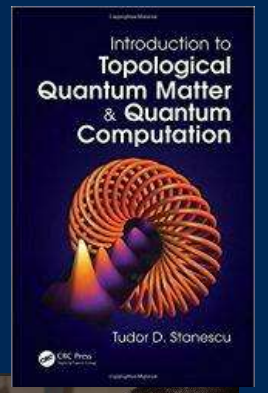
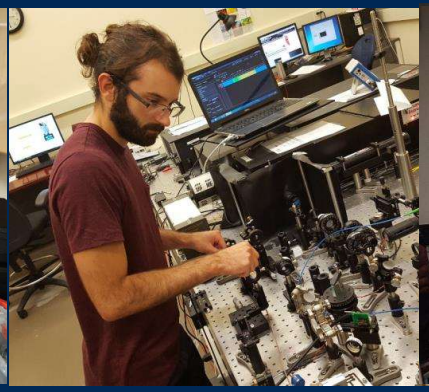
Condensed Matter Physicists at WVU

- IT IS THE WORLD AROUND US: the largest subdiscipline of physics covering everything from ordered crystalline solids to soft polymers that make up living tissue.
- IT IS USEFUL: developments have lead to countless technological applications.
- IT IS DEEP: CMP influences particle physics to astronomy, biology to sociology.
- IT IS ANTI-REDUCTIONALIST: The one place in physics we expect to see emergent properties due to systems being more than the sum of their parts.
- IT IS A PLAYGROUND: CMP is quantum many-body interactions – fields, quantum and statistical mechanics, thermodynamics, electronics, magnetism, superconductivity.











Condensed Matter Physicists at WVU

THEORY AND COMPUTATION

GROWTH of MATERIALS

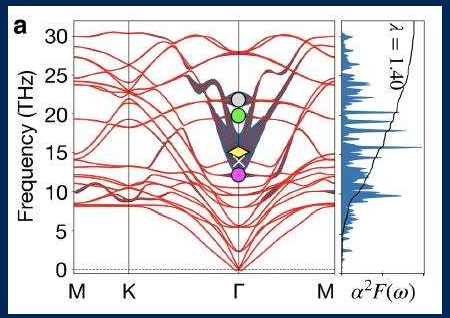
FABRICATION OF DEVICES

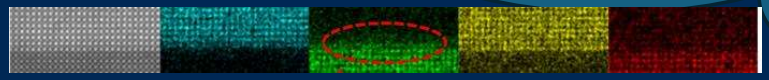
BEHAVIOR

STRUCTURAL CHARACTERIZATION

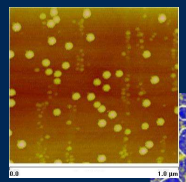
MEASUREMENT OF PROPERTIES

Electronic dispersion in space-time
-> broken symmetries
-> new phenomena

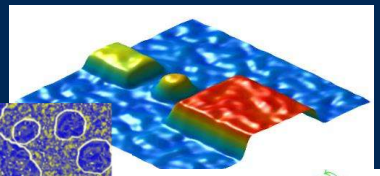


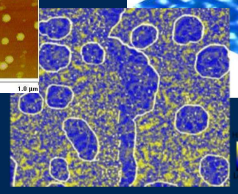


Quantum Dots

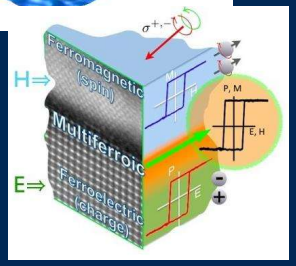


Confined 2DEG structures





Topological edge channels

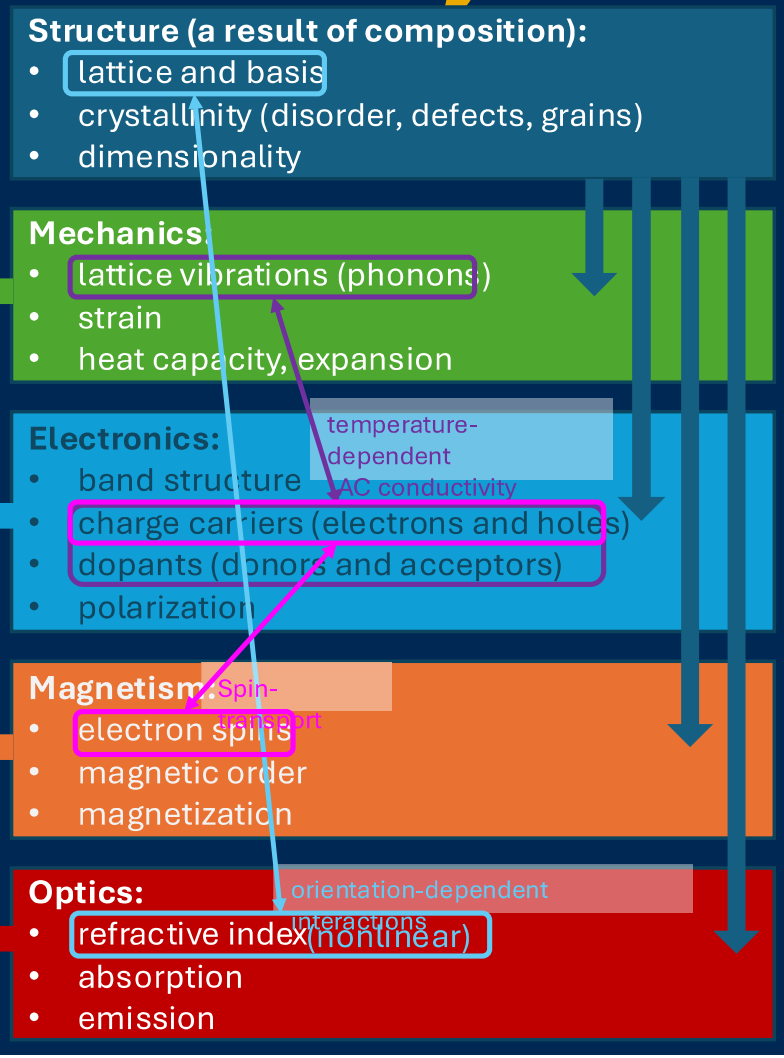


Heterostructure Devices

Apparatus



Condensed Matter Physicists at WVU



Example Devices

diodes
transistors
---
thermoelectric (Peltier cools)
---
magnetic storage
spintronics
---
light emitting diodes
lasers
quantum dot (some TVs)
optical detectors
photovoltaics
frequency converters
---
quantum technology

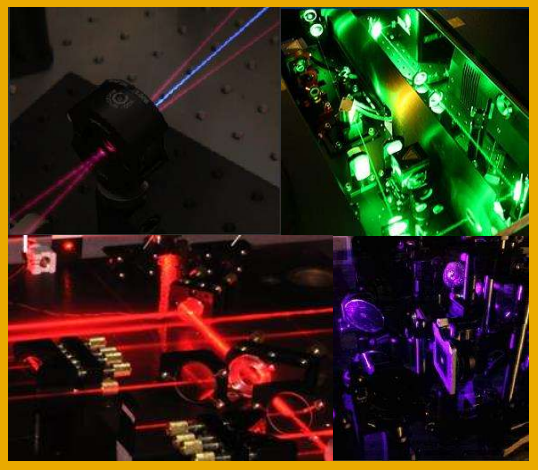
Typical solid state book:
"Introduction to Solid State Physics"
- Charles Kittel

Structure underpins mechanical, electronic, thermal, magnetic and optical properties, EACH WITH DRASTICALLY DIFFERENT TIMESCALES

Short pulses of light give access to so much of the material behavior

Physicists in the 21st century will…

…fuel the knowledge, design, and workforce needs to deliver novel optics and photonics technology

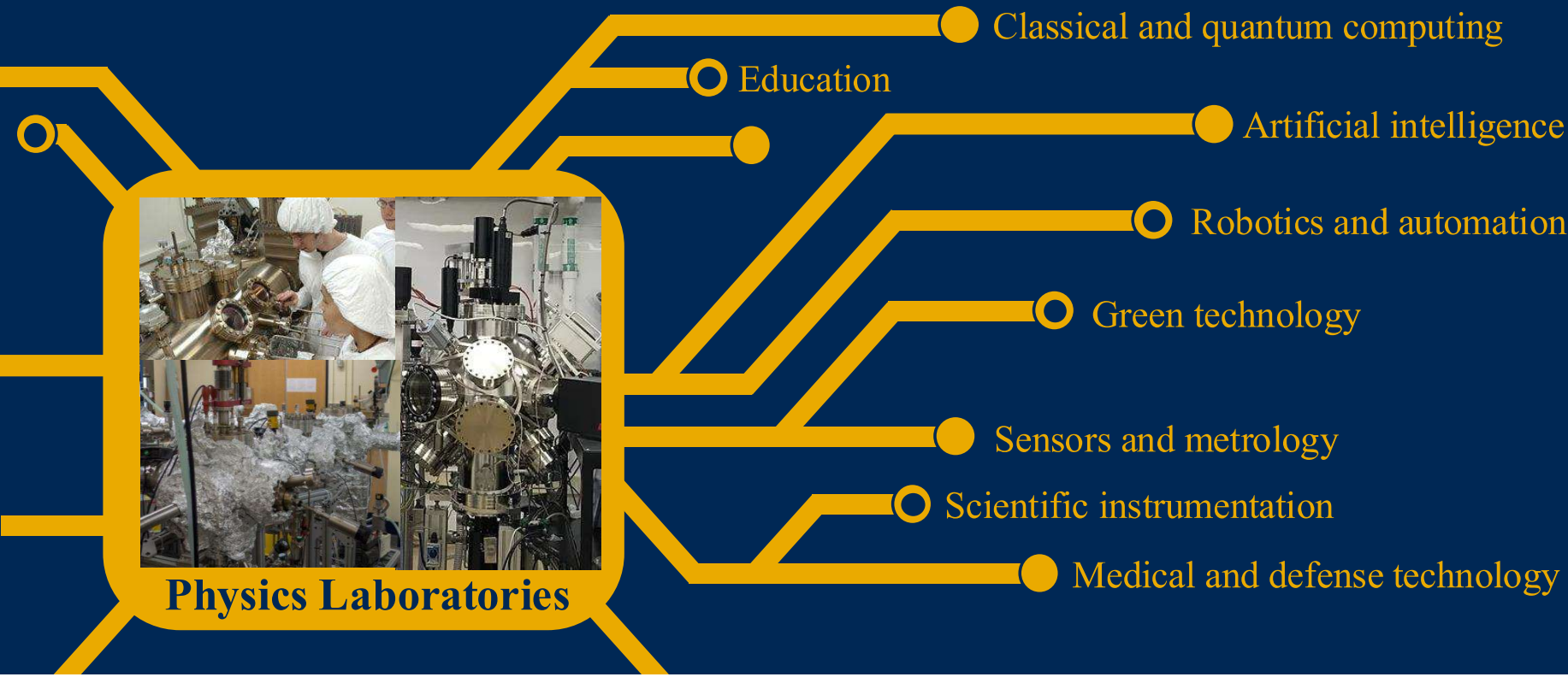


WVU Optical Labs

- Astronomy and astrophysics
- Automation / automobiles
- Chemical fingerprinting
- Communication
- Construction
- Defense technology
- Education
- Laser fusion
- Medical and process imaging
- Metamaterials
- Metrology
- Optical computing
- Optogenetics
- Quantum information
- Quantum sensing
- Semiconductors
- Scientific instrumentation
- Solar photovoltaics / photocatalysis
- Ultrafast electronics

Physicists in the 21st century will…

…fuel the knowledge, design, and workforce needs to deliver novel semiconductors



Physicists in the 21st century will…

…develop the knowledge base and workforce to apply novel (complex and quantum) materials to a diverse range of technological and societal challenges

Defense technology

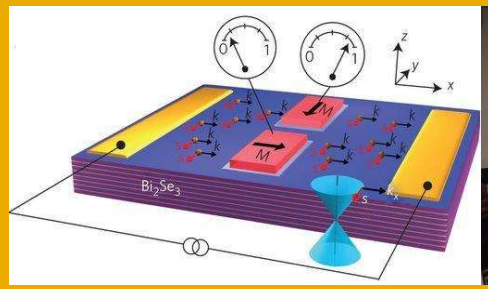
Classical and quantum computing

Scientific instrumentation

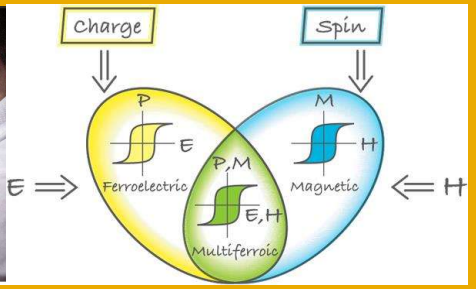
Room temperature superconductors

Energy efficient electronics

Information technology







WVU's Complex and Quantum Materials Research

Artificial intelligence

Metamaterials

Education

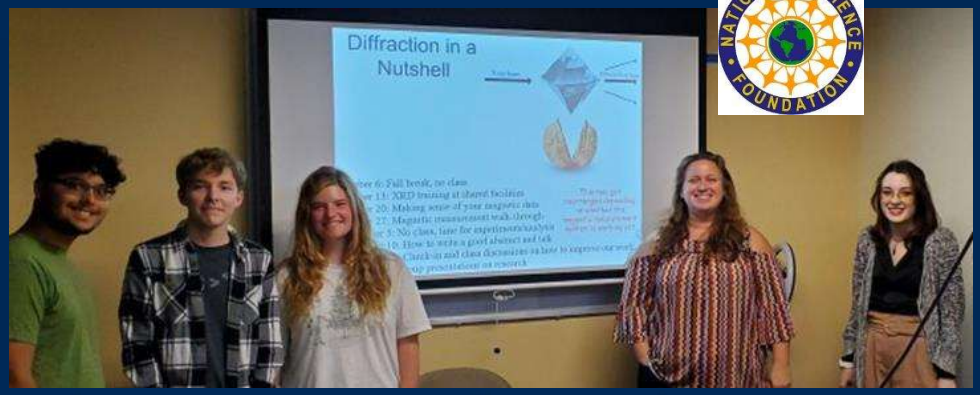
Discovery

Condensed Matter Physicists at WVU

Exploring A New Magnetic Phenomenon

Students will:

- Pick a research project
- Do magnetic measurements
- Learn how to build a research story



Opportunities this spring or summer to finesse the program

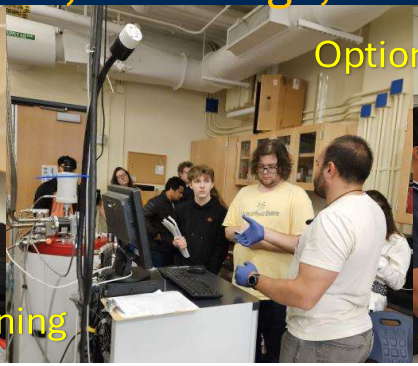
Fall 2025: 1-credit-hour undergraduate research class

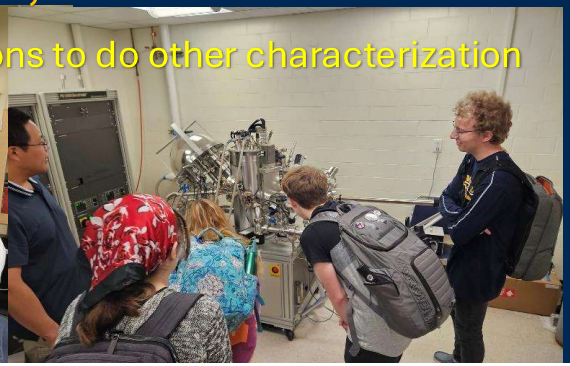
Collaborators: Rice, CMU, Oak Ridge, USF, WVU





Hands-on VSM training





Options to do other characterization

Condensed Matter Physicists at WVU

Undergraduate Student Success: Designing Materials for a Solar Future

Caden Ginter
Dual major (Physics-CS)
2023-2027



Solar panels convert solar light to electricity. The material the panel is made from from has optical properties that affect the devices' "**S**pectroscopic **L**imited **M**aximum **E**fficiency; ***SLME***).

Questions

- Which materials respond best to sunlight on Earth?
- What materials should we focus on trying to manufacture?

There are too many to make and test manually and expensive, slow and complex simulations are required to answer these questions. Caden is looking for alternatives to faster, cheaper simulations.



Condensed Matter Physicists at WVU

Example of Previous Undergraduate Student Success



Dr. Brandon Yost

- Physicist | Johns Hopkins University Applied Physics Laboratory (2024-present)
- Postdoctoral Researcher, Savannah River (2023-24)
- Physics PhD student, University of North Carolina, Chapel Hill (2016-2023)
- BS in Physics, WVU (2012-2016)

- Brandon was a co-author on a few research papers during undergraduate that improved him application to grad school

Paper | 30 October 2015

Investigation of band gap narrowing in nitrogen-doped $La_2Ti_2O_7$ with transient absorption spectroscopy†

Brandon T. Yost; Scott K. Cushing; Fanke Meng; Joeseph Bright; Derek A. Bas; Nianqiang Wu; Alan D. Bristow

Check for updates

+ Author and article information

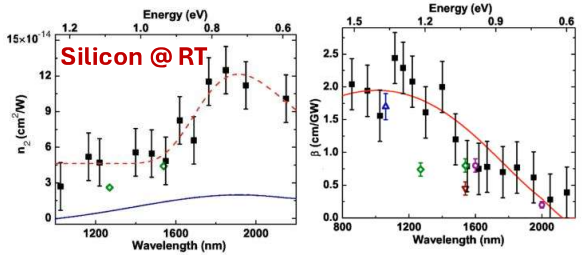
Phys. Chem. Chem. Phys. (2015) 17 (46): 31039–31043.

https://doi.org/10.1039/c5cp05637c Article history

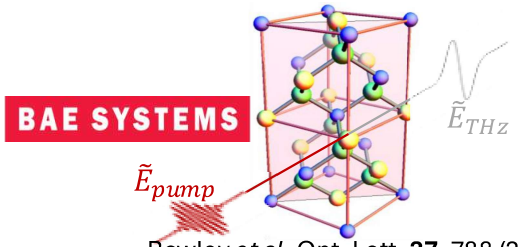
Condensed Matter Physicists at WVU

Condensed Matter Physicists at WVU

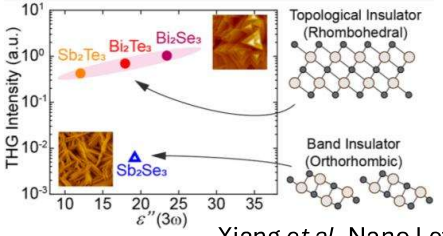
Nonlinear Optics:



-Bristow *et al*, Appl. Phys. Lett. **90**, 191104 (2007)

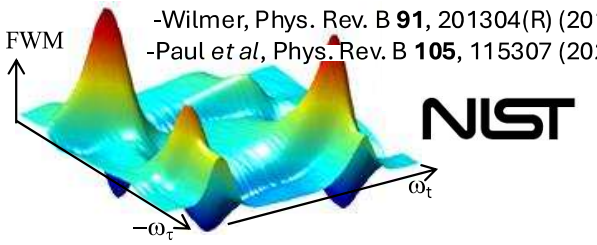


-Rowley *et al*, Opt. Lett. **37**, 788 (2012)
-Piyathilaka *et al*, Opt. Express **27**, 16958 (2019)

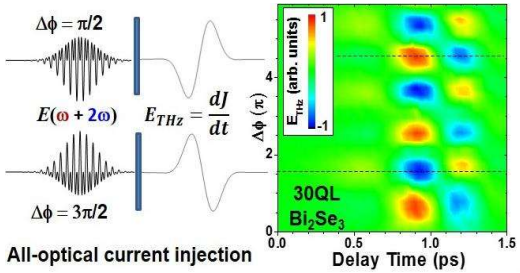


-Xiang *et al*, Nano Lett. **21**, 8872 (2021)

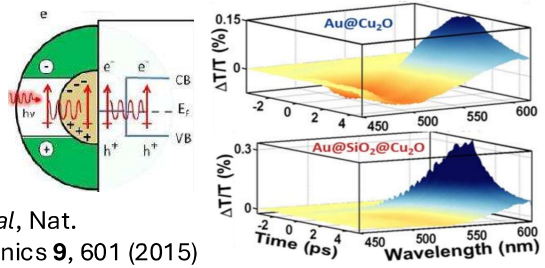
Coherent Phenomena:



-Wilmer, Phys. Rev. B **91**, 201304(R) (2015)
-Paul *et al*, Phys. Rev. B **105**, 115307 (2022)

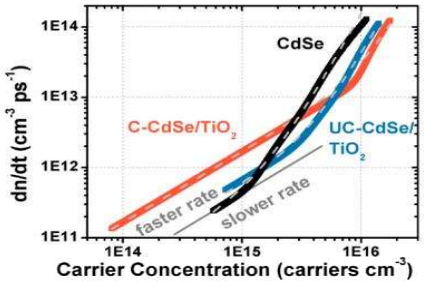


-Bas *et al*, Appl. Phys. Lett. **106**, 041109 (2015)
-Bas *et al*, Opt. Express **24**, 23583 (2016)

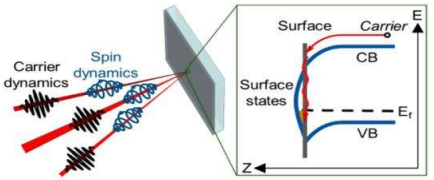


-Li *et al*, Nat. Photonics **9**, 601 (2015)
-Tirumala et al, ACS Catal. 12, 7975 (2022)

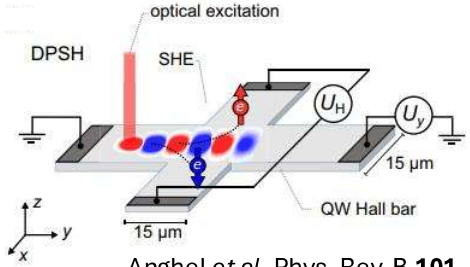
Ultrafast Dynamics:



-Li *et al*, J. Am. Chem. Soc. **136**, 8428 (2014)
-Senty *et al*, JPCC **119**, 6337 (2015)



-Yousefi Sarraf *et al*, ACS Nano **13**, 3457 (2019)



-Anghel *et al*, Phys. Rev. B **101**, 155414 (2020)

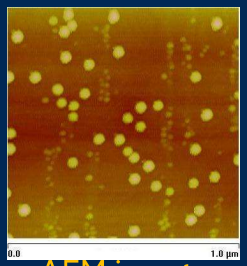
Ultrafast Nanophotonics Group – *Prof. Alan D. Bristow*

Condensed Matter Physicists at WVU

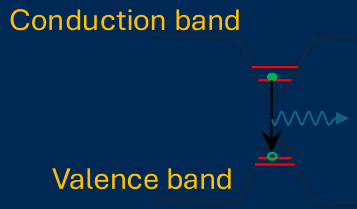
Artificial Atoms and Quantum Photonics

Quantum dots:

A hundred-thousand atoms can behave like one



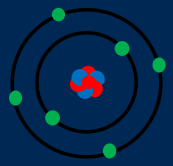
AFM image



Quantum confinement

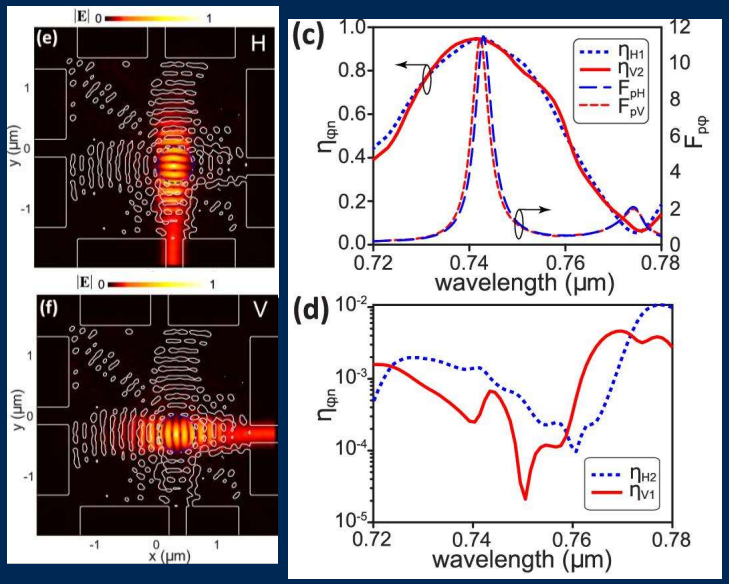
Discrete energies

Similar to an atom

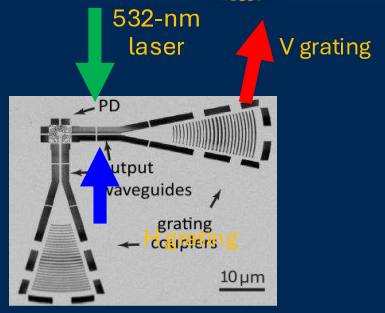


Fabricate photonic structures around QD to control emission

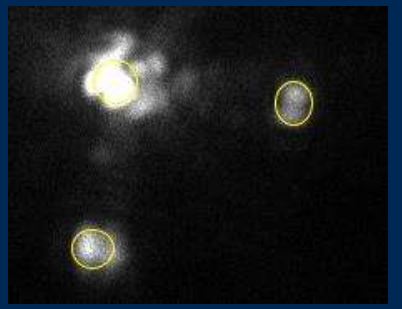
"Polarization demultiplexer" design



Simulations done in Python



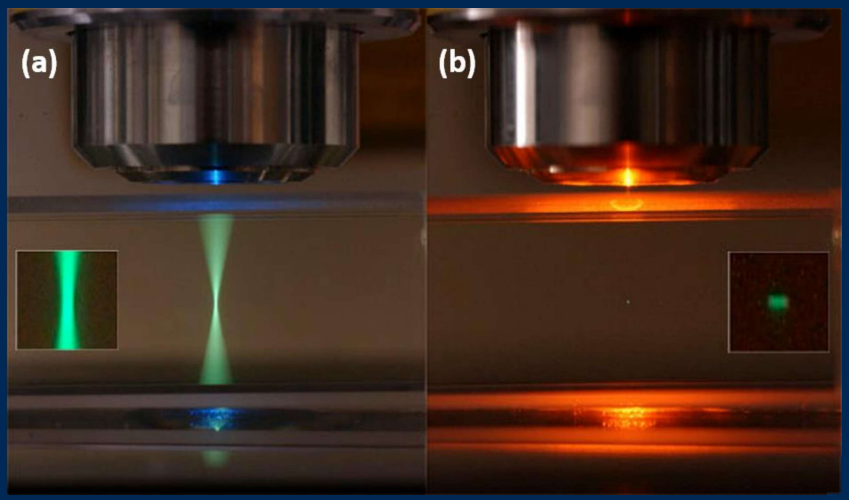
Scanning electron microscope image



Micro-photoluminescence

Condensed Matter Physicists at WVU

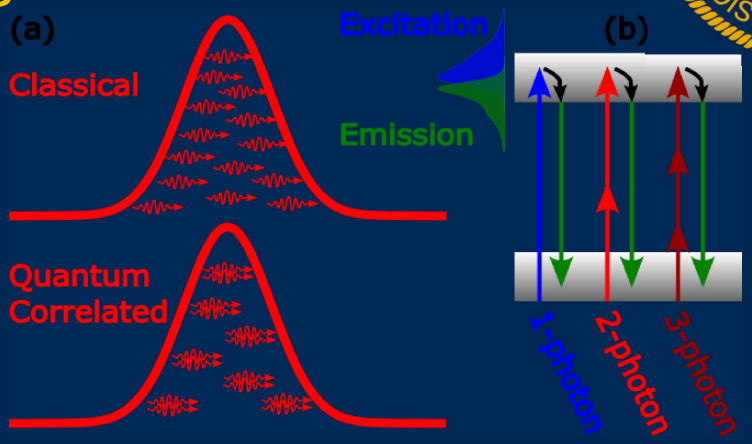
Microscopy can be enhanced by entanglement between photons

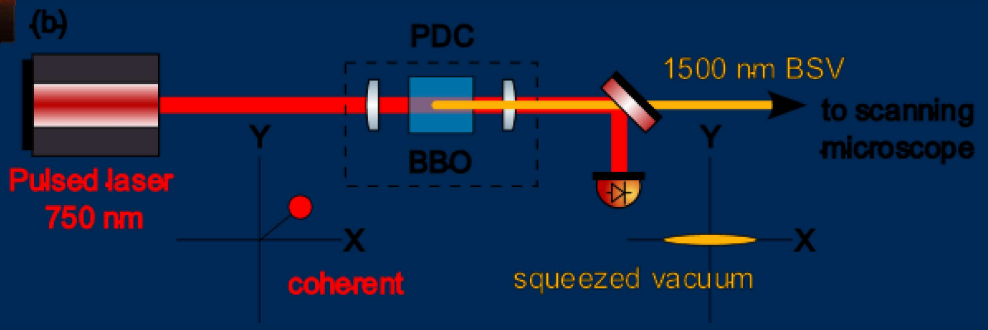


Credit: Massimo Onesto

Create entangled photons with powerful laser and special crystal.

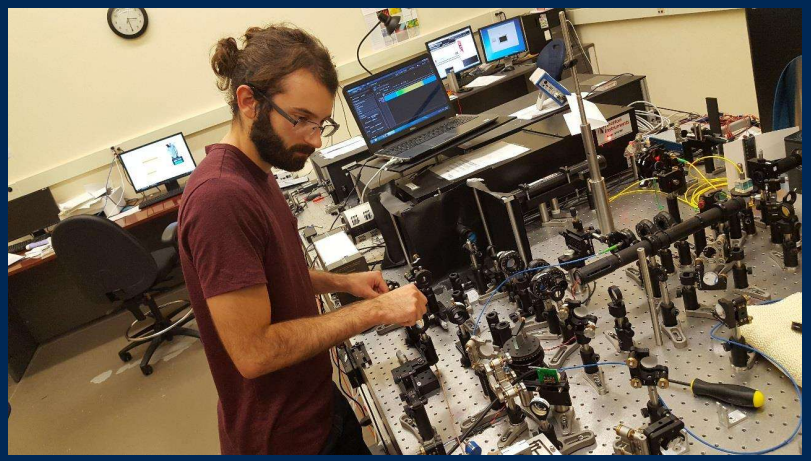
Use them to enhance microscopy of living neural tissue.





Condensed Matter Physicists at WVU

Learn skills in optics and photonics



Cainan Nichols, B.S. ’18, M.S. ’20 E. Mich. U.
Principal Systems Engineer at Northrup Grumman.



Aidan constructs a Michelson Interferometer (like LIGO but smaller)

Experimental optics tutorials:

- Laser safety
- Basics of laser alignment: mirrors, lenses, tips & tricks
- Fiber optics
- Diffraction gratings
- Polarization optics
- Gaussian beam propagation and mode-matching
- Interferometry

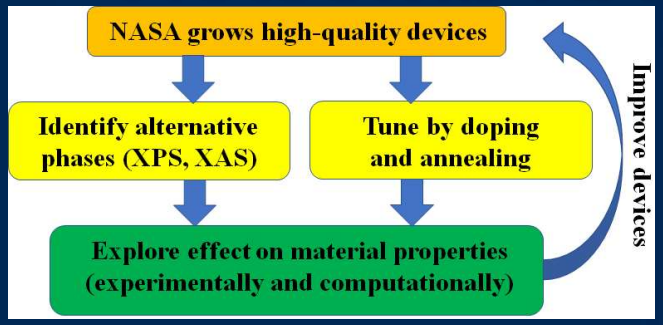
Learn scientific computing languages:

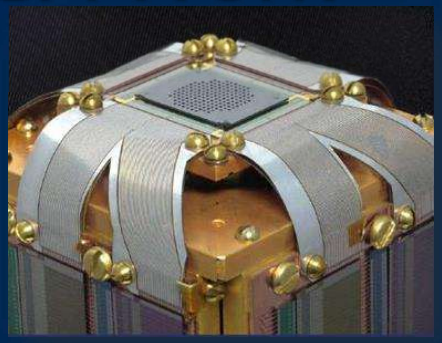
- Matlab: data processing and visualization
- Python: simulations, automation
- LabView: automation of experiments

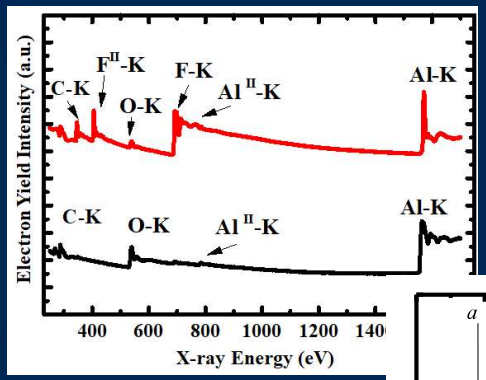
Collaborate with National Institute of Standards and Technology and Naval Research Lab (both near Washington, D.C.)

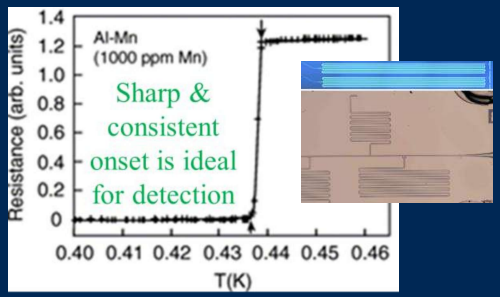
Condensed Matter Physicists at WVU

Holcomb NASA Work



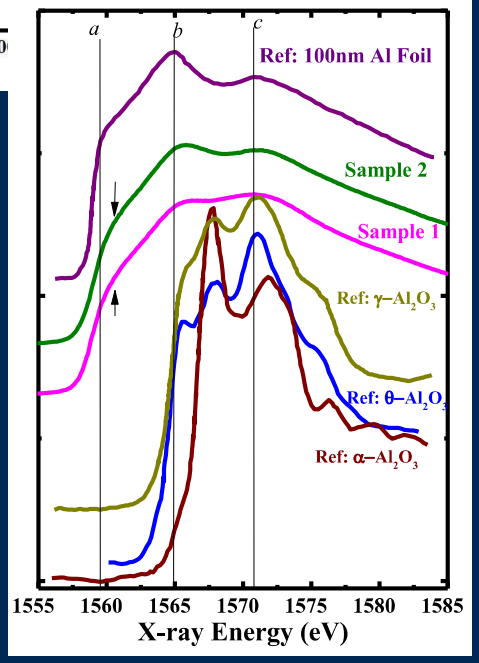


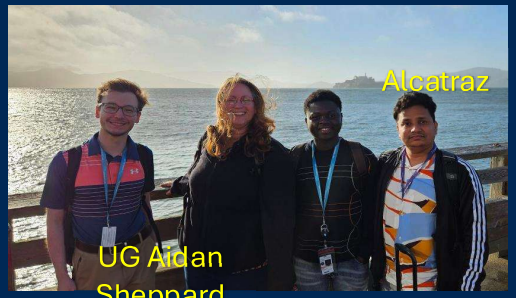


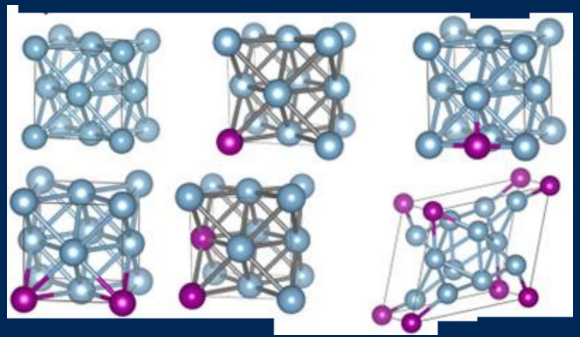


Helping NASA optimize their superconducting detectors

Holcomb leads this collaboration with Bristow, Johnson and Romero

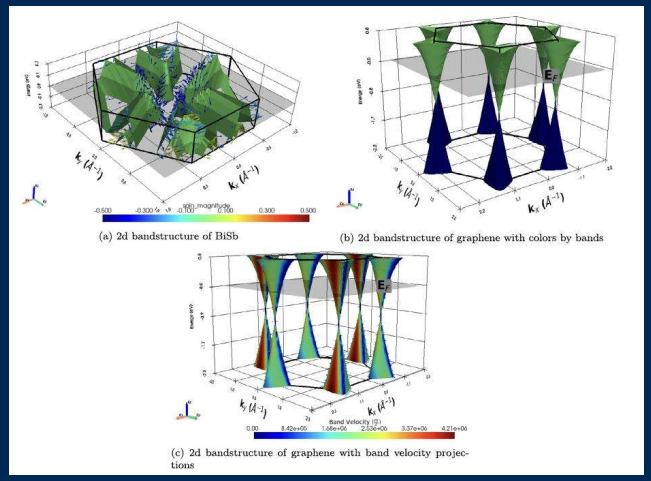




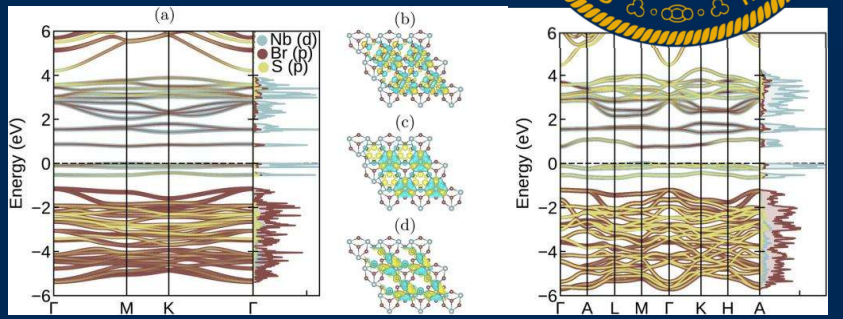


Condensed Matter Physicists at WVU

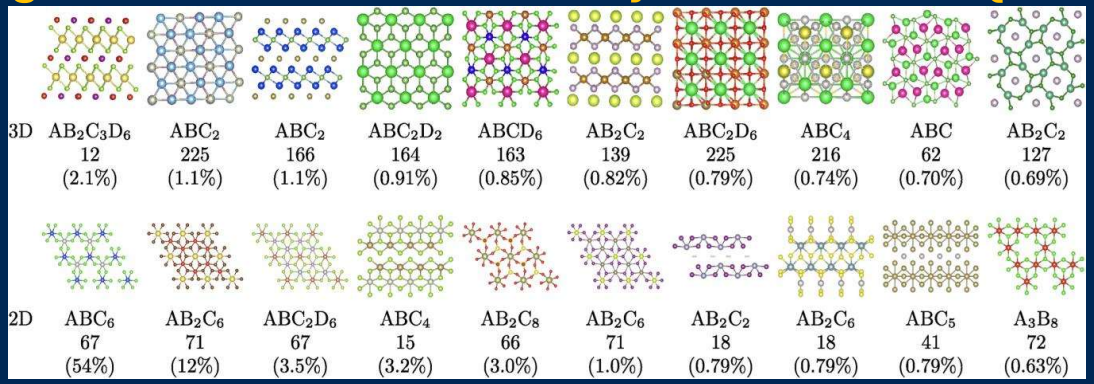
Romero's group Computational Materials Science



PyProcar: a package for electronic structure analysis



Materials engineering: two-dimensional M3QX7 compounds



3D	$AB_2C_3D_6$	ABC_2	ABC_2	ABC_2D_2	$ABCD_6$	AB_2C_2	ABC_2D_6	ABC_4	ABC	AB_2C_2
	12	225	166	164	163	139	225	216	62	127
	(2.1%)	(1.1%)	(1.1%)	(0.91%)	(0.85%)	(0.82%)	(0.79%)	(0.74%)	(0.70%)	(0.69%)
2D	ABC_6	AB_2C_6	ABC_2D_6	ABC_4	AB_2C_8	AB_2C_6	AB_2C_2	AB_2C_6	ABC_5	A_3B_8
	67	71	67	15	66	71	18	18	41	72
	(54%)	(12%)	(3.5%)	(3.2%)	(3.0%)	(1.0%)	(0.79%)	(0.79%)	(0.79%)	(0.63%)

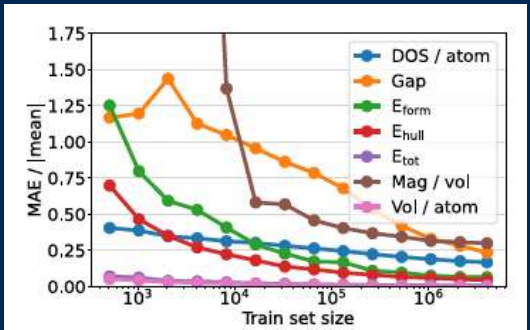
Alexandria: the world largest crystal materials database for AI modeling.

Condensed Matter Physicists at WVU

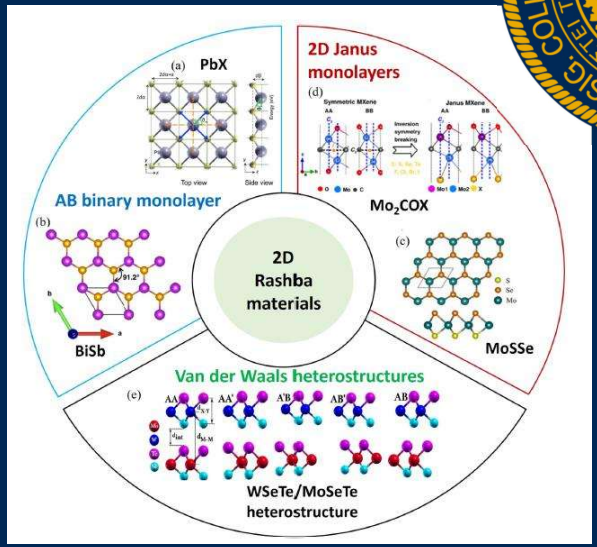
Romero's group Computational Materials Science

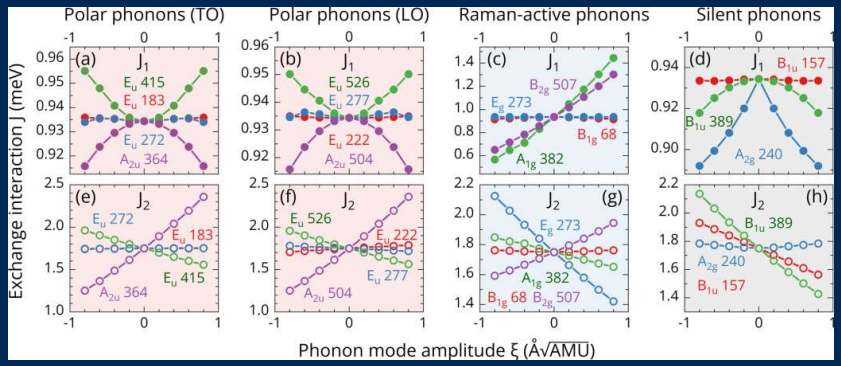
ML methods for materials discovery.

Training size effects

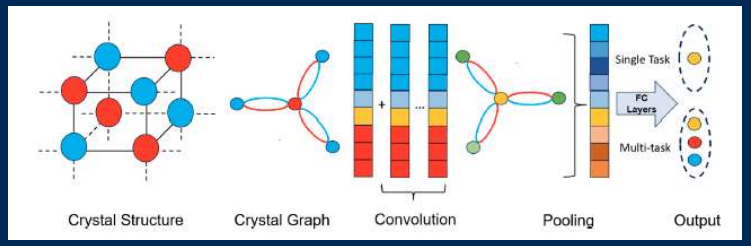


Materials design for spintronics





Magnetic excitations in novel magnetic phases (Altermagnets)

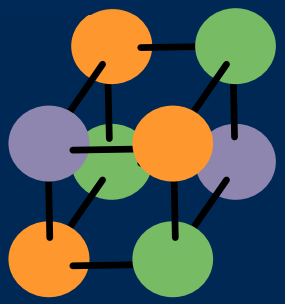


Materials property prediction through graphs neural networks

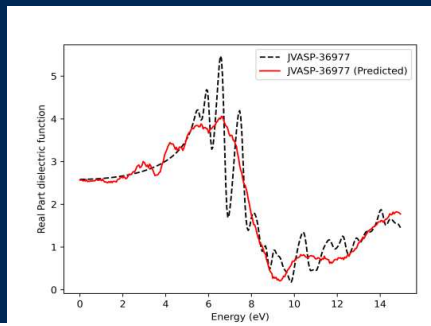
Condensed Matter Physicists at WVU

Yet Another Use for AI

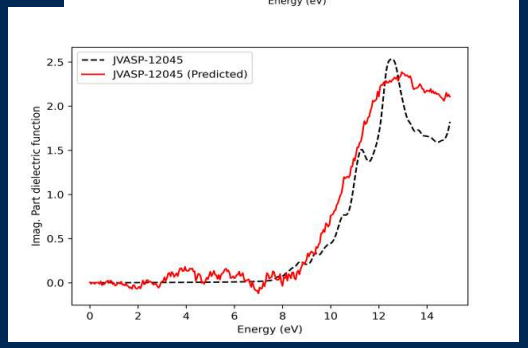
- This project uses a kind of machine learning model optimized for studying materials to predict materials that are likely to be good solar cells.
- Where traditional techniques take upward of a week, our system can run in a fraction of a second and achieve comparable results.
- Even though we can never trust an AI 100% (nobody should), it's still an invaluable tool for filtering out materials that have no chance of being useful.
- This has the potential to save a lot of time for people developing new solar materials.



Machine Learning



A few definite integrals and some arithmetic



SLME: $\eta \sim$ % sunlight collected