Welcome!

An Introduction to our Programs in

APAM

Applied Physics, Applied Math, and Materials Science

Art of Engineering

October 2, 2020

Department of Applied Physics and Applied Mathematics (APAM)

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An Introduction to our Programs in

APAM

Applied Physics, Applied Math, and Materials Science

Art of Applied Science

October 2, 2020

Department of Applied Physics and Applied Mathematics (APAM) **in SEAS**

Welcome!

An Introduction to our Programs in

APAM

Applied Physics, Applied Math, and Materials Science

Art of Applied Physical Science

October 2, 2020

Applied Physics and Applied Mathematics
COLUMBIA | ENGINEERING

APAM Department: What We Do

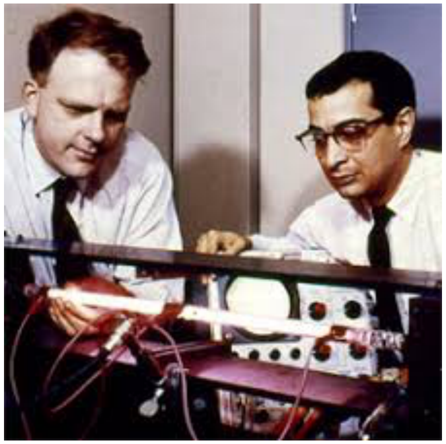
What is Applied Physics?

Linking fundamental of physics with technology and applications, i.e. “basic“ physics research **but** with a purpose

As in developing lasers, transistors, solar cells, fusion reactors, …

First gas laser

Bell Labs/Alcatel-Lucent USA Inc., courtesy AIP Emilio Segrè Visual Archives, Hecht Collection



First transistor

https://history-computer.com/ModernComputer/Basis/transistor.html

Applied Physics and Applied Mathematics
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APAM Department: What We Do

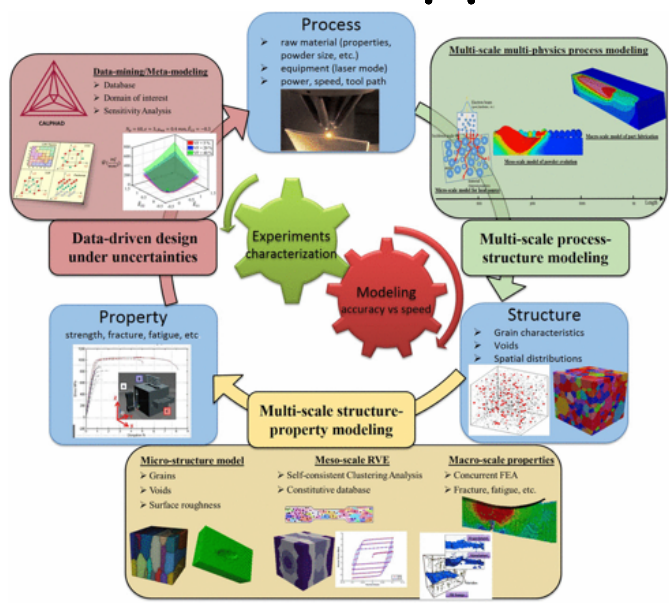
What is Applied Mathematics?

- *Using* pure math for applications

and

- *Developing* new math for applications

Multiscale modeling and computation



https://link.springer.com/article/10.1007/s00466-018-1539-z

Applied Physics and Applied Mathematics
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APAM Department: What We Do

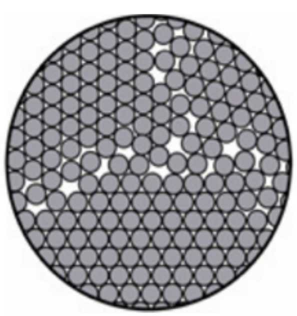
What is Materials Science?

<u>Everything</u> is made of materials

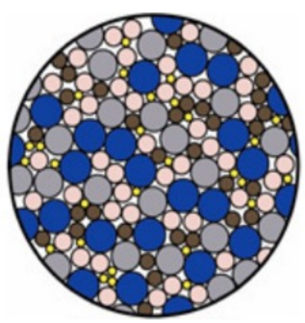
<u>New materials</u> enable revolutions in technology
(*stone age, bronze age, steel age, silicon age, …*)

<u>Improved materials</u> advance most existing technologies
(e.g. lighter alloys for aerospace, bio-compatible polymers for BME; stronger concretes for Civil, faster semiconductors for EE, etc.)

<u>Science of technological materials</u>: how to create desired properties
- relationship between *processing* and atomic *structure* (some chemistry)
- relationship between atomic *structure* and *properties* (some physics). **example:**



most metals are **crystalline**; atoms can slide at boundaries, but...



add larger atoms, cool rapidly, get a **metallic glass:** atoms are locked in place

almost perfectly elastic: ball bearing bounces on metallic glass ~200x (vs 10x for steel)

"Liquidmetal" (TM) golf club made of metallic glass

Applied Physics and Applied Mathematics
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APAM Department: What We Are

Applied Physics
Applied Mathematics
Materials Science

Undergraduate and graduate programs in each

Ties between basic science and technology

Program excellence combined with lowered interdisciplinary barriers

Our raison d'être:

We are the applied physical science department in SEAS.

The APAM Faculty

The APAM Department is composed of 29 budgeted faculty members and benefits from active collaborations with 6 nonbudgeted joint faculty members.

Applied Physics and Applied Mathematics
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APAM Department Profile – Research

Applied Physics – fusion energy and plasmas, optics and nanophysics/quantum materials physics/molecular electronics, bio-/medical physics

Applied Mathematics – earth and climate science, computation methods and applications, partial differential equations (PDEs) in optics and imaging, math of data

Materials Science – materials formation, processing, structure and applications: laser processing of films, magnetics, strain in microelectronics, nanomaterials and structure

Highlights of the Curriculum

Undergraduate Research!

Applied Physics
- Classical and Quantum Physics
- Applied Math
- Thermodynamics and Statistical Mechanics
- Electrodynamics
- Laboratory Techniques
- Area & Science Electives and Specialization
- **Seminar and Research**

Applied Mathematics
- Partial Differential Equations
- Complex Variables
- Modern Analysis
- Numerical Methods/Computational Math
- **Seminar and Research**
- Science and Math Electives

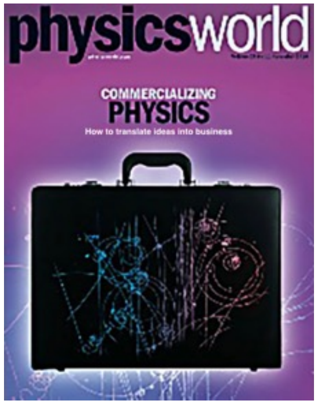
Lots of room for technical electives!

Materials Science & Engineering
- Thermodynamics and Reactions
- Crystallography and Crystalline Materials
- Synthesis and Processing
- Mechanical Behavior
- Electronic/Magnetic Properties
- **Design and Research**

Junior/Senior Seminar in Applied Physics
APPH 4901/4903

Fall 2018 Theme: Qubits: How to Build a Quantum Computer

Fall 2019 Theme: Entrepreneurship in Applied Physics and Starting a Tech Start-Up



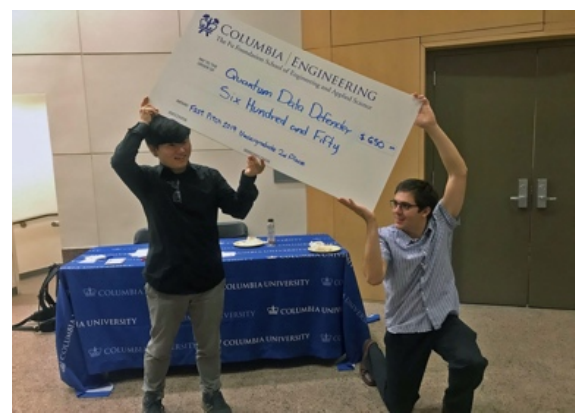
Junior/Senior Seminar in Applied Physics
APPH 4901/4903

Fall 2018 Theme: Qubits: How to Build a Quantum Computer

Fall 2019 Theme: Entrepreneurship in Applied Physics and Starting a Tech Start-Up

Applied Physics Undergraduates Explore Entrepreneurship and Win 2nd Place in Columbia's 2019 Fast-Pitch Competition

Quantum Data Defender (Student Team: Joseph Lee and James Borovilas) - secure data transmission using a scheme built upon entangled photons and cesium based quantum repeaters



Junior/Senior Seminar in Applied Mathematics APMA 4901/4903

"These examples changed my previous notion of Applied Math as a derivative of Math limited to computing and programming, and made me realize that how artistic and imaginative our work can be by weaving math models into any other disciplines."

"… it simply helps you to understand what exactly applied math is. In a broad sense, it exposes you to the various career paths following an applied math major. When I originally decided to major in applied math, I was convinced that the only thing to do with this major is either teach or go into finance. However, many interesting careers have been presented to me"

http://www.columbia.edu/~chw2/Courses/APMA4901/4901-instructions.pdf

Junior Year Lab in Materials Science MSAE 3012/3013

Topic	Details	Instruments
Diffraction	Laser diffraction, X-ray diffraction, Rietveld refinement	Siemens Diffractometer
Optical microscopy	Optical characterizations of microstructure of metals and other materials	Zeiss AxioScope A1, Leitz Orthoplan, AmScope NMM- 800TRF
Electron microscopy	SEM, Elemental analysis (EDS), Electron Back Scattering Diffraction (EBSD)	SEM in CNI
Atomic force microscopy	Imaging, data analysis	AFM workshop TT-AFM
Mechanical properties	Tension, Torsion, bending, indentation	Instron 1321/1361, Leco LM310 micro-indenter, Rockwell 3R, 4JR indenters
Material preparation	Polishing, cutting, soldering	Buehler EcoMet250/ AutoMet250, IsoMet Diamond Saw
Phase diagrams	Eutectic phase diagrams	Furnace
Electrochemistry (electrodeposition, batteries)	Deposition of Zn on Cu, making batteries	Prof. Yuan Yang's lab

and Senior Year Design Project, MSAE 3156

APAM Department Profile – Cross-Cutting Themes

(only budgeted faculty listed)

Energy

Navratil, Mauel, Boozer – fusion

Marianetti – electronic calculations of battery materials; Yang – battery materials

Im – laser processing for solar cells

Nanoscience

Venkataraman, Herman, Billinge, Chan, Pinczuk

Bio-related

Wiggins (data), Ken (medical imaging), Herman (teaching), Noyan (leads medical physics masters program)

Advanced Computation

Sobel, Spiegelman, Polvani, Marianetti (applications), Wentzcovitch

Analytic Theory

Ken, Weinstein, Wiggins, Boozer

Data Science

Wiggins, Du, Billinge

Environment

Sobel, Polvani (climate, global warming), Tippett, Mandli; Chan; Noyan (infrastructure)

Optics, Electronics, and Magnetics

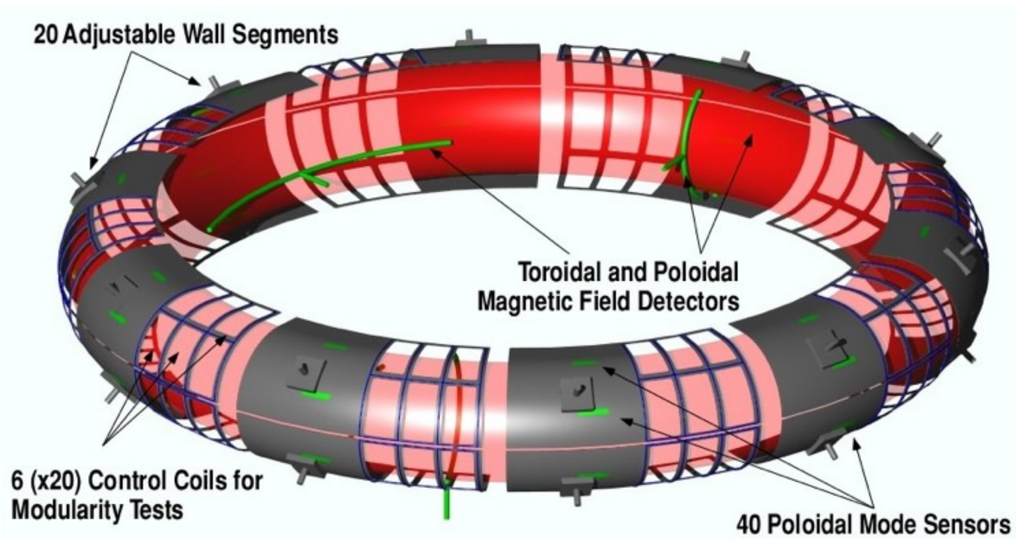
Gaeta, Im, Noyan, Herman, Pinczuk, Venkataraman, Bailey, Weinstein, Yu

Mauel, Navratil, Boozer, Applied Physics

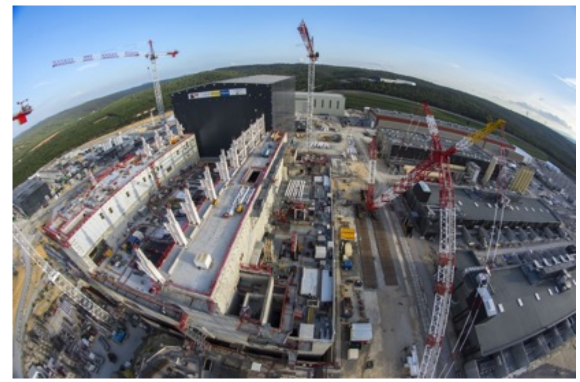
Fusion Energy and Plasma Physics

Greenhouse gas-free source of energy

High Beta Tokomak (HBT-EP) Stabilizes Plasmas



ITER



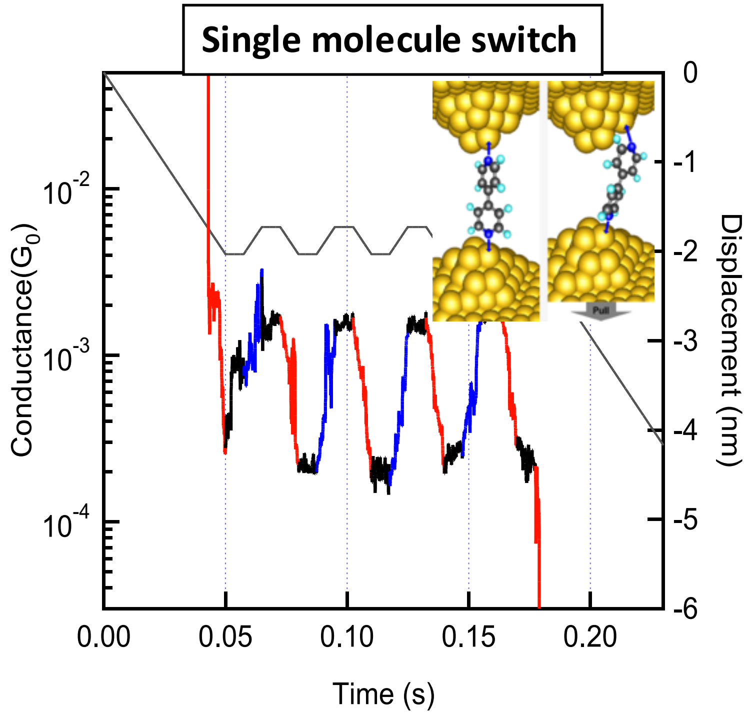
October 2019

https://www.iter.org/

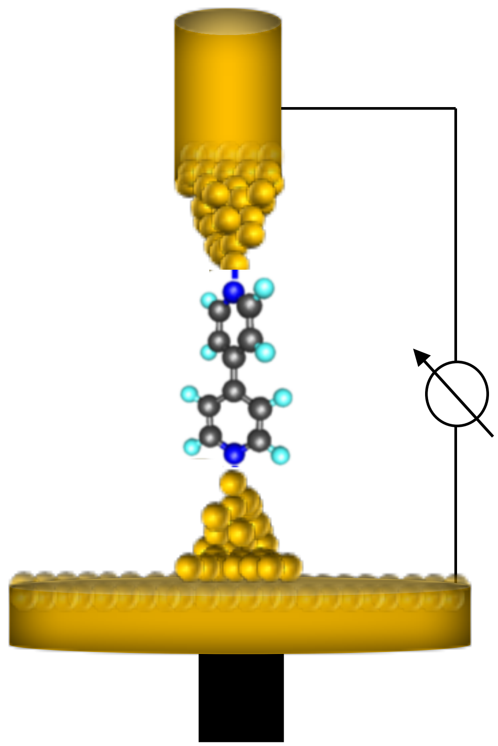
AP

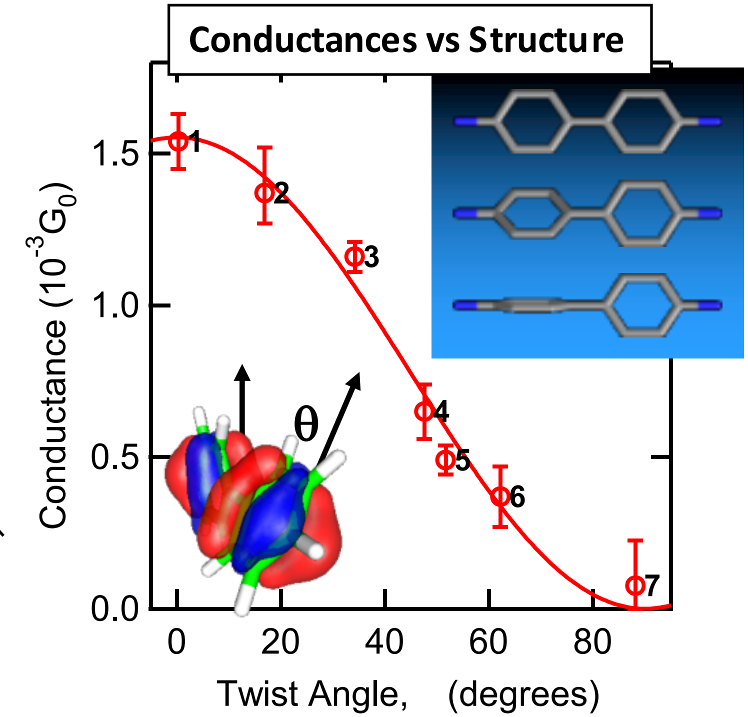
Latha Venkataraman, Applied Physics

We measure of fundamental properties of single molecule devices, including electronic, mechanical and thermal properties.



Quek et al, Nature Nano. 2009





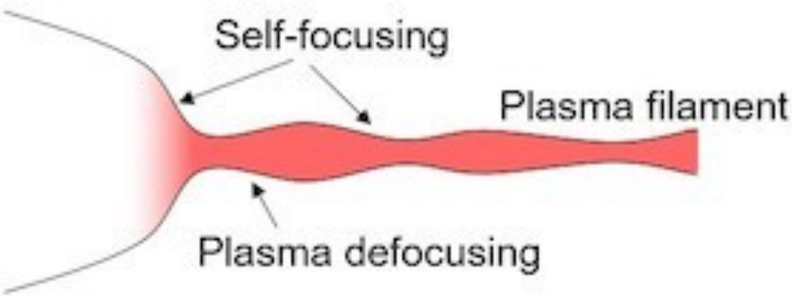
Venkataraman et al, Nature 2006

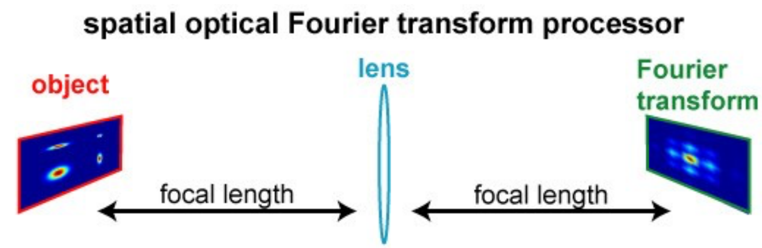
Our experimental research focuses on understanding the interplay of physics, chemistry and engineering at the nanometer scale.

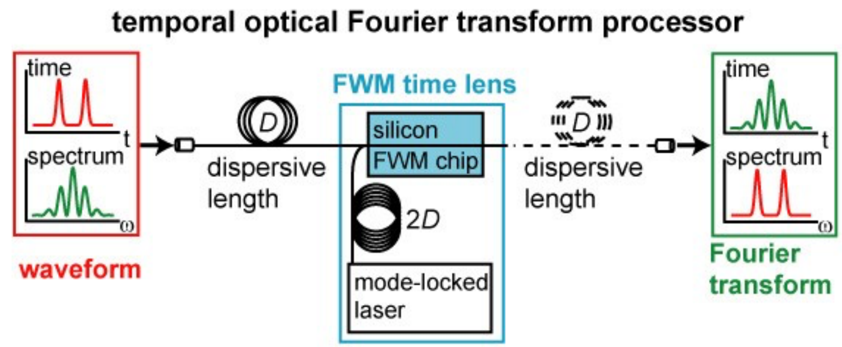
AP

Alex Gaeta, Applied Physics

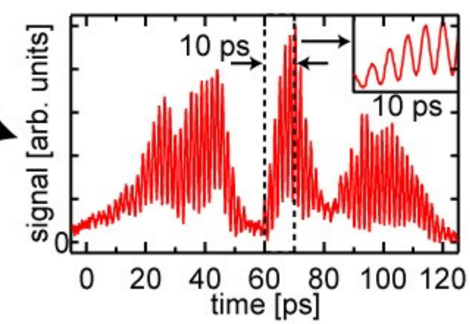
Intense Ultrafast Pulse Propagation &
Optical Computing and Signal Processing







Measurement of a highly complex waveform with 220-fs resolution



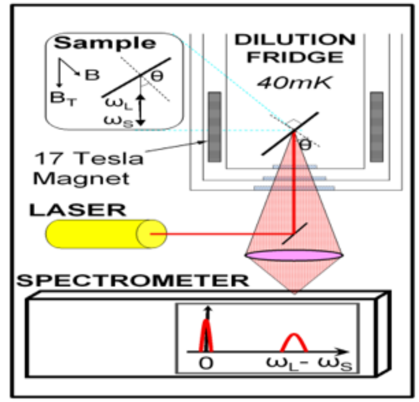
AP

Aron Pinczuk, Applied Physics

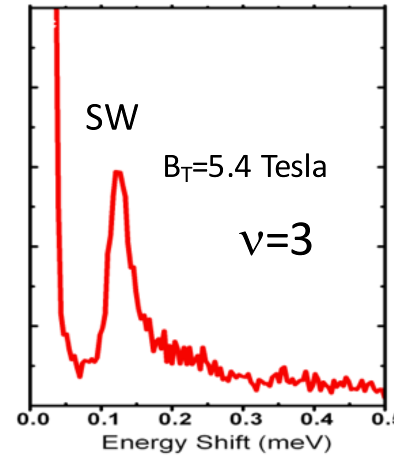
Quantum Hall Phases 'Seen' as Quantum Fluids

Charge carriers in nearly perfect GaAs/AlGaAs heterostructures and in graphene are paradigm materials in studies of electron fluids at forefront of basic physics and in exploration of future technologies

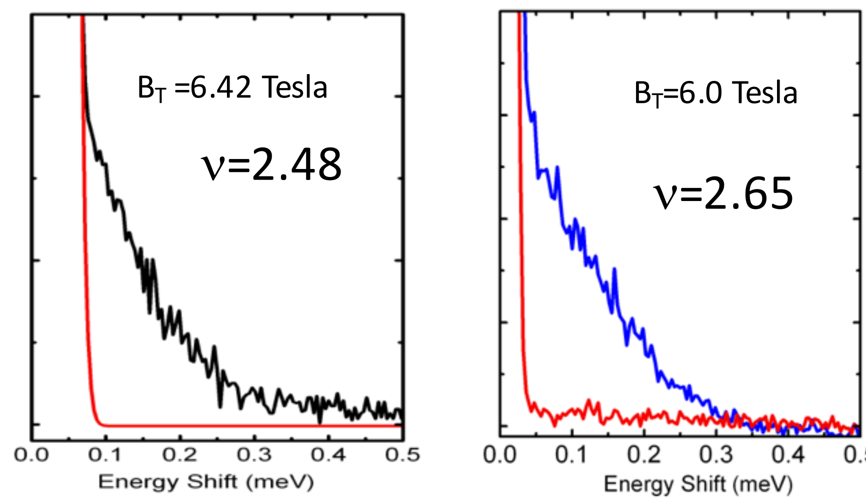
Physics of electron fluids of the fractional quantum Hall effect are 'seen' directly in spectra of low-lying excitations above the ground state. The experimental method is inelastic light scattering (top left figure). The status of spin polarization is monitored by measurements of spin waves (top right figure.) Quantum Hall phases proposed for applications in quantum computation are the focus of current experiments (two lower figures) The revealed a surprising lack of full polarization of spin has considerable impact because current theory predicts full spin polarization for the state.



schematic of the inelastic light scattering experiment



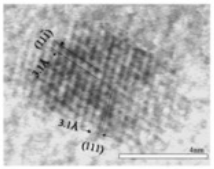
sharp spin wave (SW) reveals polarization of spin

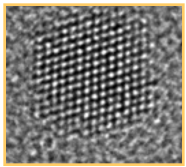


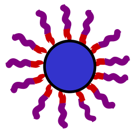
broad spectra of spin excitations at filling factors $\nu\cong5/2$ and $\nu\cong8/3$ indicate loss of spin polarization. Values of magnetic field are shown. The red traces indicate backgrounds

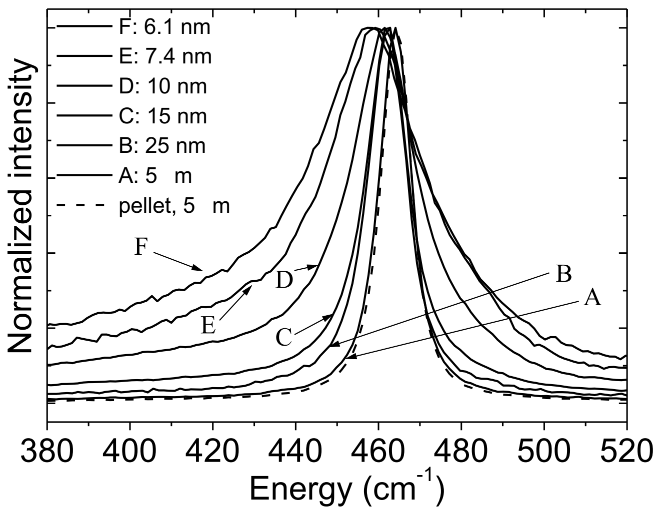
Irving Herman, Applied Physics and MSE

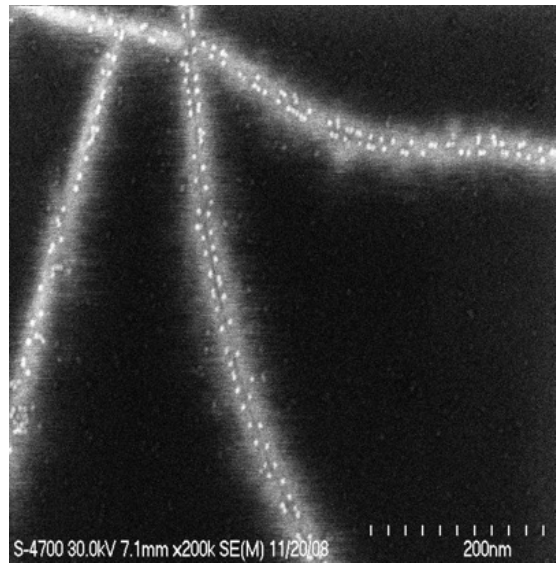
Assembly and Analysis of Nanomaterials

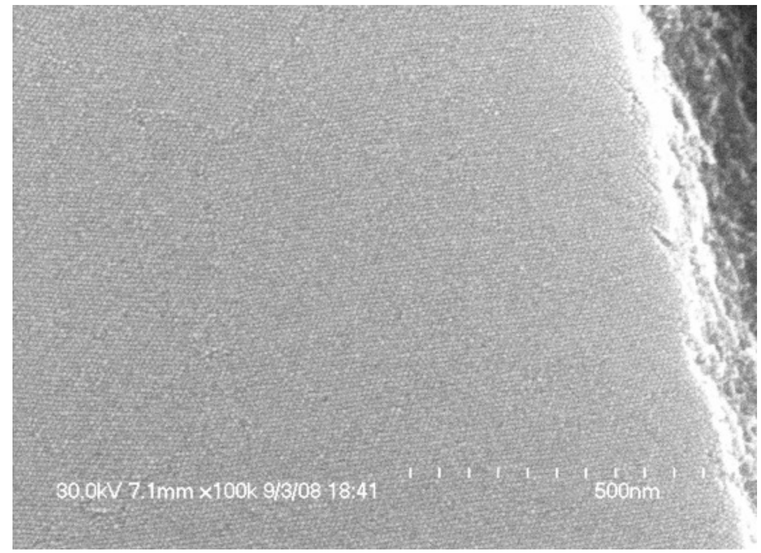












Optical Properties of Ceria Nanocrystals

CdSe Nanocrystal/ Single-walled Carbon Nanotube Hybrids

Spatially-selective Formation of 3D Ordered Arrays of Nanocrystals

and

Oleg Gang, Applied Physics and MSE

DNA-assisted Assembly and Analysis of Nanomaterials

AP-MSE

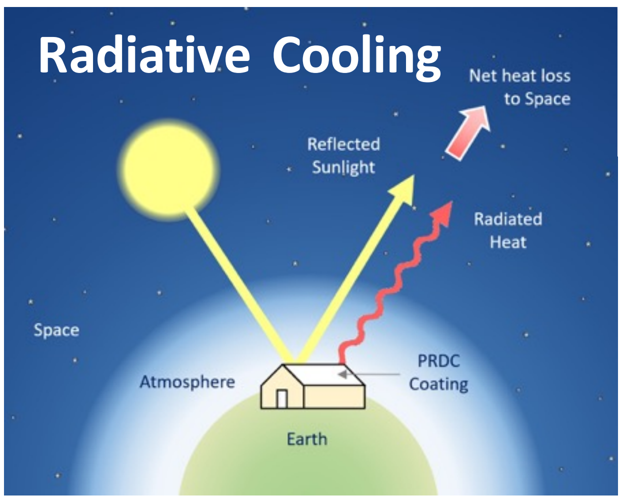
Yuan Yang, MSE

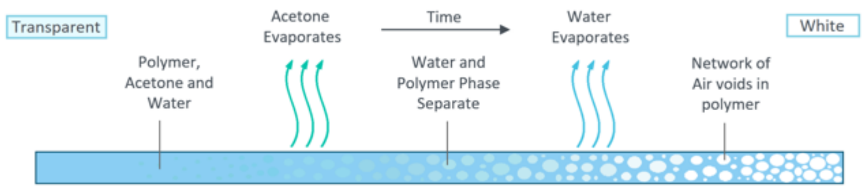
Battery and Thermal Management Materials

Nanfang Yu, AP

Metamaterials: Flat Optics

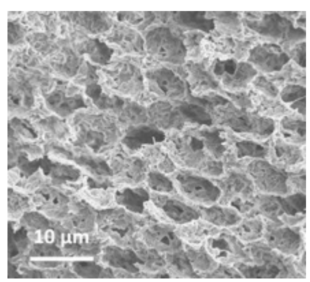
Porous Polymers for Passive Daytime Radiative Cooling

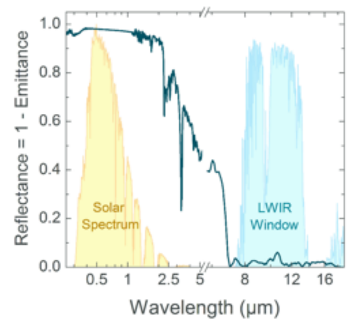


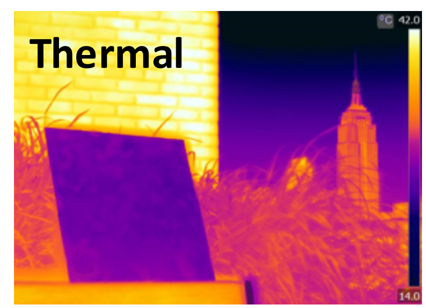


Like bubbles in a soap-foam, these nanopores and micropores scatter sunlight and lead to a remarkably high solar reflectivity of 96%-99.6% – allowing the coating to avoid heating even under strong sunlight.

- Using the sky to cool structures
- Reducing/replacing electrical cooling







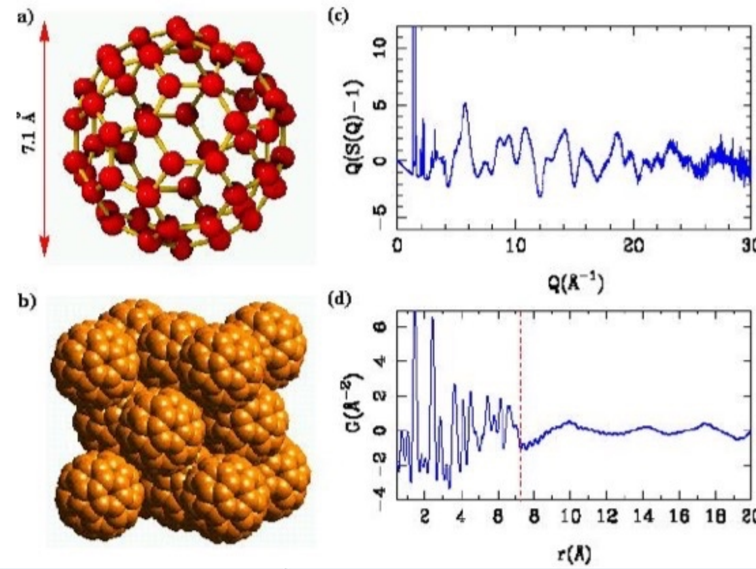
Mandal et. al. *Science* (2018)

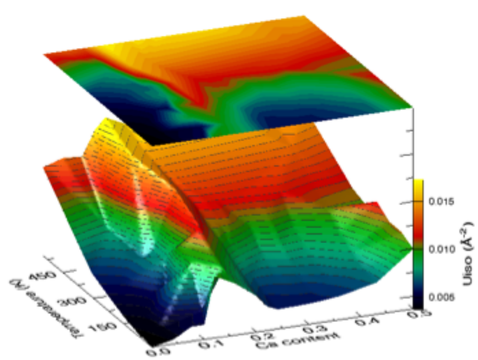
AP-MSE

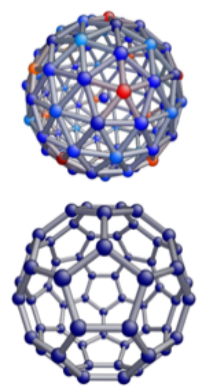
Simon Billinge, MSE and Applied Physics

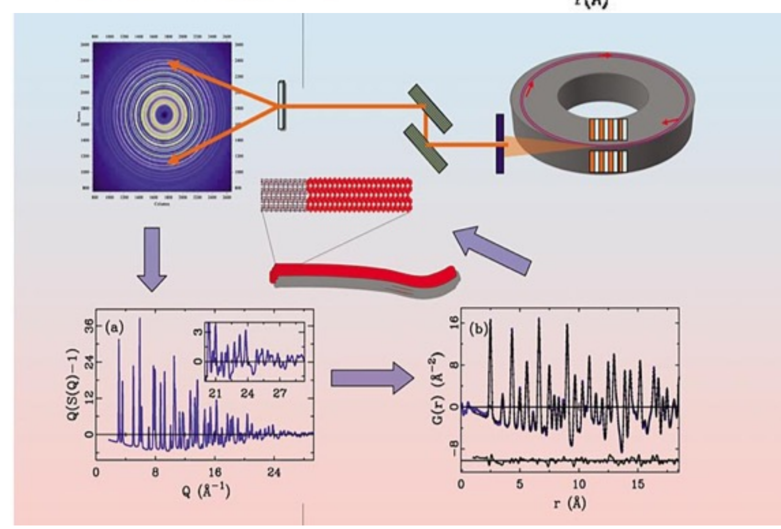
Characterizing Materials at the Nanoscale

- Problem: How do we learn how atoms arrange themselves in nanostructures?
- Solution: Use the world's most powerful x-ray and neutron sources and the world's most powerful computing resources, develop novel experimental methods and algorithms.
- Impact: develop next generation electronics, photovoltaics, batteries, pharmaceuticals, catalysts, understand fundamental materials physics and chemistry of superconductors, minerals and other complex nanostructured materials









MSE-AP

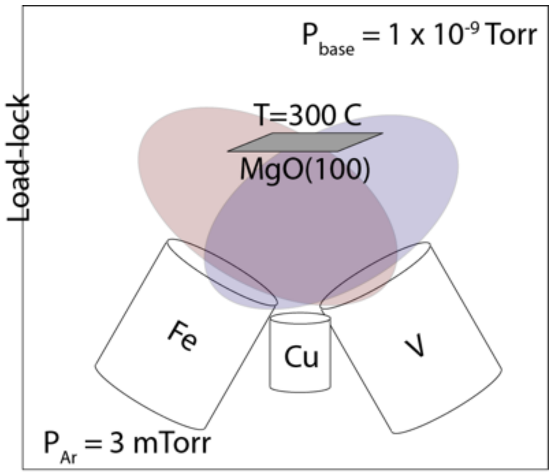
William Bailey, Materials Science and Eng.

Magnetic Ultrathin Films and Spintronics

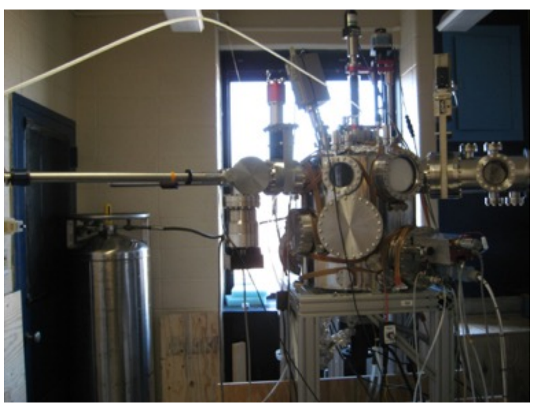
Novel magnetic ultrathin films and alloys…

optimized for ultrafast performance

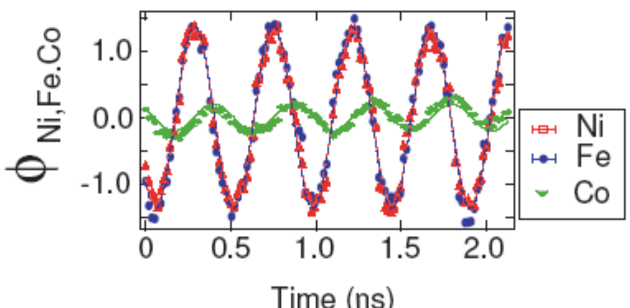
…for use in GHz magnetic / spin electronic devices.



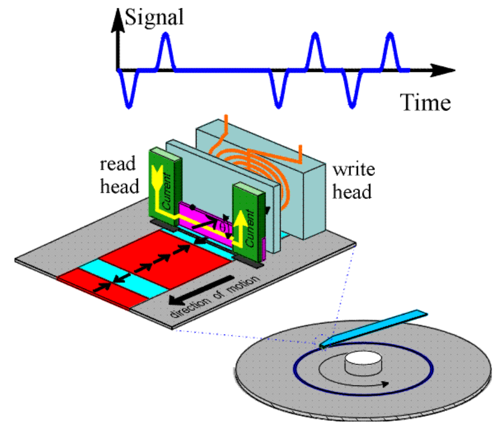
UHV cosputtering of epitaxial Fe_xV_{1-x}



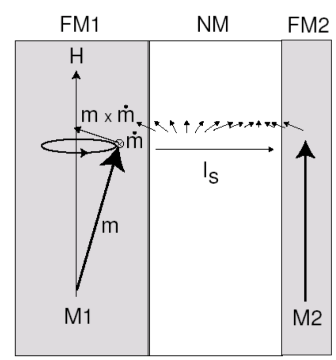
MBE deposition for in-situ studies



synchrotron-based studies of picosecond magnetization dynamics



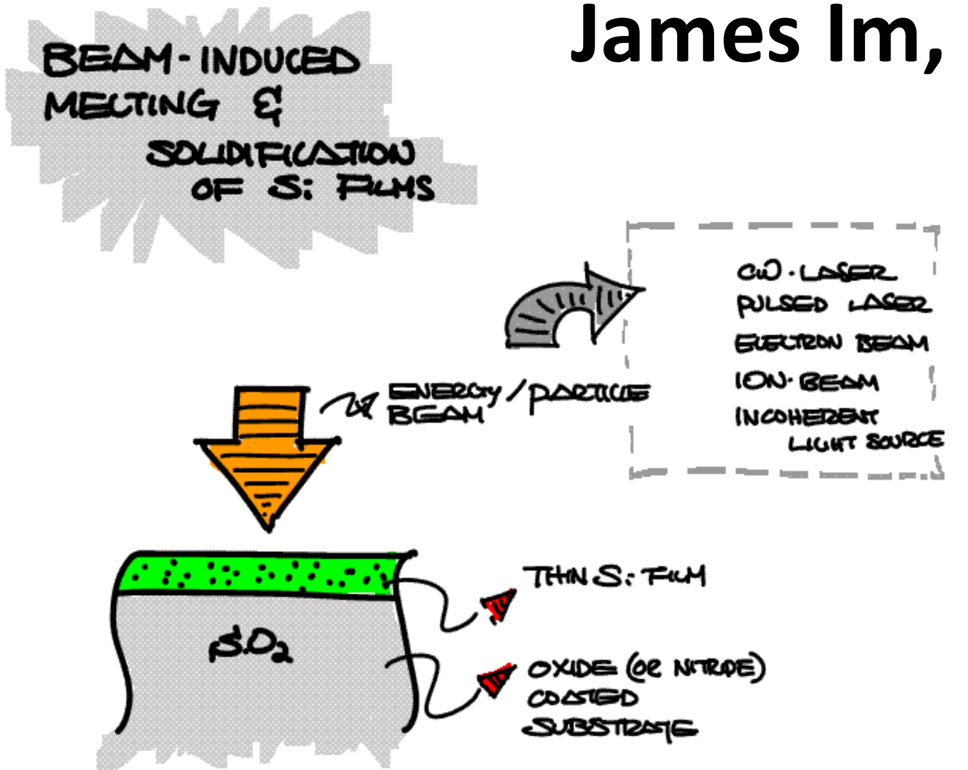
Ghz magnetic data storage / hard drives based on tunneling magnetoresistance

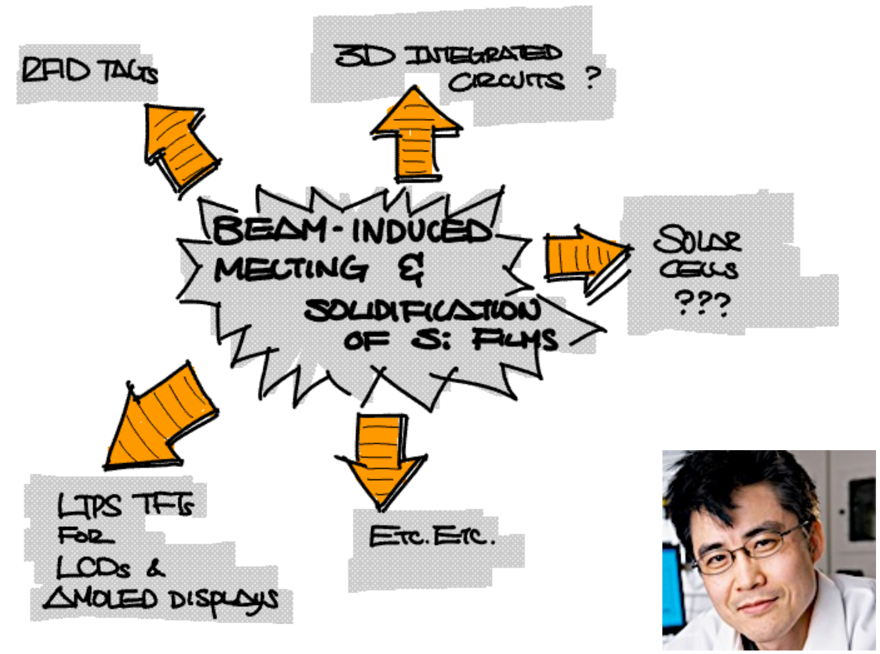


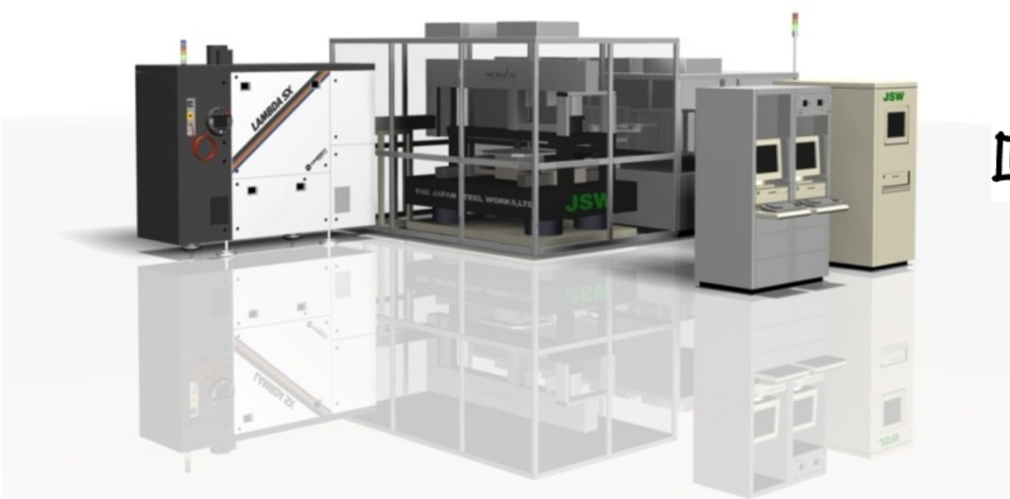
"Spin battery" for novel computing

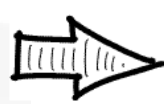
MSE-AP

James Im, Materials Science & Engineering









MSE

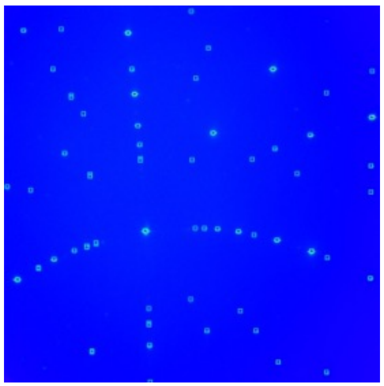
I. C. Noyan, Materials Science and Engineering

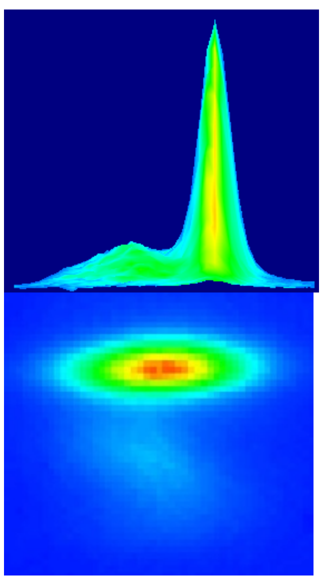
Applied Diffraction Theory and Analysis

X-ray and neutron diffraction analysis of material structure.

Experiment modeling and data simulation.

Industrially relevant measurements.



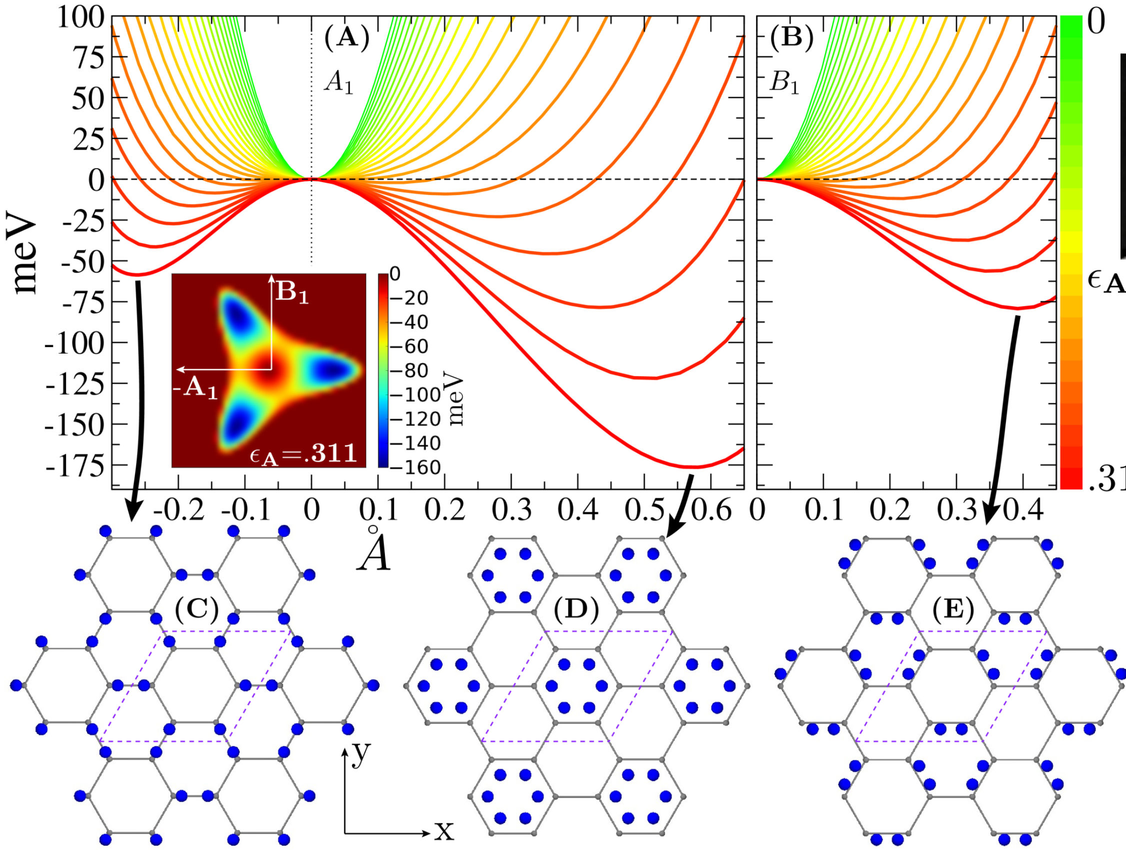


MSE

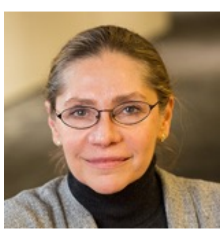
Chris Marianetti, Materials Science and Eng.

Electronic Structure Calculations of Electronic Materials

K1 phonon instability in graphene under equibiaxial tension



Renata Wentzcovitch,
Electronic Structure Calculations
For geophysical materials



MSE-AP-AM

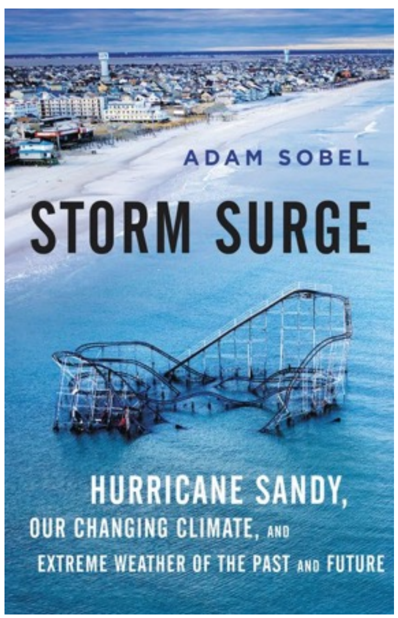
Adam Sobel, Applied Mathematics

Computation: Atmospheric Models and Global Warming

The Columbia Initiative on Extreme Weather and Climate is focused on understanding the risks to human life and property from extreme weather events, both in the present and future climates, and on developing solutions to mitigate those risks.

Columbia Initiative on
Extreme Weather and Climate
Adam Sobel, Director

- NY Times



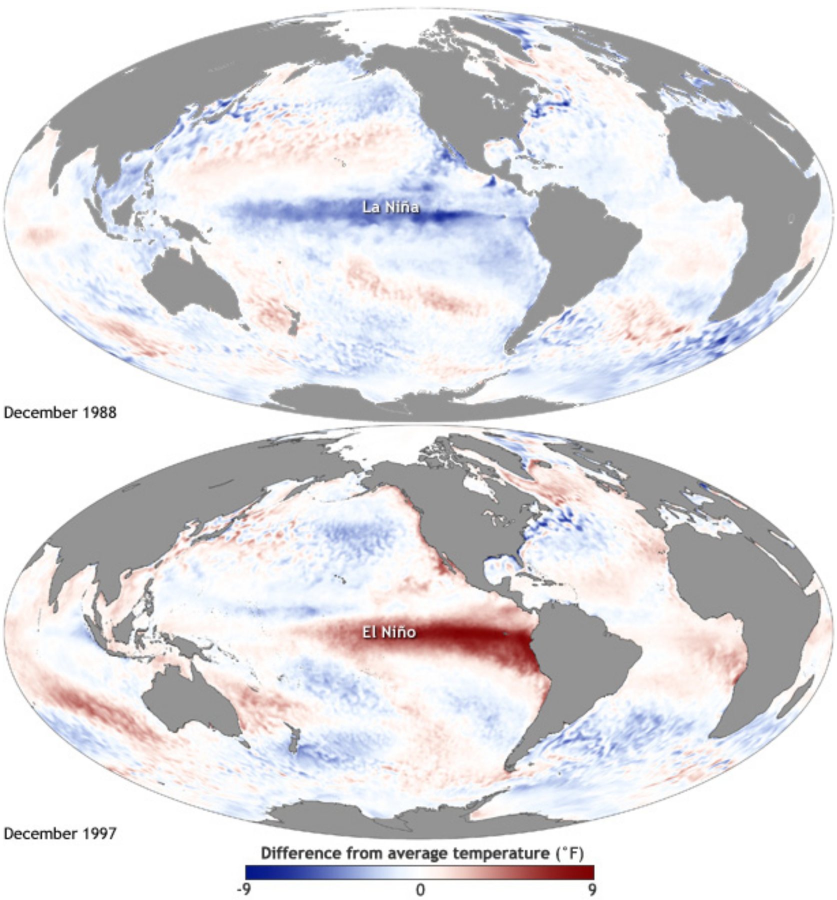
AM

Michael Tippett, Applied Mathematics

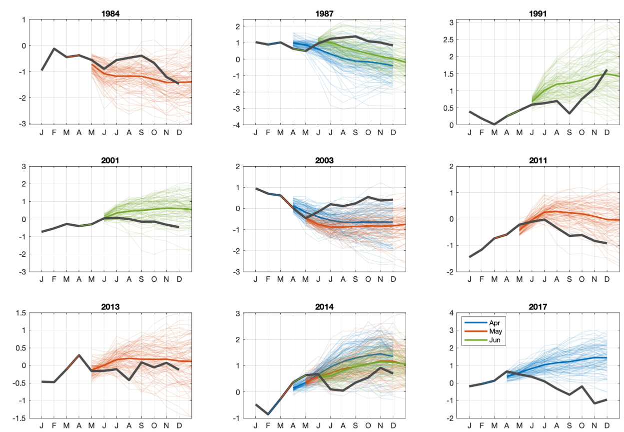
Variability & Predictability of Weather and Climate

Statistical analysis of model and observation data
Uncertainty quantification

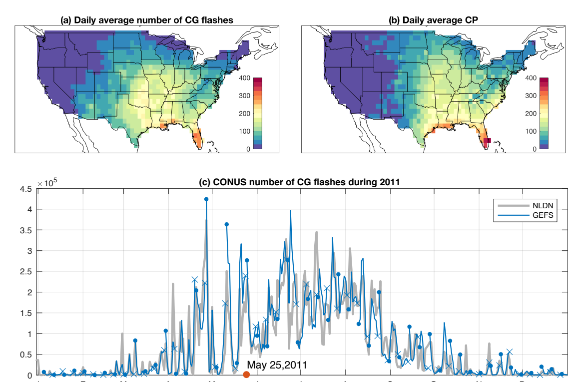
El Niño-Southern Oscillation



Excessive momentum and false alarms in late-spring ENSO forecasts

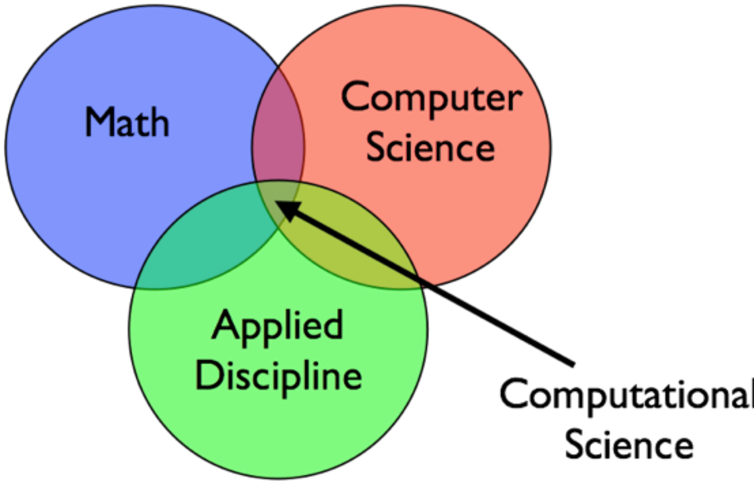


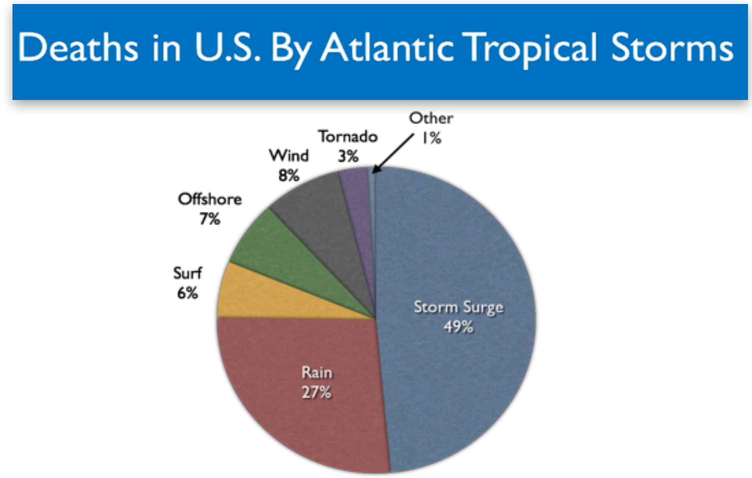
A baseline for the predictability of U.S. cloud-to-ground lightning



Kyle Mandli, Applied Mathematics

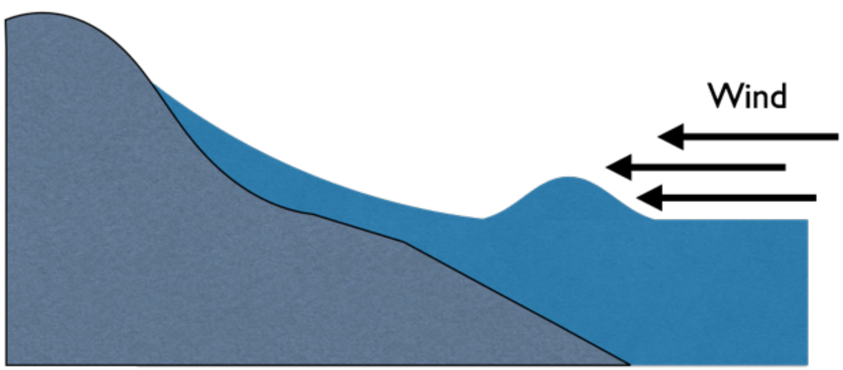
Computation: Storm Sturges

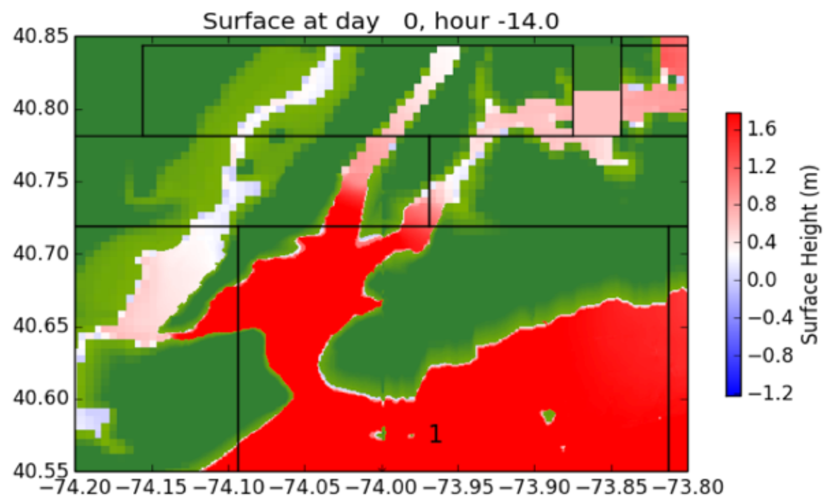




*Edward N. Rappaport, 2014: Fatalities in the United States from Atlantic Tropical Cyclones: New Data and Interpretation. Bull. Amer. Meteor. Soc., **95**, 341–346.*

Storm Surge





Adaptive Mesh Refinement

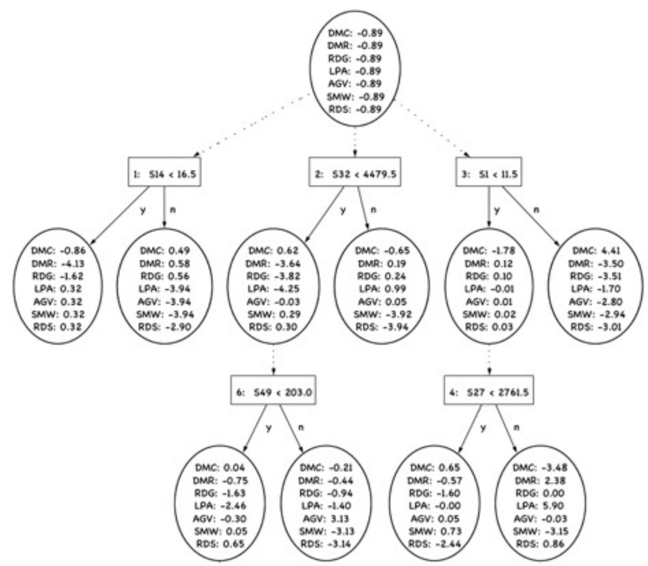
Chris Wiggins, Applied Mathematics

Personalized Medicine

- develop mathematical methods beyond those of the 20th century, which were typically limited to simple response models

- interpretable modeling rather than deep learning or other ‘black box’ computational approaches

Machine learning



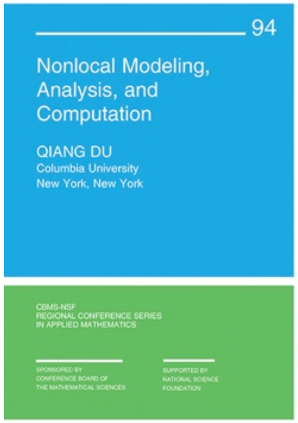
- Also teaches the Applied Math junior/senior seminar

- NY Times

AM

Qiang Du, Applied Math (+ Data Science)

http://cm3.apam.columbia.edu



Mathematics holds the key to the solution of many modern scientific and engineering challenges.

Sample ongoing projects@CM3:

nonlocal models and simulations,

traffic flow modeling of autonomous vehicles.

deep neural networks, nanoscale inverse problems, ……

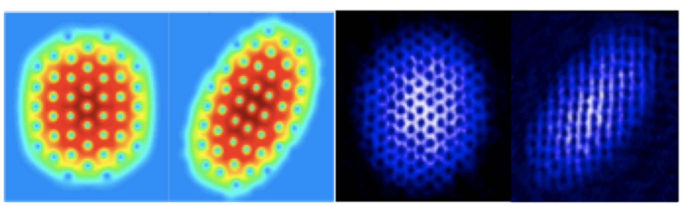
Computational Mathematics Multiscale Modeling

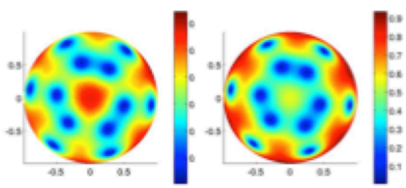
CBMS-NSF series 2019, SIAM

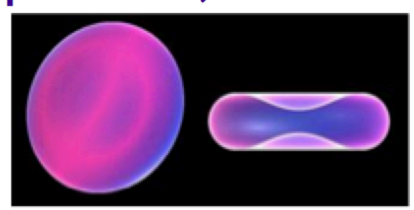
Mathematics + Physics + Data + AI

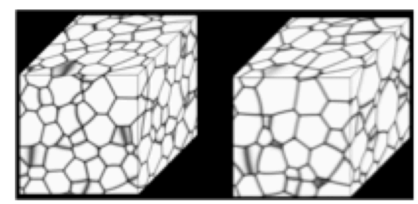
funded by NSF-DMS, NSF-CCF, NSF-DMR, ARO, AFOSR

Applications in phys.-bio.-materials:: superfluid, membrane, fractures...

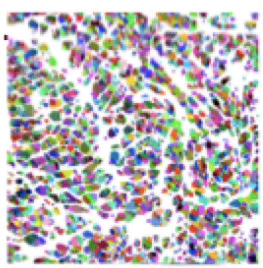


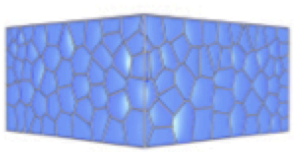


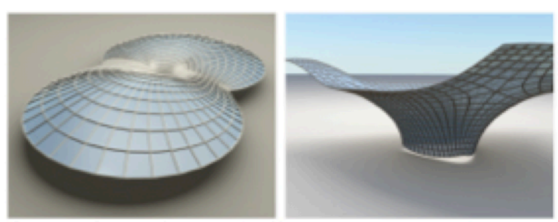


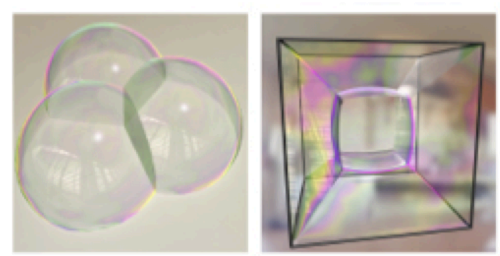


Applications in info/data sciences: mesh, UQ, time series, deep learning,









AM

Applied Physics and Applied Mathematics
COLUMBIA | ENGINEERING

Career Directions for Applied Physics, Applied Mathematics & Materials Science Majors

YOU CAN DO ANYTHING!

Graduate programs in **program-related areas**.

Easy entry into many types of graduate-level programs in **science and engineering** fields.

Superb preparation for a wide range of positions in **university, government, and industrial organizations**.

Careers in general technology areas, energy and nanotechnology, and any career requiring either strong experimental, theoretical, or calculation skills, such as data science or finance.

Pre-med, pre-dental, pre-teaching, and other pre-professional students, such as patent law.

Excellent preparation for careers at **the interfaces of biology, medicine, and physics/mathematics/materials science**.

Applied Physics and Applied Mathematics
COLUMBIA | ENGINEERING

If you are considering a career in research:

Undergraduate Research Opportunities in APAM

Will show only a few of the many opportunities

Contact the faculty directly!

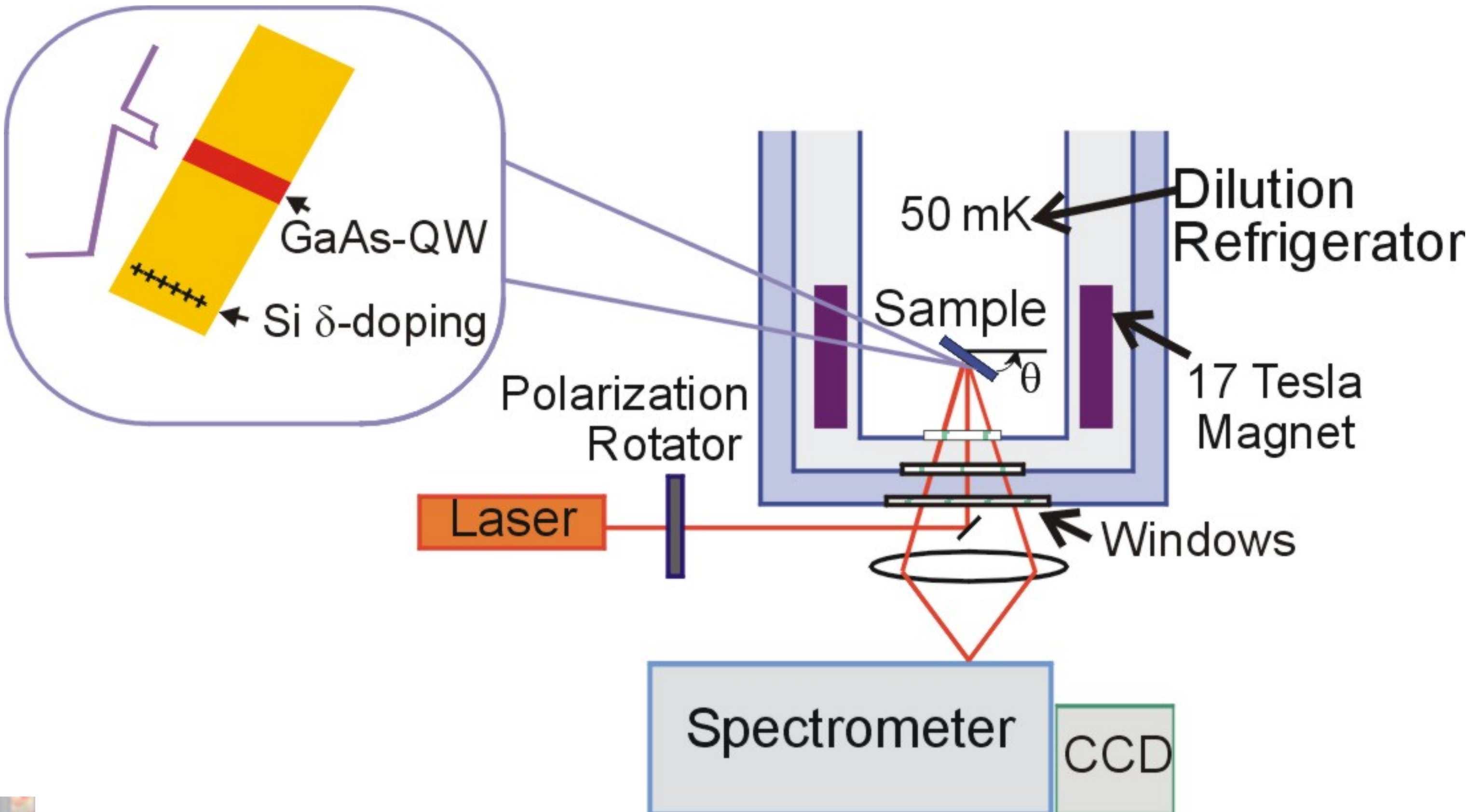
Fusion Energy Plasma Physics Research

Andres Marco Miller (APAM '20 --- AP senior)
was awarded a "Best Undergraduate Poster" Award
from APS Division of Plasma Physics in October 2019

Appl Phys

Spectroscopy of Nanostructures: Semiconductors in the Pinczuk Group

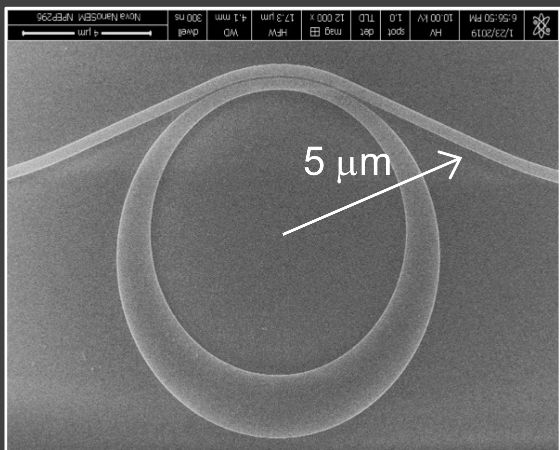
millikelvin spectroscopy

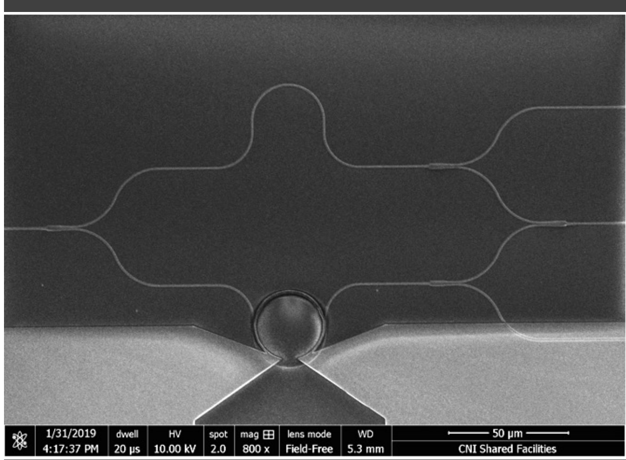


Appl Phys

Flat optics: Metasurface based active & passive devices in the Yu Group

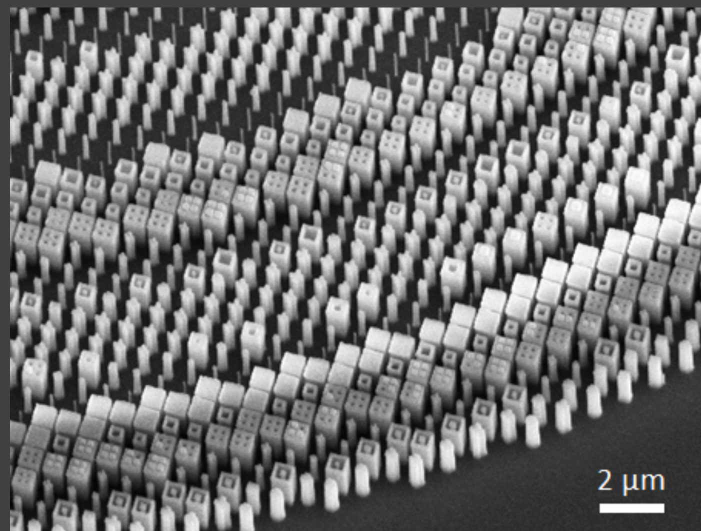
Pure-phase optical modulators in the visible

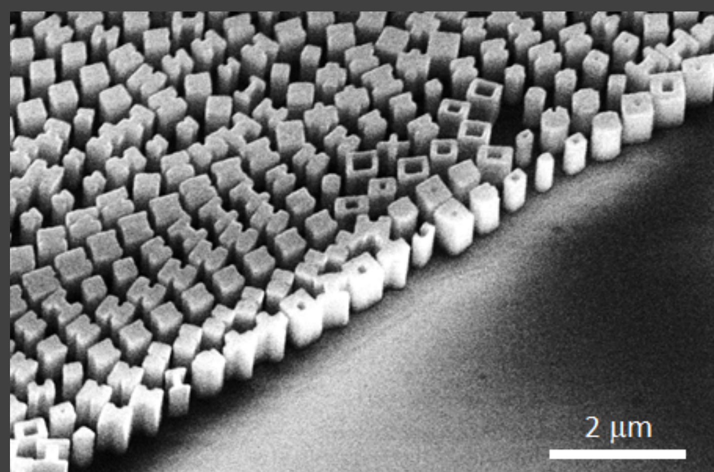




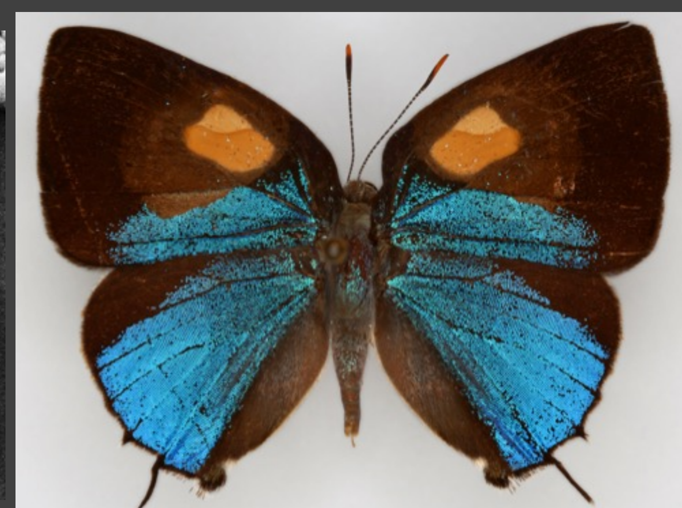
50 μm

Metasurface-based flat lenses & holograms





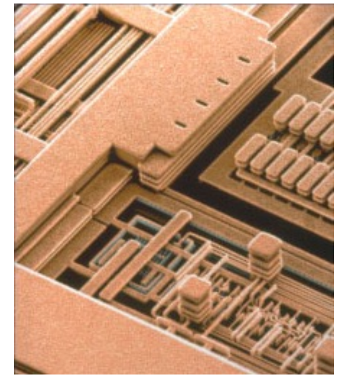
Biophotonics & bio-inspired optical materials

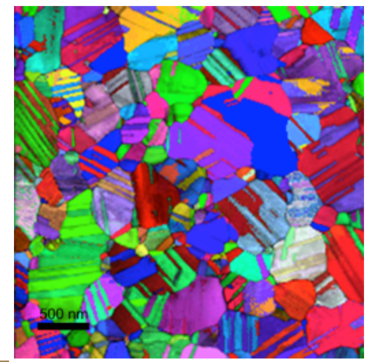


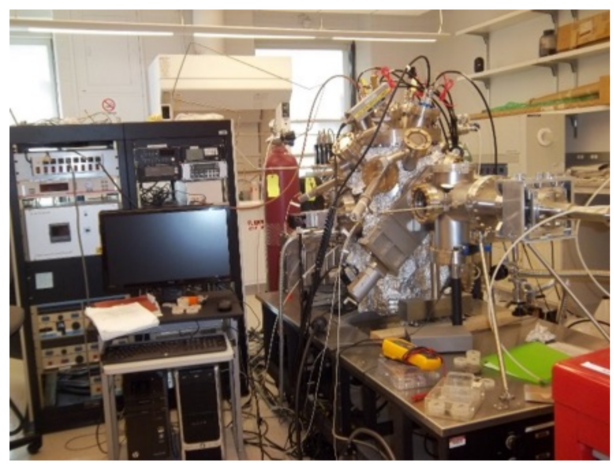
Appl Phys

Barmak Research Group: Materials Synthesis, Structure, Properties

- **Broad range of projects for undergrad research**
  - Integrated circuits and metallic interconnects beyond Cu
  - Next generation electronics: transition metal dichalcogenides
  - Spin torque devices: β-W
  - Pressure sensors: silicides
  - Hard disk drives and magnets for clean energy: FePt, FeNi
  - Degradation and preservation of early European printed books



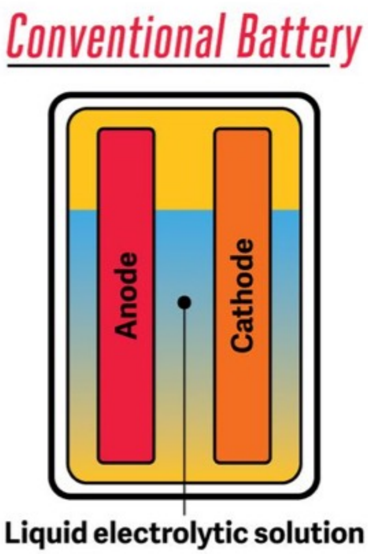


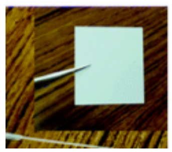


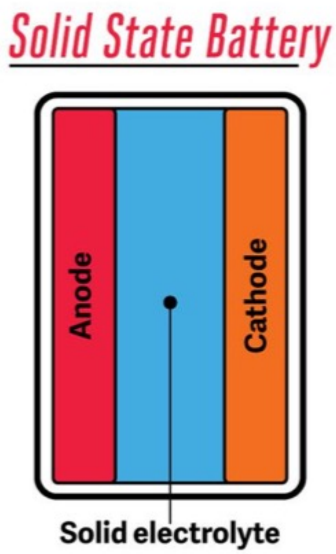
Mat Sci

Material Designs for Future Batteries and Cooling in the Yang Group

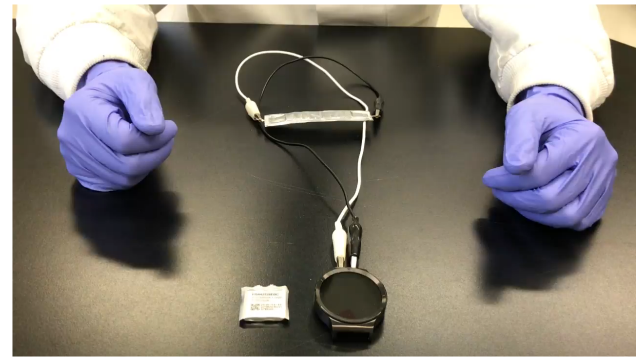
Safe Batteries



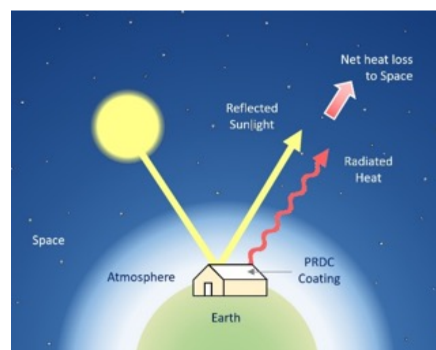




Flexible Batteries

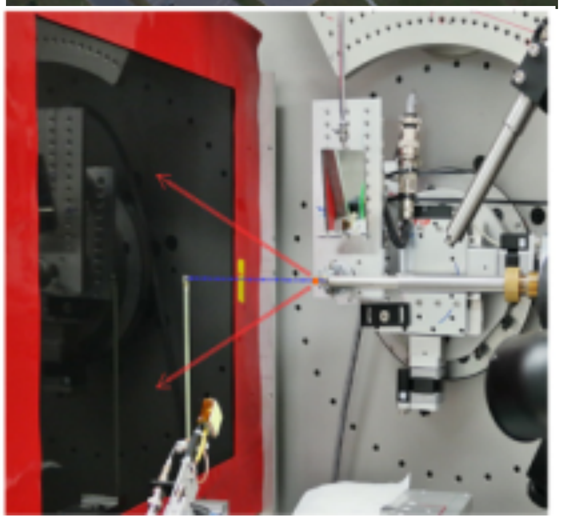


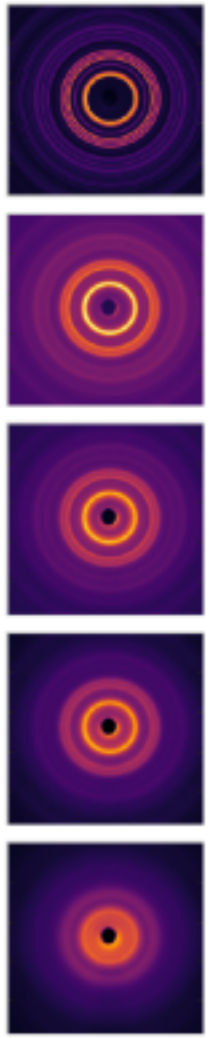
Cooling Paints

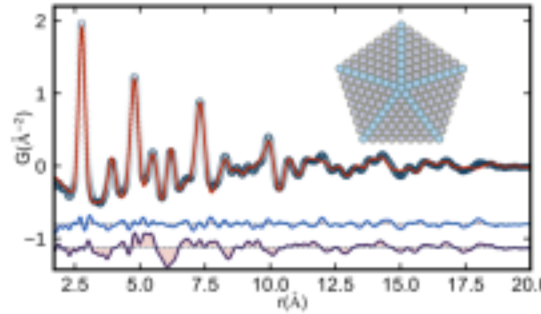


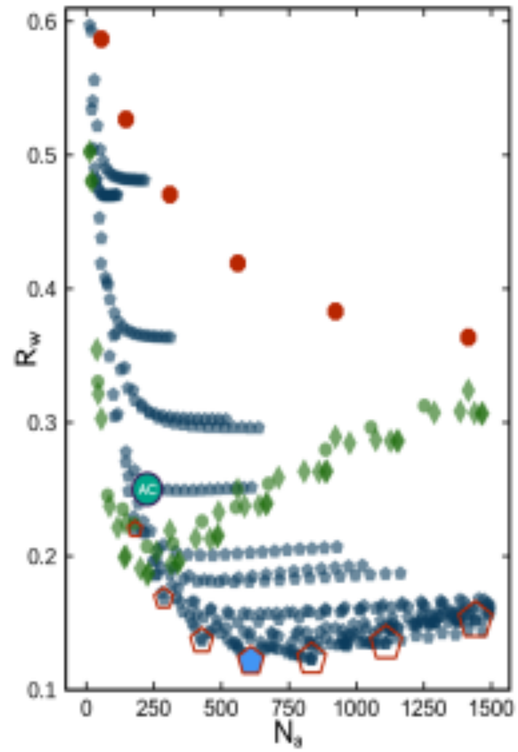
Mat Sci

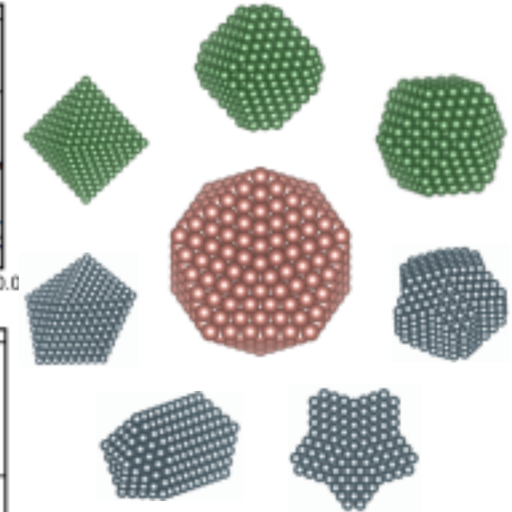
Understanding Structure of Nanomaterials from x-ray and Neutron Experiments in the Billinge Group

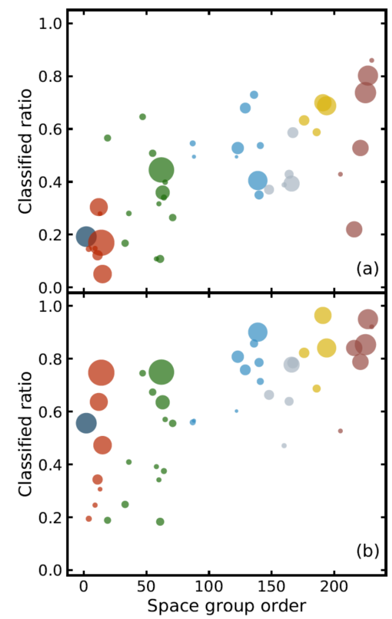












Study nanostructure using state-of-the-art x-ray sources, computation and Machine Learning

Mat Sci

Atmospheric Dynamics and Extreme Weather in the Sobel Group

Columbia Initiative on
Extreme Weather and Climate
Adam Sobel, Director

- We currently have two undergrad students doing research on tropical cyclones
- Projects generally involve statistical data analysis
- No prior knowledge of atmospheric science required or expected, but you do need interest in the subject
- We already get more students coming to us on their own than we can take, so we don’t advertise!

AM

Coastal Flooding Research in the Mandli Group

- Run simulations of past storms
- Contribute to open source software for flood prediction
- Help compute probabilistic coastal flooding
- Forecasting storm surge potential

Appl Math

Applied Physics and Applied Mathematics
COLUMBIA | ENGINEERING

Majoring in... **Applied Physics, Applied Mathematics,** or **Materials Science**?

Where did last year's grads go?

86% Concrete Plans (Employed, Grad School)

61% Employed

25% Grad School

14% Still Searching, Taking Time Off

**Data from the 2017 Graduating Student Survey: 63.6% response rate*

What are recent alumni doing?

EMPLOYMENT

U.S. Department of Energy
Kulite
Truveris
Achievement First
NASA
ARUP
Northrop Grumman
L2
citigroup
IBM

GRAD SCHOOL

UCL
Caltech
Columbia University in the City of New York
Princeton University
Stanford University
Harvard University

My Columbia Applied Physics, Applied Mathematics, or Materials Science degree prepares me to...

- Analyze and interpret complex data
- Function effectively on a multidisciplinary team
- Use appropriate statistical models
- Implement strong experimental, theoretical and calculation skills
- Approach problems scientifically
- Problem-solve
- Communicate effectively
- Quickly learn to adapt to advances in technology

For more industries and job titles to explore, visit What Can I Do With This Major? at cce.columbia.edu/thismajor or schedule a meeting with a CCE career counselor: bit.ly/CCECareerCounseling

COLUMBIA UNIVERSITY CENTER FOR Career Education

Applied Physics and Applied Mathematics
COLUMBIA | ENGINEERING

"Stop by" APAM
200 Mudd

* apam.columbia.edu

** email faculty

*** my office is 208 Mudd

iph1@columbia.edu

iph1 = iph one = iphone