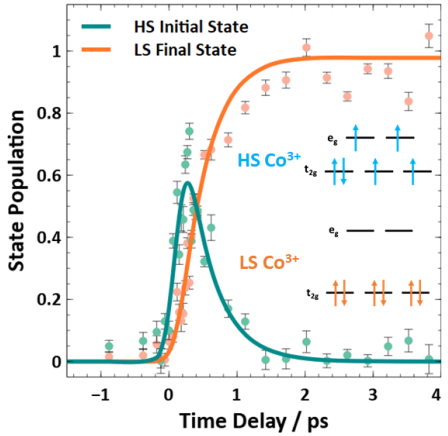
Extreme UV (XUV) spectroscopy



Kawakami



$CoFe_2O_4$ epi-films



Baker

- Londo, … Kawakami, Baker, *10.26434/chemrxiv.11559531* (2020).

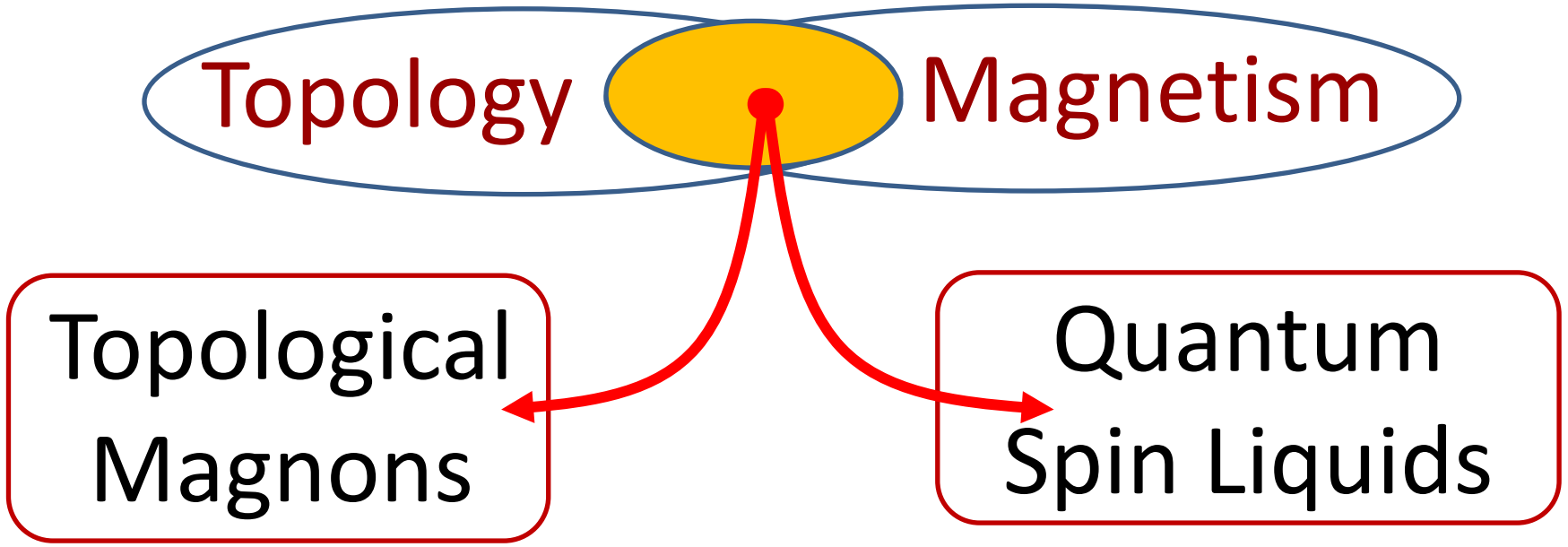
XUV Spectroscopy at OSU

- XUV spectroscopy is ideal for probing interfacial charge & spin dynamics (Baker)
  - ➢ *Baker lab offers all XUV capabilities for IRG-1*
- NSF mid-scale infrastructure grant at OSU:
  - ➢ *National Extreme Ultrafast Science (NEXUS) Facility (Baker: PI; Kawakami: co-PI)*
  - ➢ *NEXUS will expand XUV capabilities*
    - ❑ *time-resolved XAS, XMCD, ARPES*

- *Optical pump: excitations of charge transfer & spin crossover*
- *Ultrafast XUV probe: **element-specific**, **charge** and **spin** states (Baker)*
- *Theoretical Modeling of ultrafast optical excitation (Landsman)*

Landsman

IRG-2: Topology and Fractionalization in Magnetic Materials



- Goal: Extend the topological paradigm to strongly interacting quantum materials
- Challenging scientific problems
  - Topology of magnon bands
  - Fractionalized excitations in quantum spin liquids

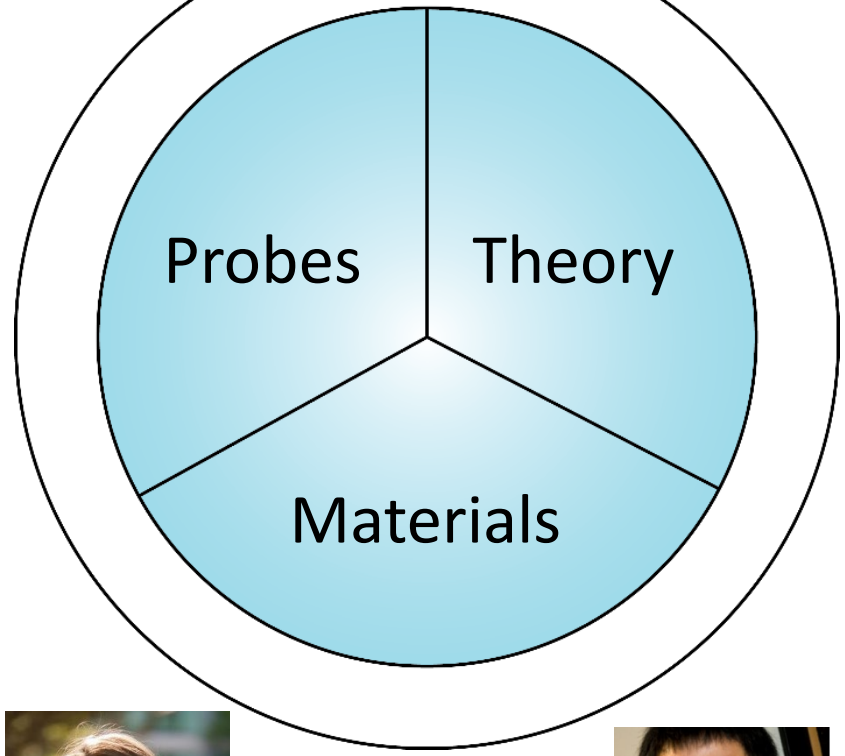
Our Team

Joseph P. Heremans
(Mech Aero Eng/Prof.) Thermal, spin and charge transport

Yuan-Ming Lu (Phys./Assoc. Prof.)
Theory of topological materials

Roberto Myers
(Mat Sci Eng/Prof.)
Space- and time-resolve
spin transport

Nandini Trivedi (Phys./Prof.)
Theory and Simulation of quantum materials



Rolando Valdés Aguilar
(Phys./Asst. Prof.)
Optical and THz spectroscopy

Brian Skinner
(Phys./Asst. Prof)
Transport theory

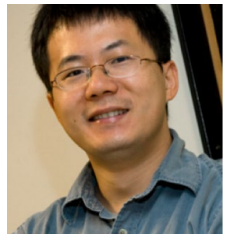
David McComb (Mat Sci Eng/Prof.) Electron microscopy: STEM, EELS

Vicky Doan-Nguyen
(Mat Sci Eng/
Asst. Prof.) Inorganic materials synthesis

Diversity
Women: 3
URM: 2
Depts: 4
Rank:
4 Asst. Profs

Joint Publications

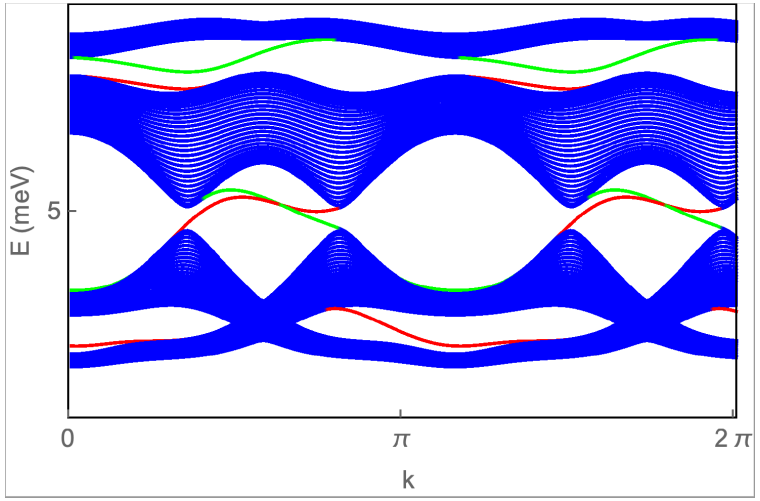
Kate Ross (Phys., Colorado State/ Asst. Prof.) Inelastic neutron scattering & oxide synthesis



Yiying Wu (Chemistry/Prof.)
Metal-organic materials synthesis

Finding materials with topological magnons

Classification of magnon band topology



Lu and Lu,
Phys. Rev. Res. (under review)

Hwang, Trivedi, Randeria
Phys. Rev. Lett. (under review)

Database search for new materials:

e.g., TM tri-halides

Anion	Total	ICSD + Insulator
F	6201	571
Cl	2421	903
Br	1047	98
I	903	63



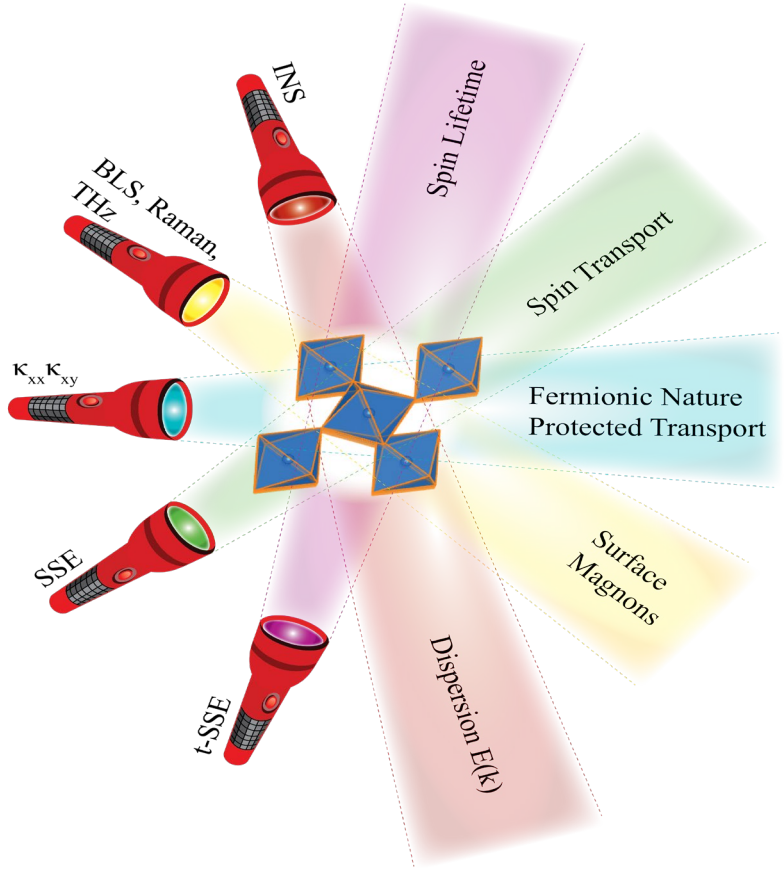
Defects;
Chemistry
→ Synthesis

Use magnetic properties and high transition temperature to down-select

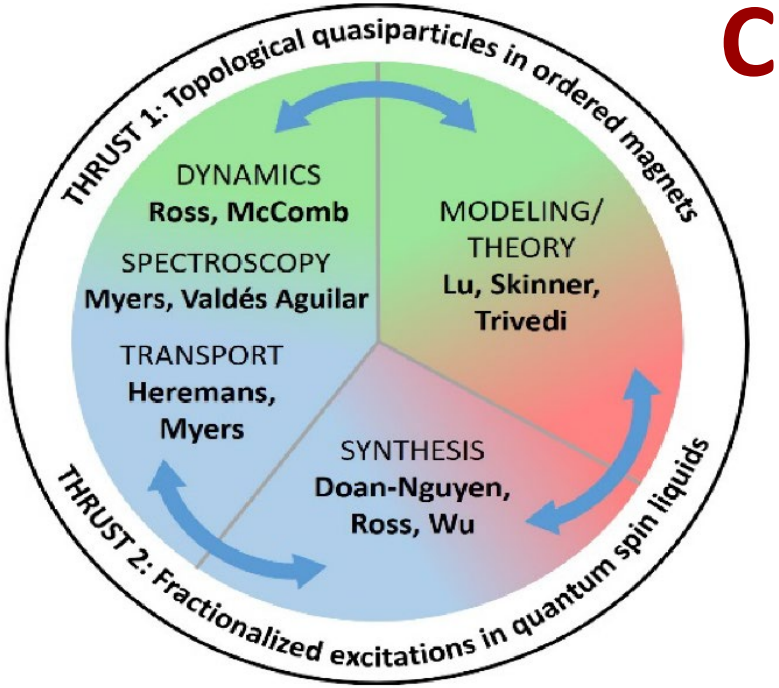
	T_N (°K)
CrF_3	80
MnF_3	43
FeF_3	394
CoF_3	460

- Systematic search
- Investigation of high Tc topological magnon materials

Conclusions



Diverse and complementary experimental and theoretical tool-boxes



Challenging scientific problems

- Topology of magnon bands
- Fractionalized excitations in quantum spin liquids

Diversity Strategic Plan

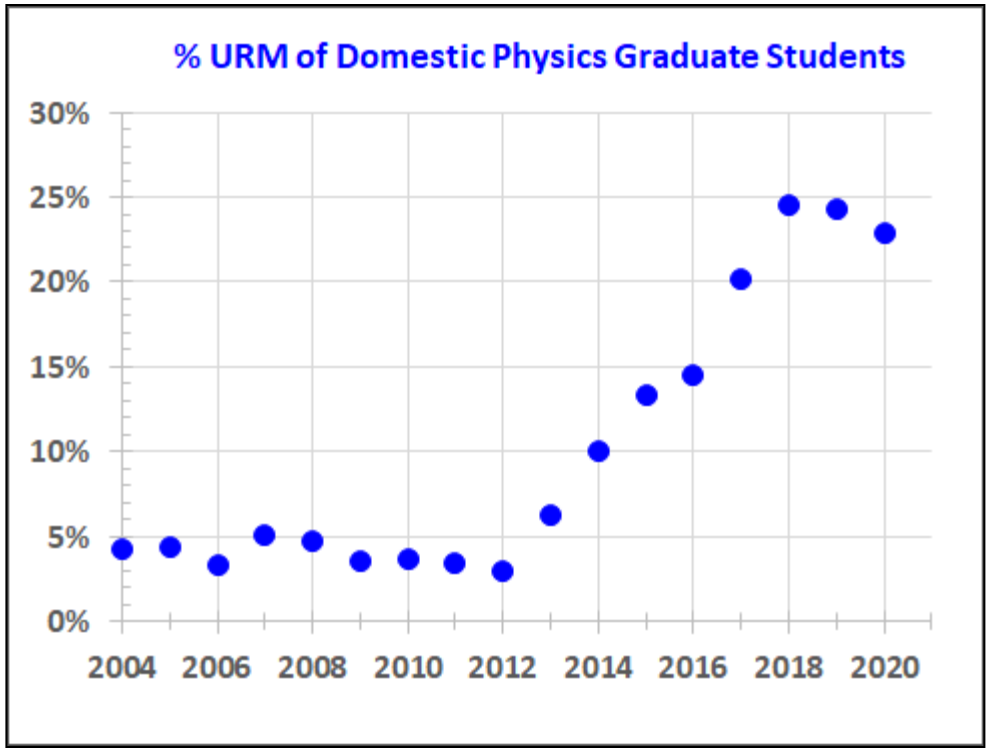
1. Improve access to STEM pathways for diverse populations from K-12 through postgraduate study
2. Fundamental research to generate new knowledge to advance methods to help students enter STEM.
3. Attract, nurture, and promote education and career development for a diverse community
4. Ensure an inclusive environment for all
5. Diversity Action Plan: concrete, measurable steps toward diverse faculty and enhanced climate

Bi-weekly contact with ~ 400 K-5 students

Midwest Conf. for Undergrad Women in Physics (CUWiP) at OSU Jan 2016

Enhancing Diversity at Graduate Level

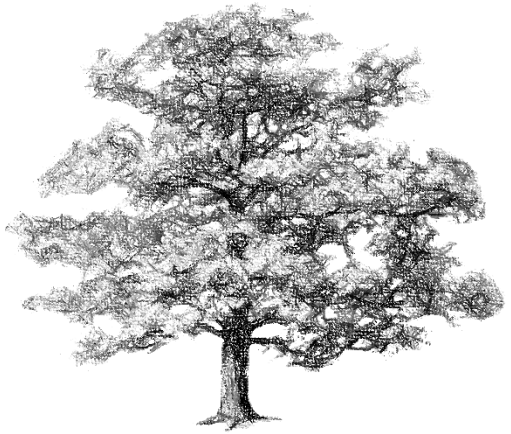
- Physics MS-PhD Bridge program to prepare talented URM's for PhD programs
  - Initiated by CEM
  - 6 CEM Faculty on Bridge Program Leadership Team
- **23%** of domestic graduate students are URM
- Attractive environment
  - Doubling of **non-Bridge** URM applications to the Physics graduate program
  - Model for other OSU departments developing bridge programs including Astronomy and Chemistry



Seeding excellent science, building teams, supporting emerging leaders

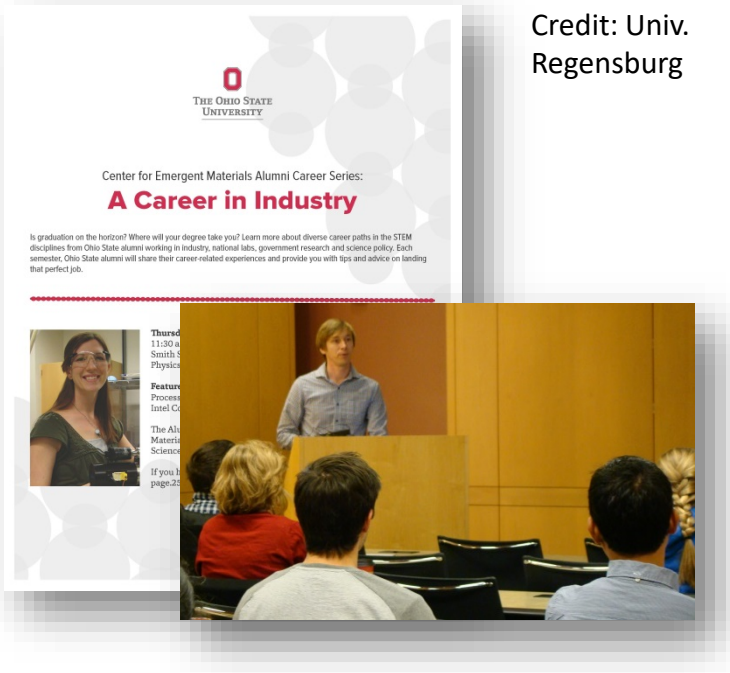
- Bring new scientists, teams and ideas to readiness for external funds
  - Access to broad audience through University funded materials seed programs
  - Both proposed IRGs began as seeded proto-IRGs
- Seed proposals undergo rigorous, externally reviewed grant selection process
  - University funds → single investigator and small-team grants
  - CEM seed program → build IRGs and develop their leaders
- Leadership Institute: Prepare emerging leaders as they build convergent proto-IRG teams
- University support → leadership development

NSF seed funds → science



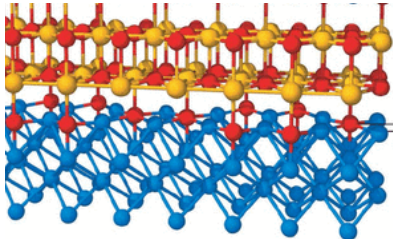
PREM, REU and Collaborations and Industry Interactions

- NSF PREM: Partnership for Research and Education in Materials
  - California State University at Long Beach, a minority serving university
  - Strong link through Bridge program
- Student committee: Internal Advisory Committee
  - Plan and implement student-led POEM workshop
  - Integrates PREM students and faculty
- Industry interactions
  - Professional Development Course, Alumni Career Series
  - Midwest MRSEC Consortium Industry Workshop
- Center-to-center international collaboration
  - Collaborative Research Center SFB 1277 at the University of Regensburg: *Emergent Relativistic Effects in Condensed Matter*
- REU
  - Held online for six students
  - Two students are continuing



Credit: Univ. Regensburg

Proposed Center for Emergent Materials



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