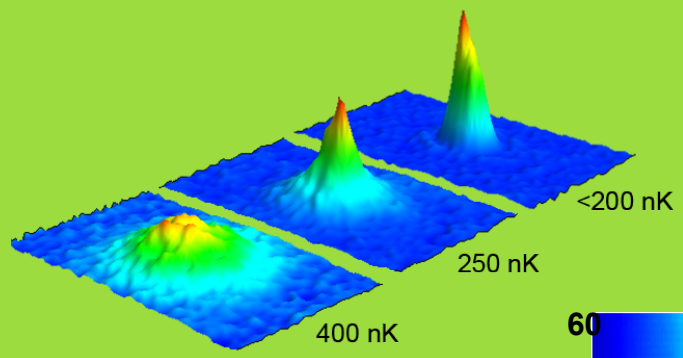
Experimental Physics Research @ University of Washington (UW)

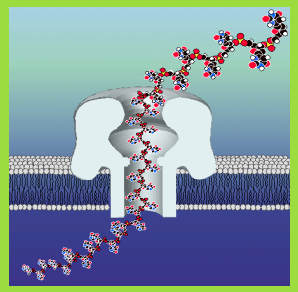
Alvaro E. Chavarria (CENPA)

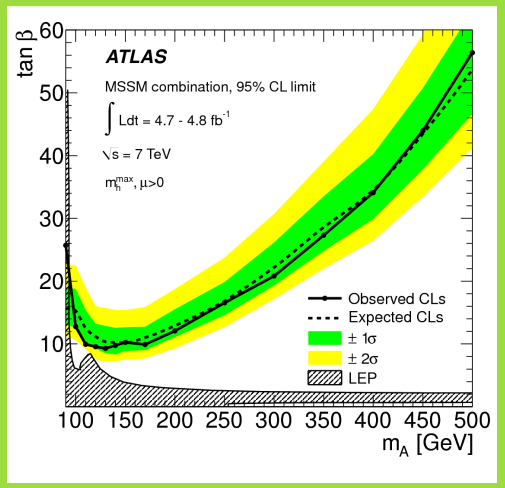
2018 Physics Visiting Weekend

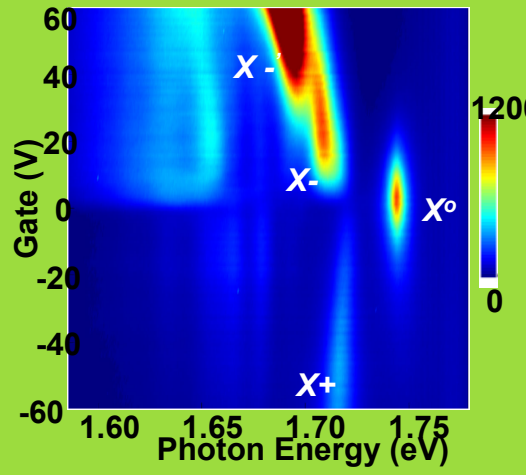
Broad Research areas…

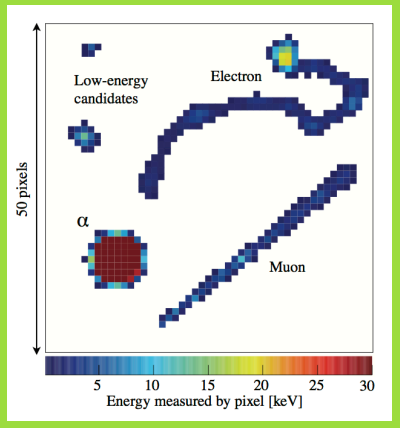
- Astrophysics/Cosmology
- Atomic Physics
- Biological Physics
- Collider/Particle Physics
- Condensed Matter
- Energy Sciences
- Gravitational Physics
- Nanoscale Physics
- Neutrino Physics
- Nuclear
- Precision Measurement
- Physics Education
- Quantum Information









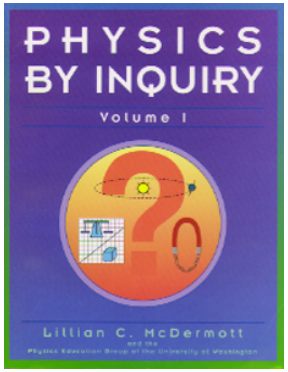


Physics Education Group at UW

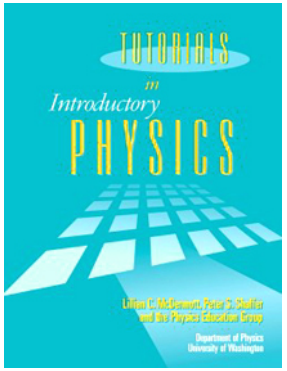
McDermott, Heron
Shaffer, Brahmia

Research on the learning and teaching of physics (K-20+)

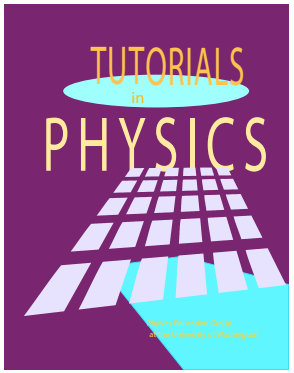
- Determining what students can and cannot do after typical instruction
- Identifying conceptual and reasoning difficulties that students encounter during physics instruction
- Designing and testing instructional strategies (at UW and elsewhere)



K-12 Teachers *(Preservice & Inservice)*



Students in introductory physics courses

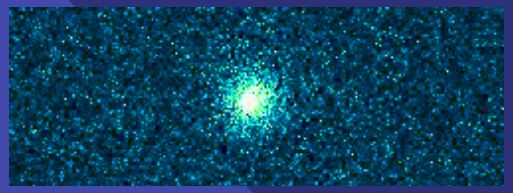


Students in advanced physics courses *(E&M and QM)*

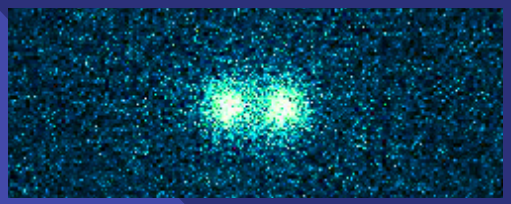
Research-based & research-validated approach to improving STEM education from kindergarten to university and beyond

Blinov Group: Trapped ions = qubits

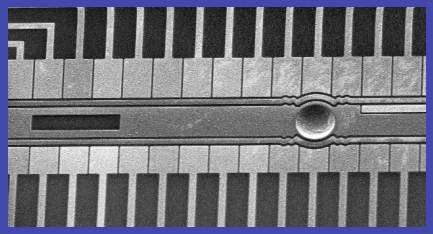
Individual ions suspended
in free space, cooled by lasers

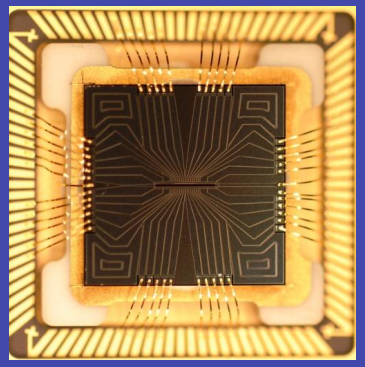


1 qubit

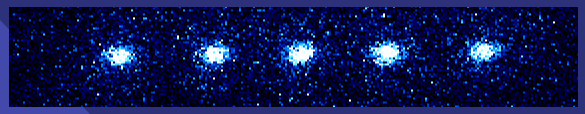


2 qubits



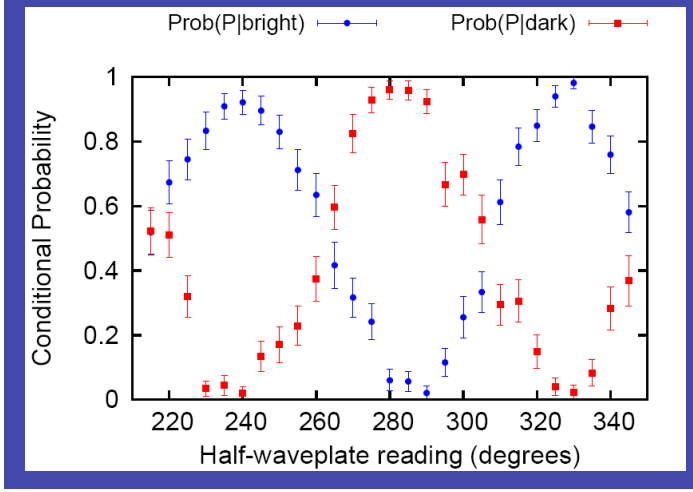


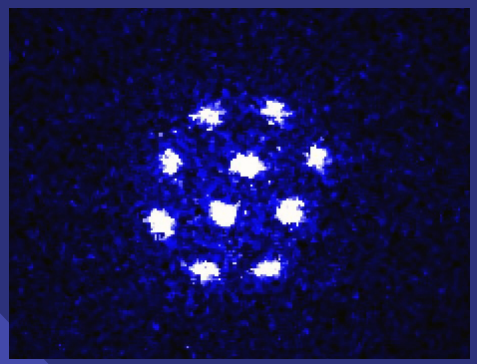
Chip-scale ion traps



5 qubits

Ion-photon entanglement





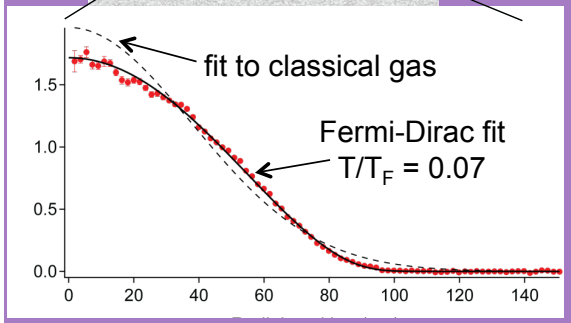
n qubits

Gupta group: NanoKelvin Matter and Atom Lasers

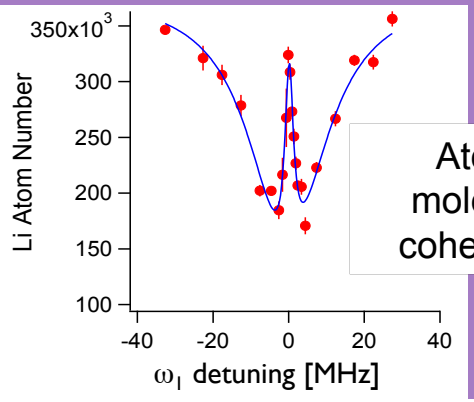
QUANTUM SIMULATION of complex systems eg. High T_c SC; superfluids
QUANTUM INFORMATION and CHEMISTRY with ultracold molecules

Precision BEC interferometry: Testing Fundamental Physics

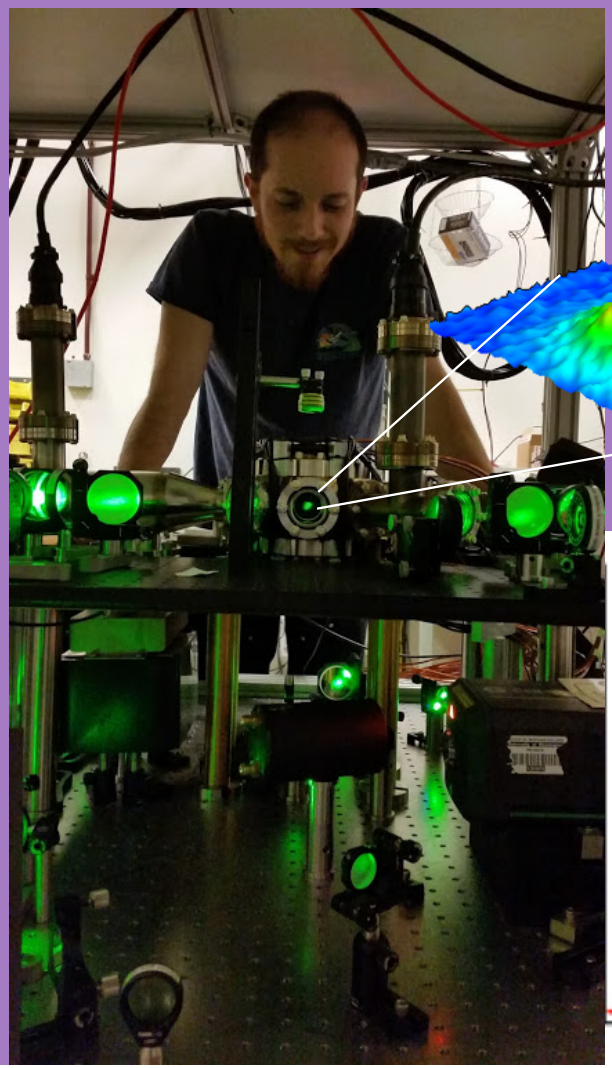
Photographs of Quantum Matter



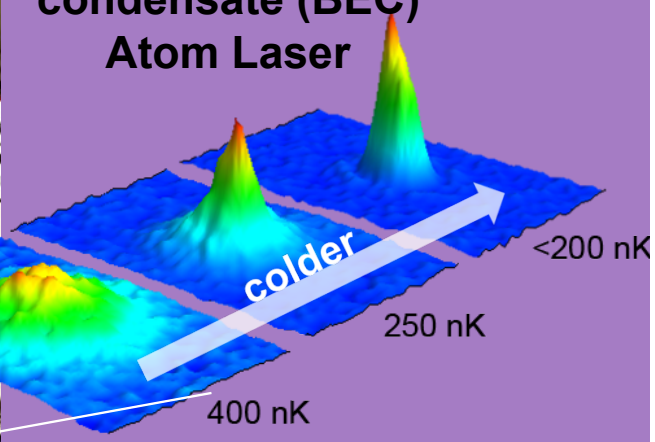
Bose-Fermi Double Superfluid



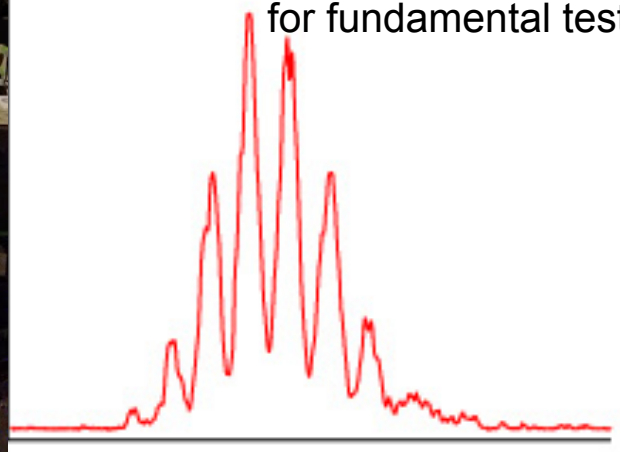
Atom-molecule coherence



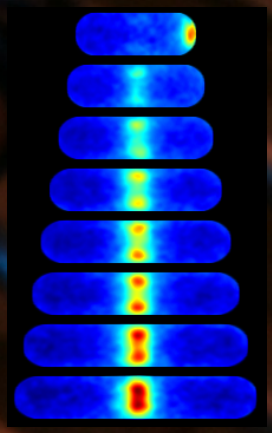
Bose-Einstein condensate (BEC) Atom Laser



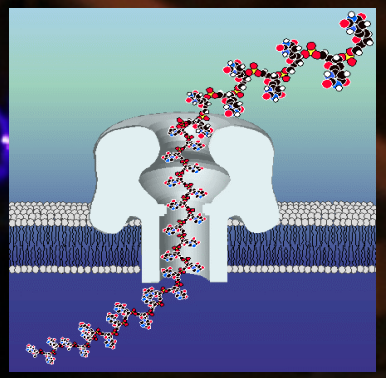
BEC interferometer for fundamental tests



Biophysics @ UW

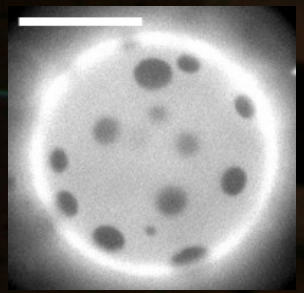


Many opportunities in biophysics on campus…
BioE, Med School, Chem are located next door to Physics
Many faculty are excited to take physics students.



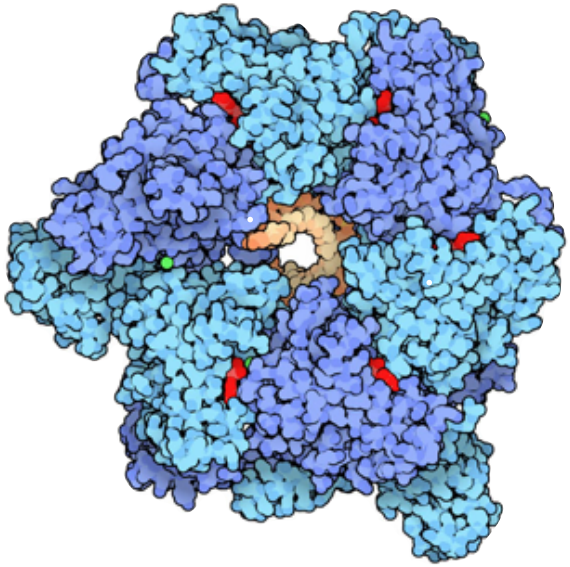
Biophysics in the Physics Department (Experiment):
- **Jens Gundlach –** Single-Molecule DNA sequence w/ nano-pores
- **Paul Wiggins –** Bacterial Ultra-Structure w/ SM fluor, Super-Res

Many other "physicists" studying biophysics:
- **Chip Asbury** (PBio) – Mitosis w/ Single Molecule biophysics
- Adrienne Fairhall (PBio) – Neuro, Theory
- David Baker (BioChem) – Protein Folding
- Sarah Keller (Chem) – Lipid membrane physics
- Wendy Thomas (BioE) – Cell adhesion/Catch-bonds
- Fred Rieke (PBio) – Signal transmission in neurons
- Paul E. Kinahan (BioE): PET scan/BioMedical Imaging
- Gordon, Hille, Zagotta (PBio) – SM Channel Physiology
- Many, many more...

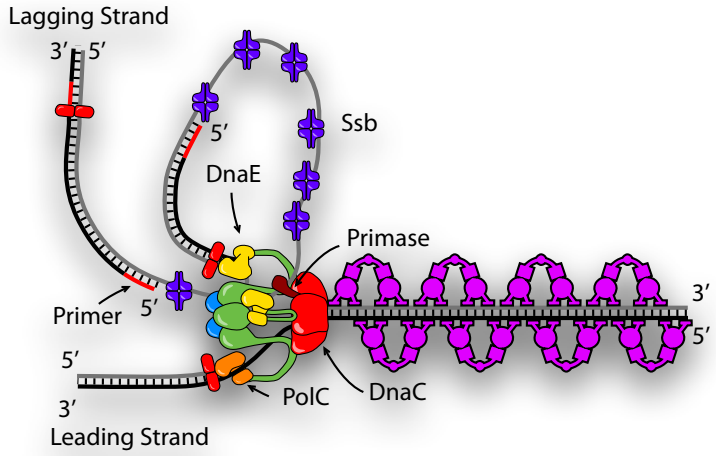


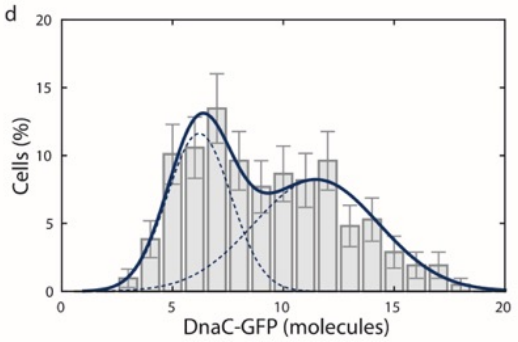
Visualization of replication in living cells w/ single-molecule microscopy

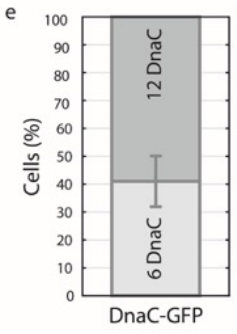
Paul Wiggins (UW Departments Physics, Bioengineering and Microbiology)



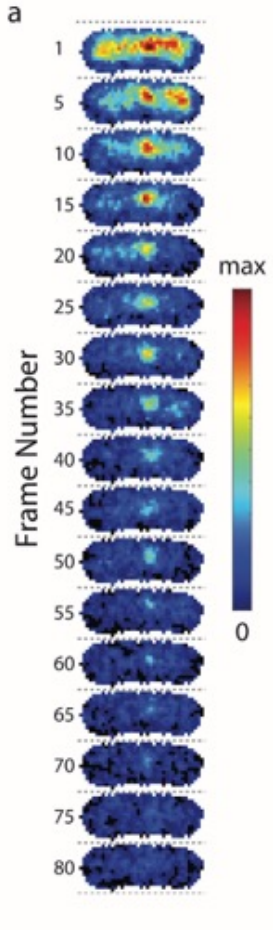
Active ⇋ Stalled?







Discovery: Replisome falls off multiple times per cell cycle!

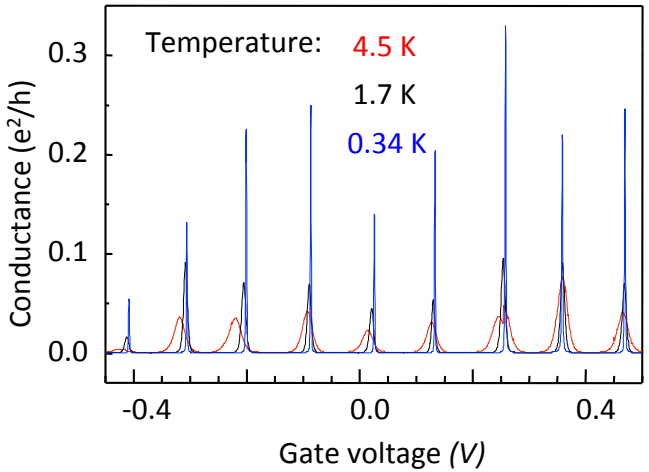


UNIVERSITY of WASHINGTON

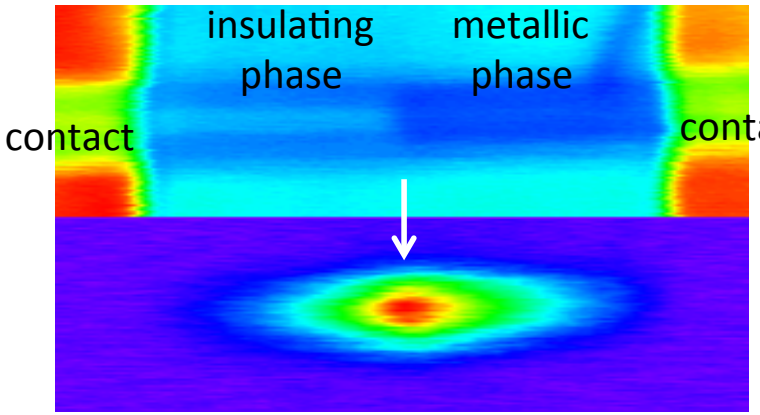
Nanodevice Physics Lab

B308
PI: David Cobden

Physics in 1D: quantum dots, Luttinger liquids, etc (in nanotubes and nanowires)

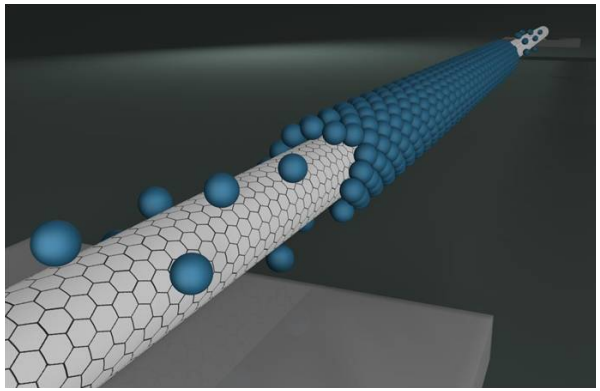


Correlated-electron solid-state phase transition (in VO_2 nanobeams)



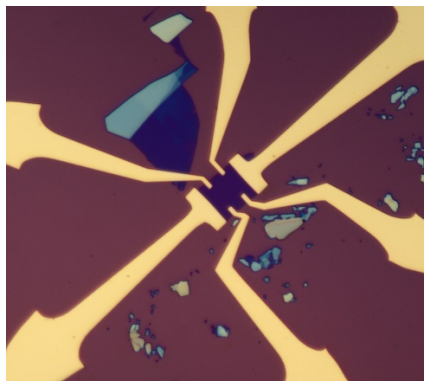
Scanning photocurrent map

Phase transitions on a cylinder

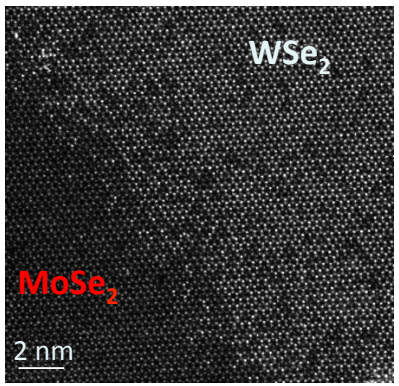


Nanotube nanoguitar

Physics in 2D: beyond graphene



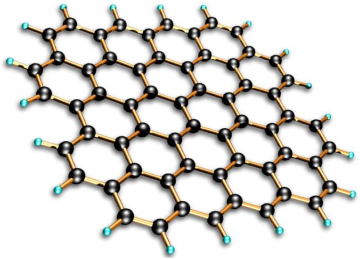
4-layer WTe_2 device (topological?)



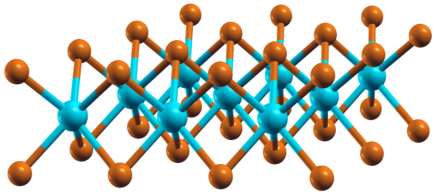
In-plane 2D semiconductor junction (TEM image)

Xu Group: Nanoscale Optoelectronics and Spintronics

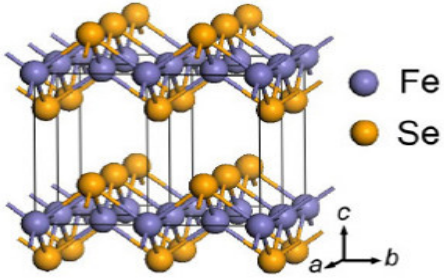
Graphene



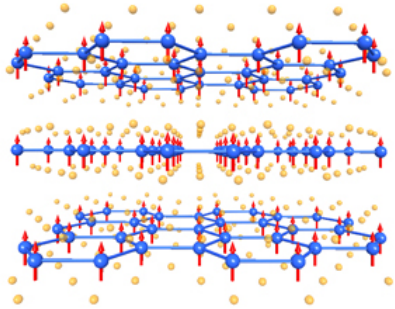
2D semiconductor

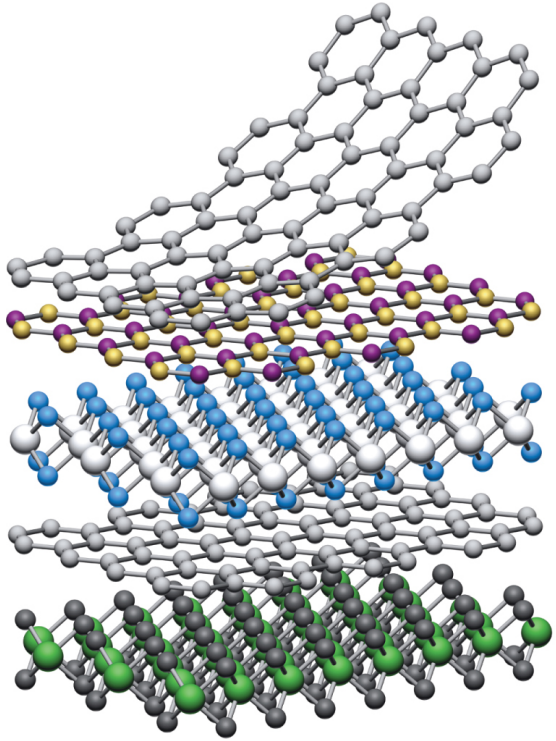


2D Superconductor



2d Magnets

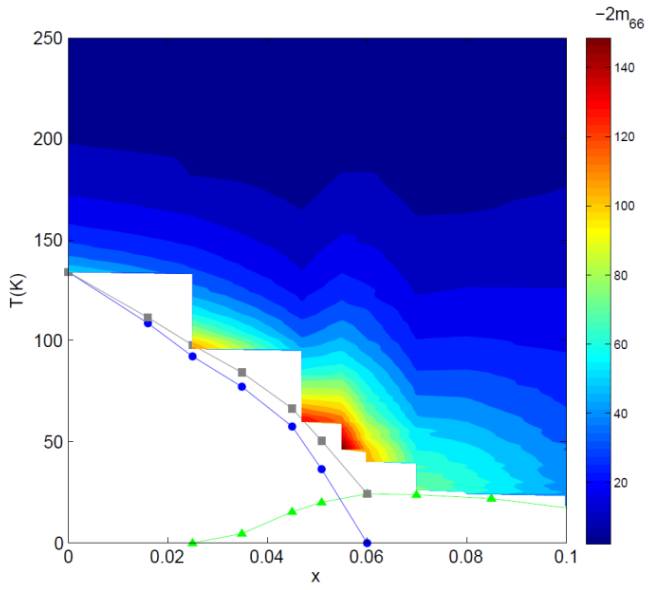




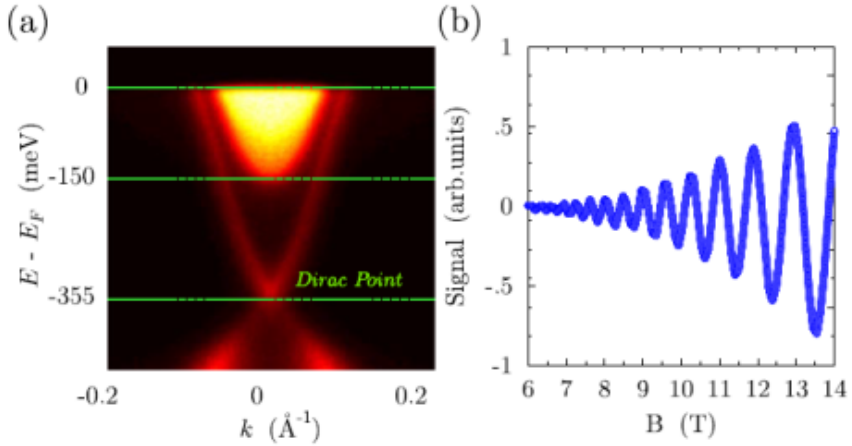
New tool box for technologies

Atomically thin
Transparent
Flexible
Optically Active
Broadband Absorption
Exposed States
Proximal Gates
High Mobility
Impermeable to gas
Large surface to volume ratio

Chu group: Quantum Materials



Iron Arsenides:
High temperature superconductivity resides near a Quantum Critical point



Topological Insulators:
Relativistic Fermions emerging from the topology of electronic structure.

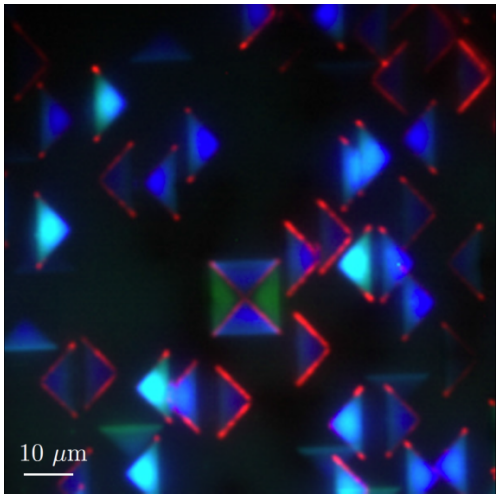
Iron Based Superconductor $Ba(Fe_{1-x}Co_x)_2As_2$

1. Make real **single crystals** (see pics on the left and right!)
2. Explore and characterize exotic quantum phases by thermodynamic, magnetic and transport measurements.
3. Design novel experiments (such as applying **strain**) to manipulate these quantum phases, and to further reveal the driving mechanism behind these complex behaviors.

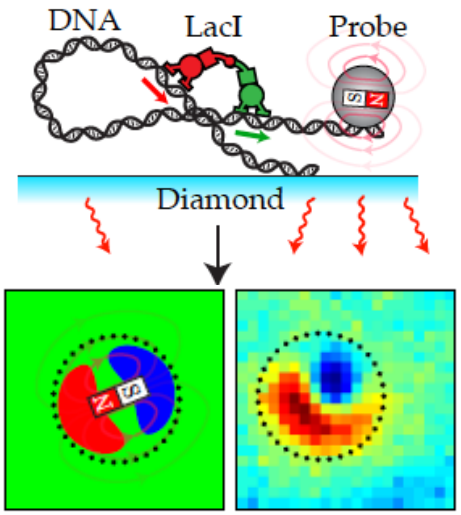
Topological Insulator Bi_2Te_3 Bi_2Se_3,

Fu Lab: Solid state quantum optics, spintronics, and sensing

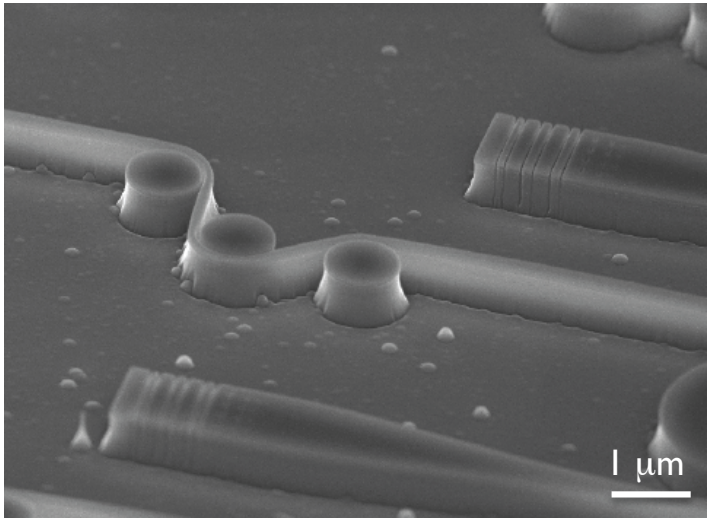
Confocal image of excitons confined to 2-dimensional defect in bulk GaAs



Diamond-based magnetic sensor for biophysics

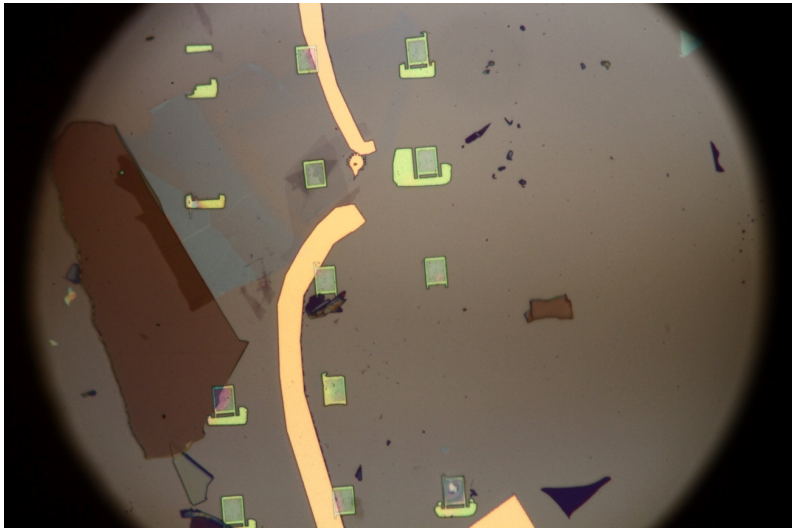


Optical waveguides and resonators in diamond for quantum optical networks

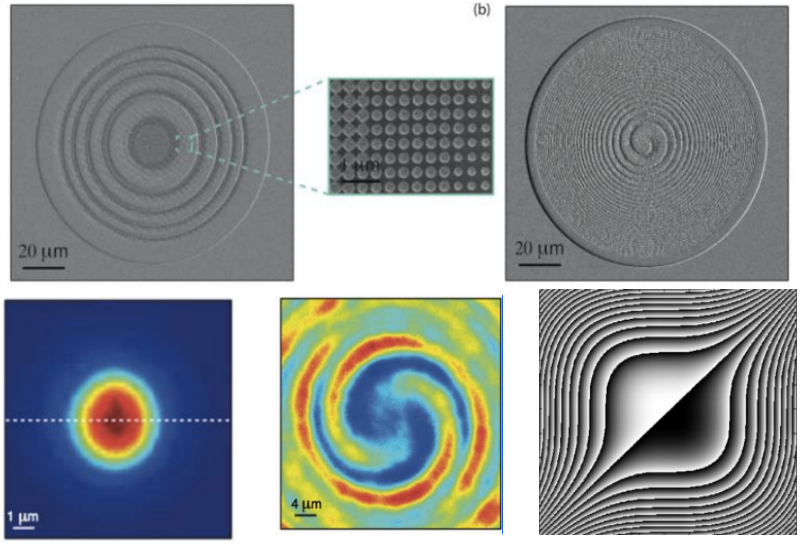


- "Atomic physics" with impurities in semiconductors and diamond.
- Impurity and photonics engineering for quantum information optical networks (fabricated at UW!)
- Room temperature, nanoscale magnetometry with impurities in diamond.

Majumdar Group: Nanophotonics

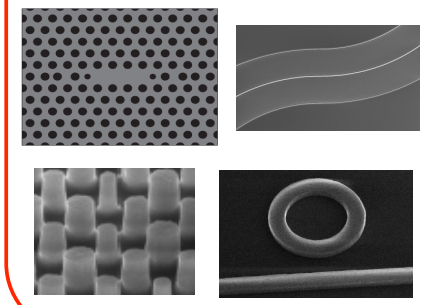


2D material-cavity integrated devices:
2D material LED integrated on top of the cavity. We are also looking at better modulator, detector and light-sources



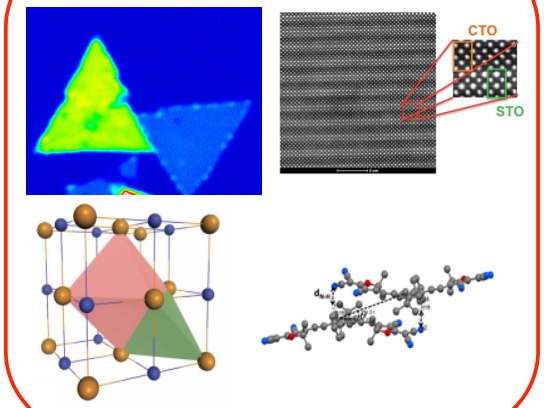
Nanoscale phase control of light by dielectric metasurface:
Build ultra-small optical elements using nanophotonic technologies to build implantable optical sensors..

Light



1. Understand the fundamental light-matter interaction in nanoscale.
2. Use this fundamental physical knowledge to build low-power, ultra-compact devices for optical communication, computing and sensing

Matter

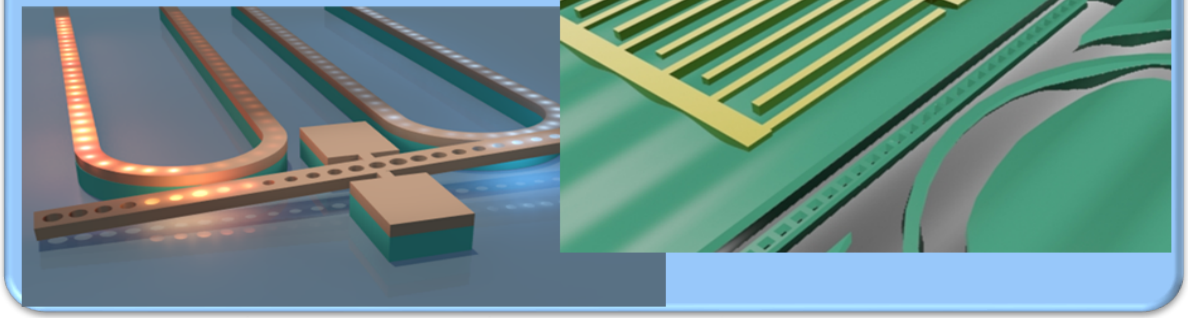


Li Group: Integrated Photonics

New Optical Physics

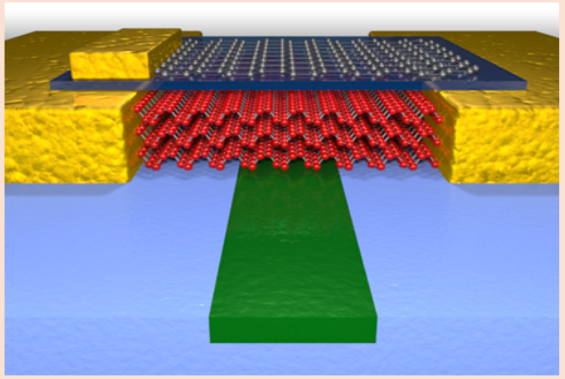
GHz Acousto-Optics

Cavity Optomechanics

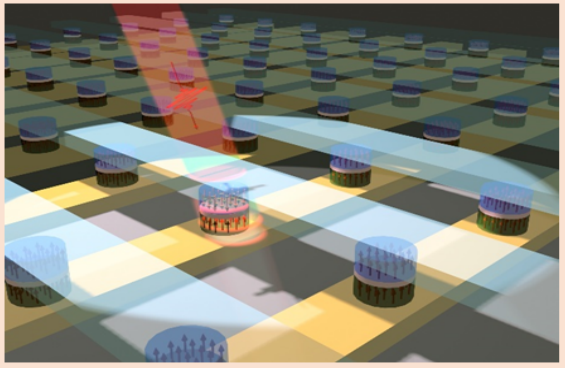


New Optical Materials

2D Material Optoelectronics

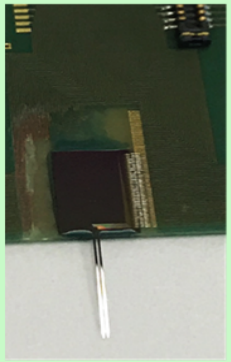


Optical Spintronics



New Applications

Neurophotonics



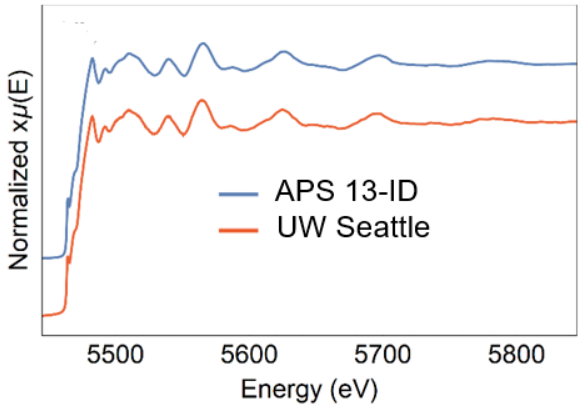
Photonic Sensors

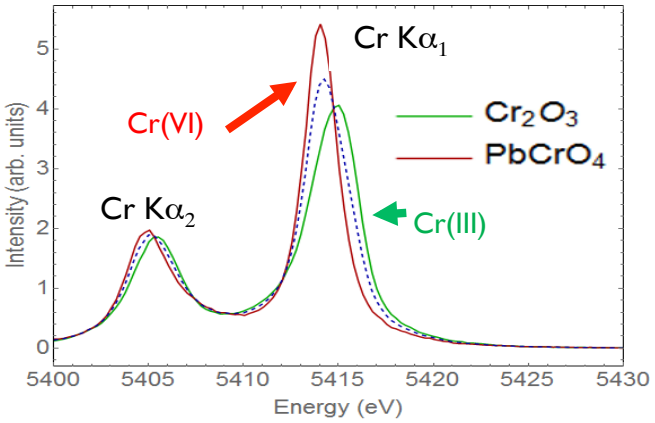
Group website: http://light.ece.uw.edu

Seidler group: Advanced X-ray Spectroscopy Lab (PAB228)

Bringing new x-ray technology to public health, new materials discovery, and astrophysical matter in extreme conditions.

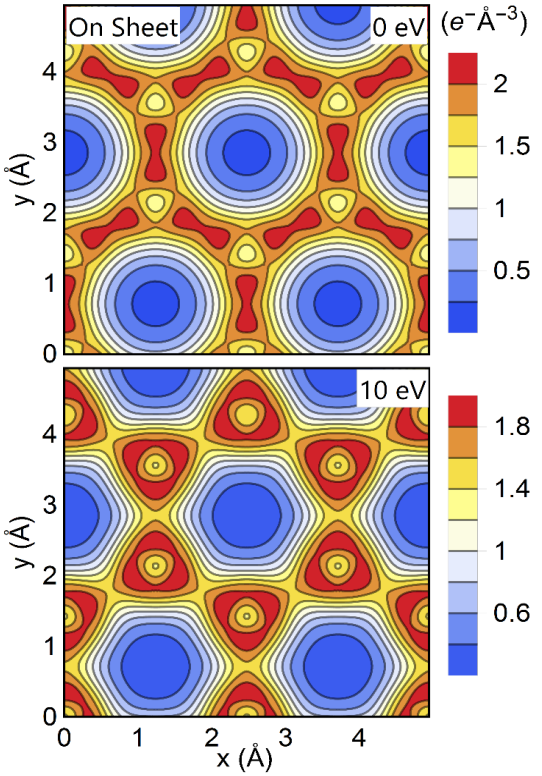
World-class spectroscopy without a synchrotron!





High resolution x-ray spectroscopy to identify toxic Cr(VI) in consumer products

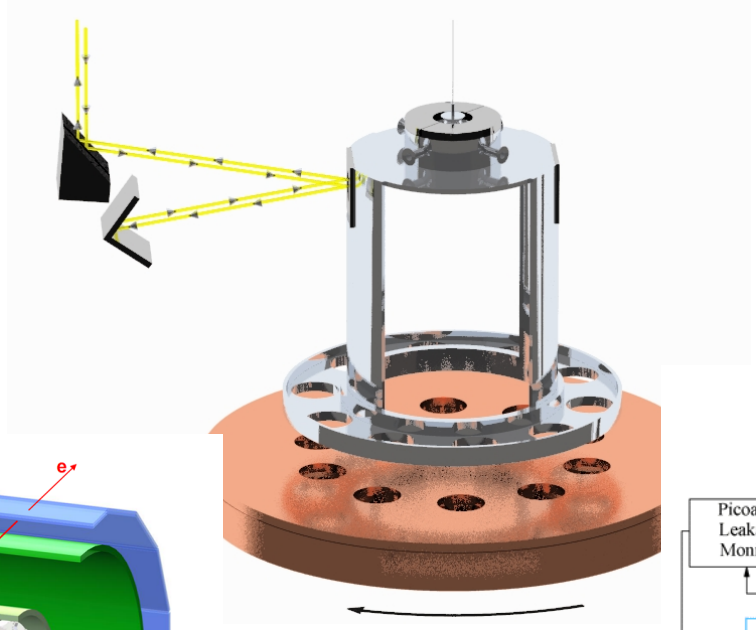
Spectrometer design for use in labs, synchrotrons, and free electron laser

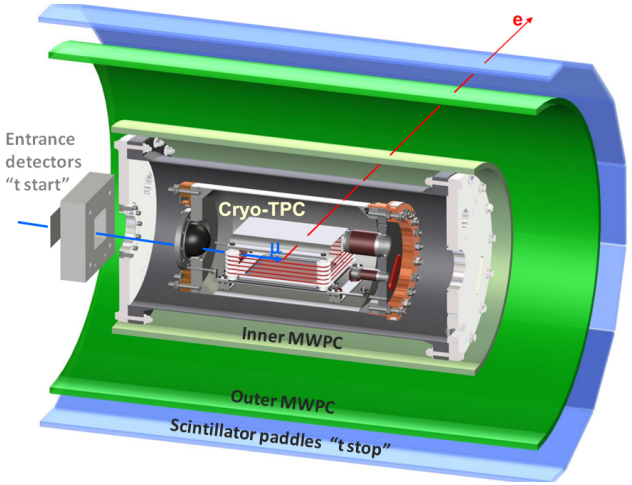


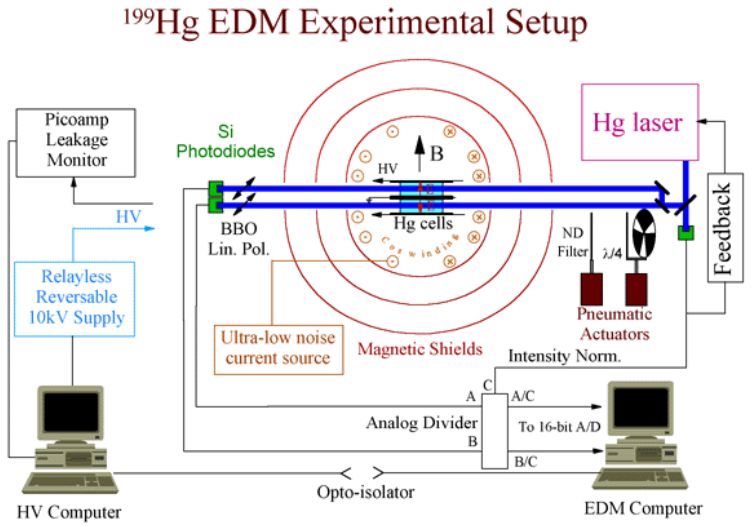
Electronic structure in dense plasma physics

Precision Measurements

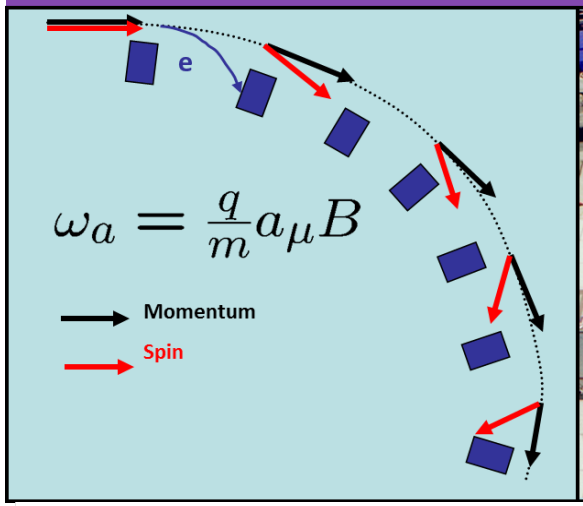
- Tests of gravity
- Measurements of fundamental constants
- Search for violations of fundamental symmetries

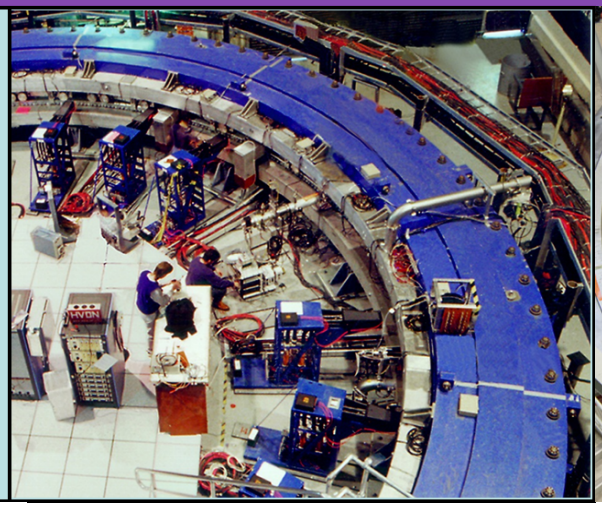


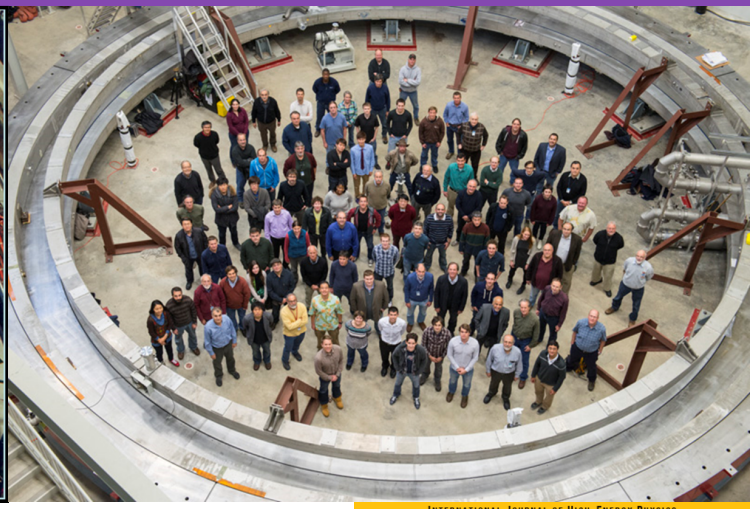


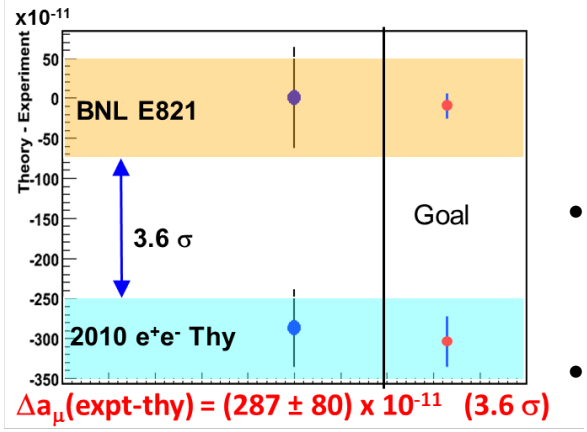


Precision Muon Physics









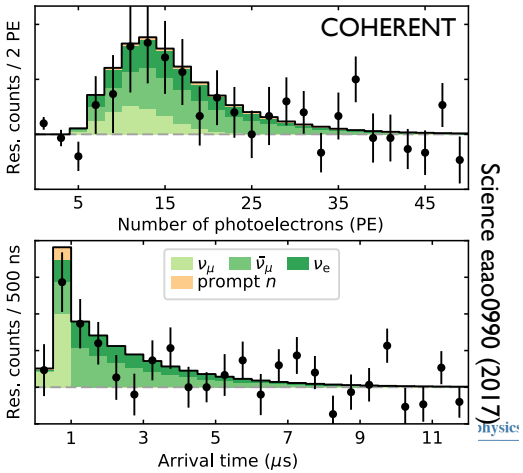
- **UW Group is largest University Group** in experiment (5 faculty/sr. scientists; 2 pdra, 4 gs, 4 ugs
- **UW Responsibilities**
  - Detectors, electronics, ω_a
  - NMR Probes, B field
  - Muon storage simulation
  - Data Analysis
  - Co-Spokesperson of experiment

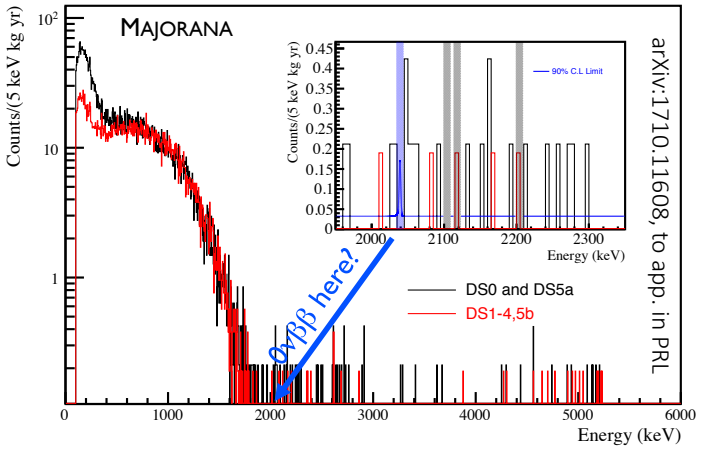
CENPA
Center for Experimental Nuclear Physics and Astrophysics

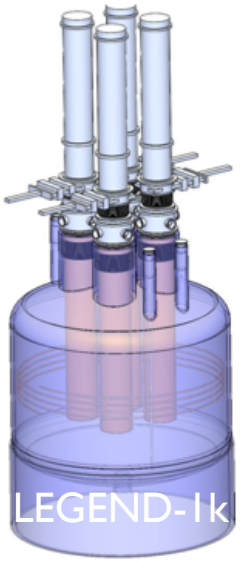
W

Detwiler Group: Neutrino Physics

- **Searching for Matter Creation**
  - **Nature of the neutrino: Majorana?**
  - **Implications for matter-antimatter asymmetry of the universe**
  - **Connection to GUT-scale physics**
- **MAJORANA and LEGEND**
  - **Searches for "neutrinoless double-beta decay" with Ge detectors**
  - **MAJORANA (~30 kg) currently running in SD, analysis in progress**
  - **LEGEND (~200 kg → ~1 ton) R&D underway, start in ~2021**
- **Other neutrino physics: COHERENT neutrino scattering measurement**
  - **Deploying a 1-ton array of NaI detectors at the SNS.**
  - **Sensitive to new interactions of neutrinos with matter and nuclear physics relevant to 0νββ searches.**
- **Also: KamLAND / KamLAND-Zen, and radioactivity monitoring**

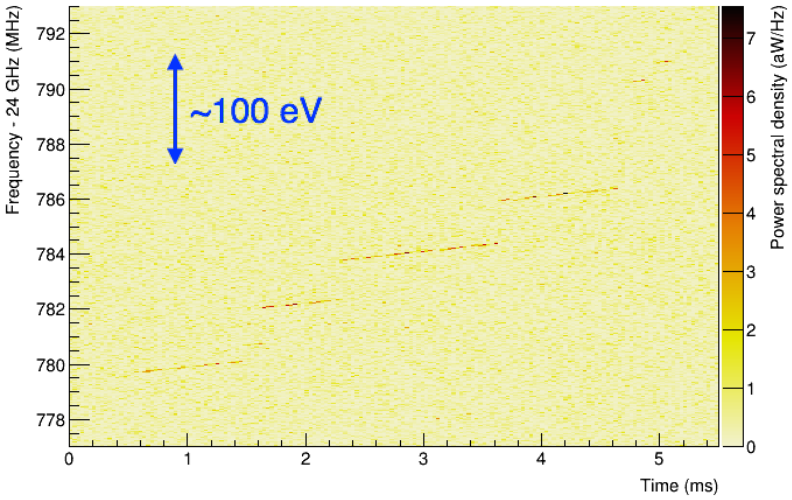


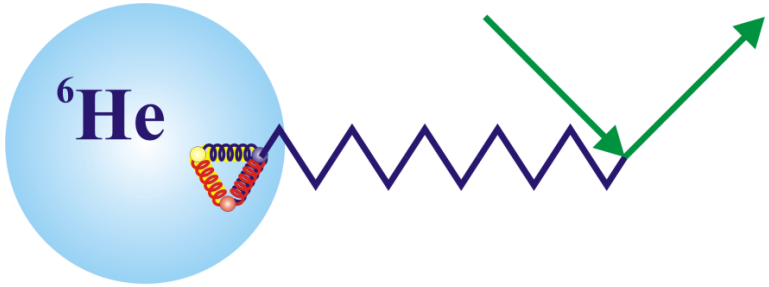




Neutrino Physics

- Absolute mass of the neutrino
  - Nonzero but not yet measured
  - Important input for cosmology
  - Best method: ^{3}H beta decay kinematics
- KATRIN experiment in Germany
  - World's largest ultra high vacuum vessel
  - Lots of commissioning data to analyze. **Physics run started in 2018**
  - Contact: Doe, Enomoto, Robertson
- Project 8
  - New method! Measure electron *E* via cyclotron *f* in a B field
  - Proof-of-principle demonstrated! Many possible applications.
  - **First ^{3}H measurements last October.**
  - Contact: Robertson, Rybka



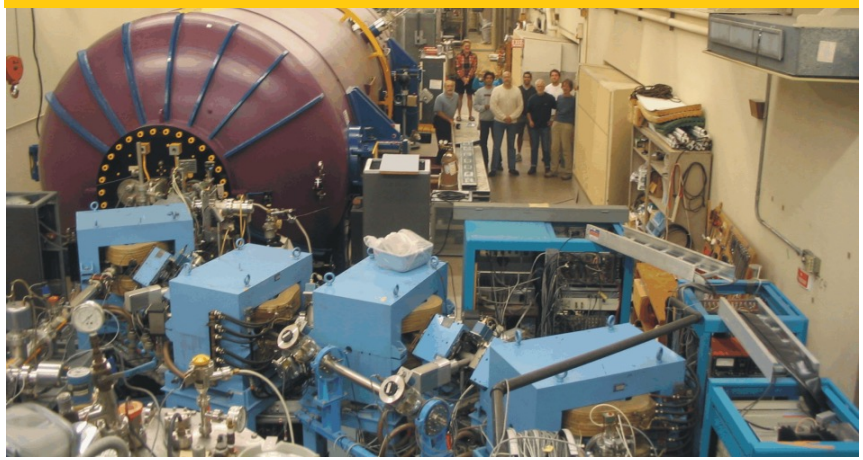


Fundamental Interactions

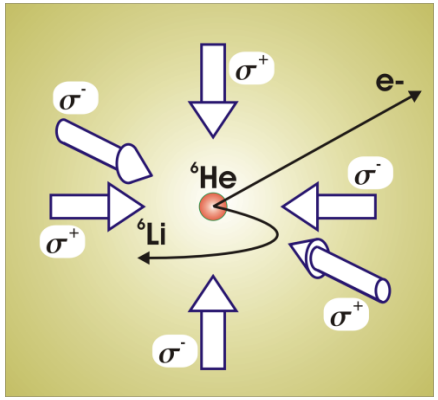
Experimental Nuclear Physics: Searches for Tensor Currents in Nuclear β decays

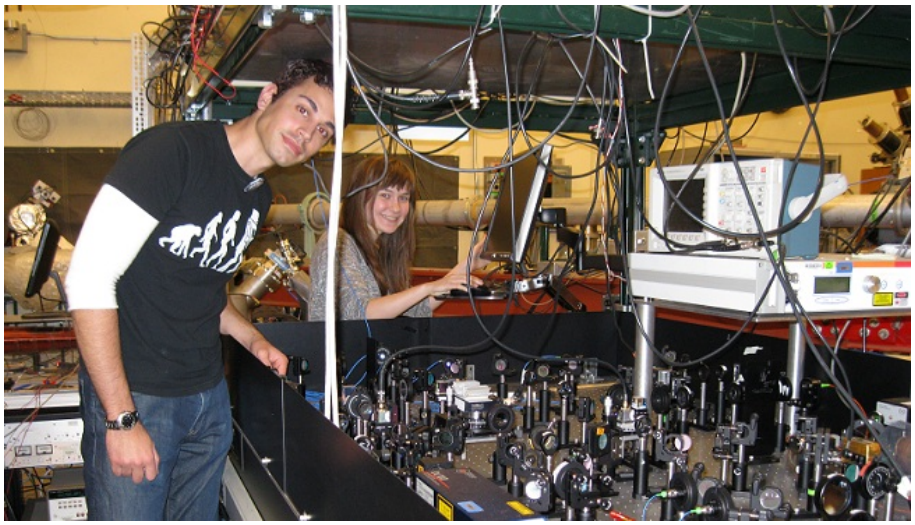
We search for new physics (tensor currents) predicted by models that go beyond the Standard Model.

Intense production of ^{6}He at CENPA allows for high-precision searches.



Laser trapping of ^{6}He allows unprecedented sensitivity





Particle Physics @ the LHC

The Higgs boson discovered in 2012!

Nobel Prize in 2013

Last missing fundamental particle of Standard Model (SM)
Now it is our tool for new discoveries!

Still many unresolved issues driving the field

- Is there more than one Higgs?
  - **Prof. A. Goussiou** is leading searches for Beyond the Standard Model Higgs
- What is Dark Matter?
  - **Prof. S.-C. Hsu** is leading the search for Dark Matter produced in association with the Higgs.
- Are there Exotic Decays of the Higgs?
  - **Prof. H. Lubatti and Prof. G. Watts** are leading searches for exotic decays of the Higgs to long lived particles.

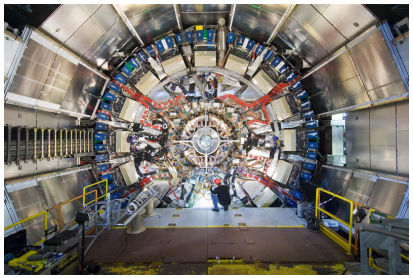
Run 2 has 4-times more data than Run1!

❑ Increased physics reach for all new physics searches!

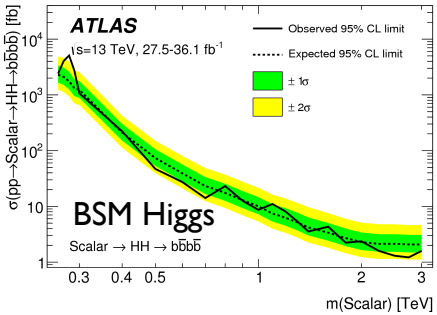
HL-LHC moving forward

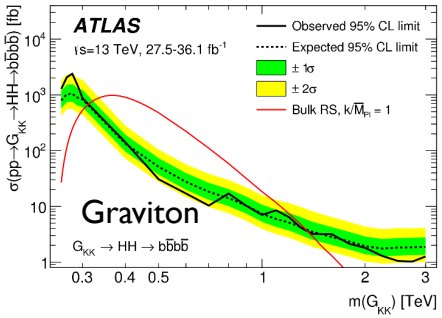
→ Inner Tracker Pixel upgrade projects.

Timing ideal for new graduate students



- Search for Higgs beyond the SM (BSM)
  - UW group led SUSY Higgs search at ATLAS in Run 1: H/A → ττ
  - and search for general 2 Higgs Doublet Models: A → Zh with h→ττ
  - Now search for di-Higgs production – could be evidence for BSM Higgs or Graviton in Extra Dimensions: X → hh → bbbb





- J. Schaarschmidt (postdoc) leading the BSM Higgs group of ATLAS
- A. Goussiou leading the BSM Higgs group of the LHC Higgs ATLAS+CMS+Theory effort

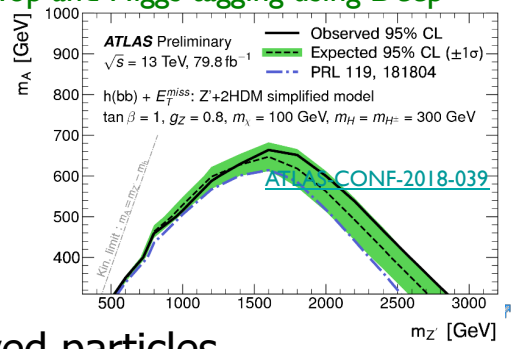
A. Goussiou, J. Schaarschmidt

Particle Physics @ the LHC

- BSM Search with Deep Learning
  - – UW group led search of dark matter production in association with Higgs, and dark matter mediator A or Z'
  - – Developing boosted W, Top and Higgs tagging using Deep Neural Network

Meehan (postdoc) leads ATLAS Jet & Dark Matter group

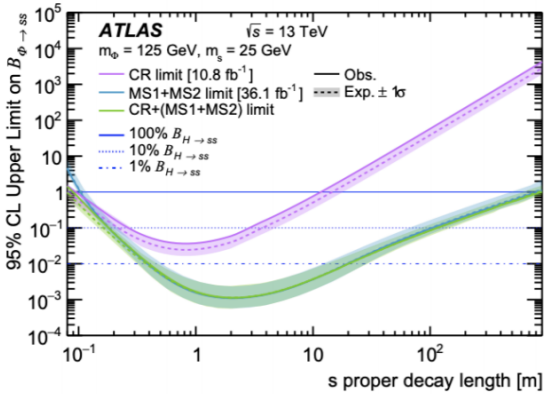
S.-C. Hsu, S. Meehan



- Search for long-lived particles
  - – Higgs (scalar) Portals to a hidden sector
  - – Mixing of Higgs bosons with a hidden sector Higgs (scalar) boson which decays to 2 long-lived scalars that decay to a pair of heavy quarks
  - – This is Beyond the Standard Model: any signal is a discovery

Current limits vs. lifetime set by our UW group

H. Lubatti, G. Watts, C. Alpigiani, E. Torro



- Lifetime Frontier

The ATLAS detector is not sensitive to ultra long lived particles due to backgrounds

MATHUSLA

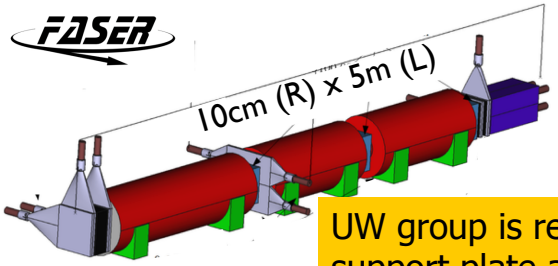
Proposed a ~10^4 m^2 detector on surface above LHC pp collision point to search for ultra long lived particles (up to the big-bang nucleosynthesis limit, 0.1 s!)

Built a test detector and took data in 2018!

Proposed by UW group – now analyzing 2018 data

FASER

Proposed a detector situated 480m along the line-of-sight of the proton collisions in front of the ATLAS to search for light, weakly-coupled particles

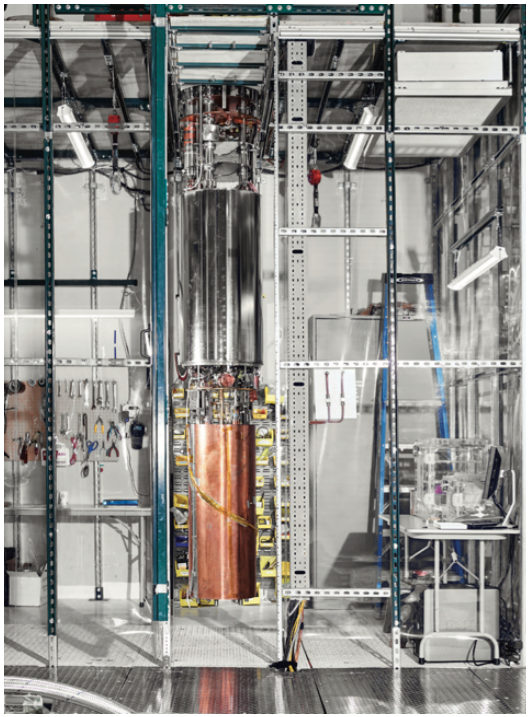


UW group is responsible for support plate and tracking.

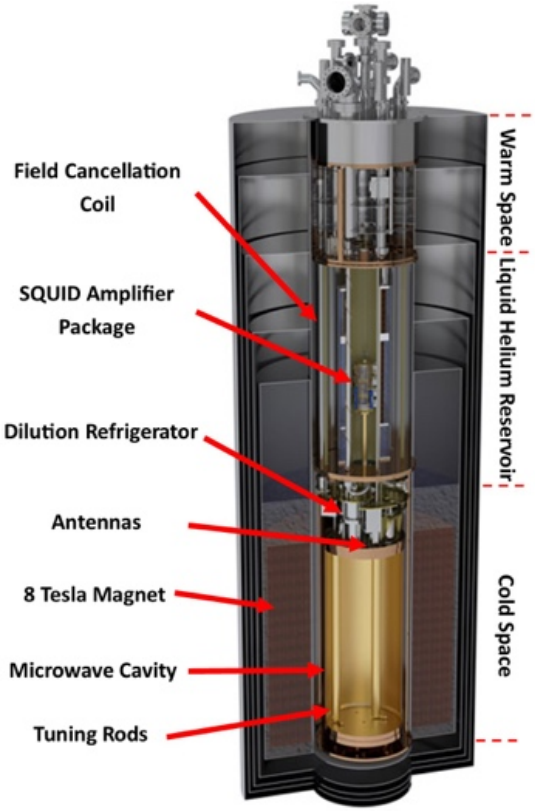
Axion Dark Matter Experiment (ADMX)

- The Axion is a well-motivated dark matter candidate.
- ADMX (sited at UW) uses state-of-the-art quantum sensing to detect the yoctowatts (10^{-24}) of power from axion dark matter conversion to photons.

Recent ADMX Collaboration Meeting



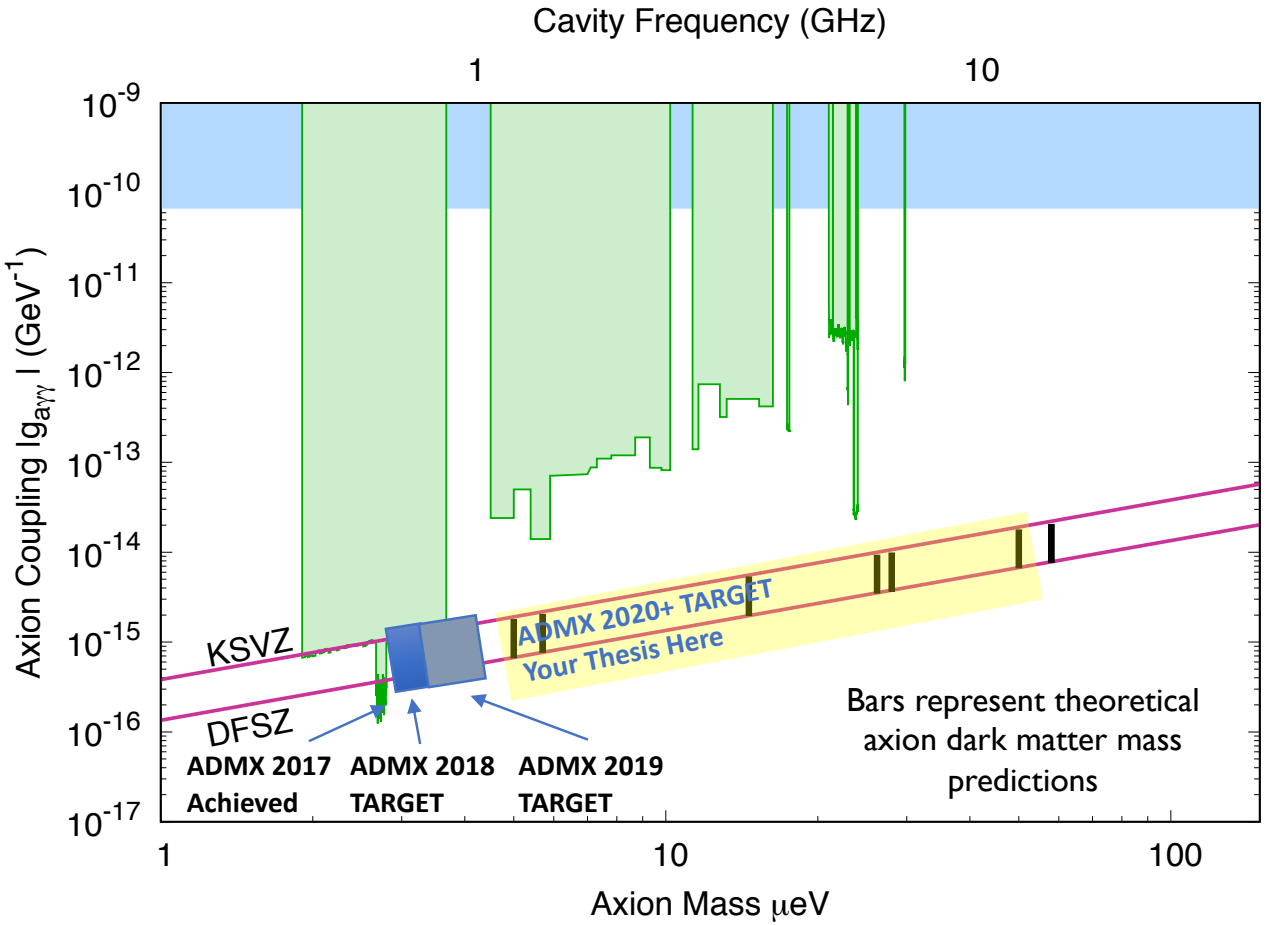
ADMX insert during assembly
(Scientific American, Jan. 2018)



ADMX cutaway view

ADMX Results and Prospects

- Over the next 5 years we are taking data sensitive to the most likely dark matter axion parameters: You could be a part of of the great discovery!

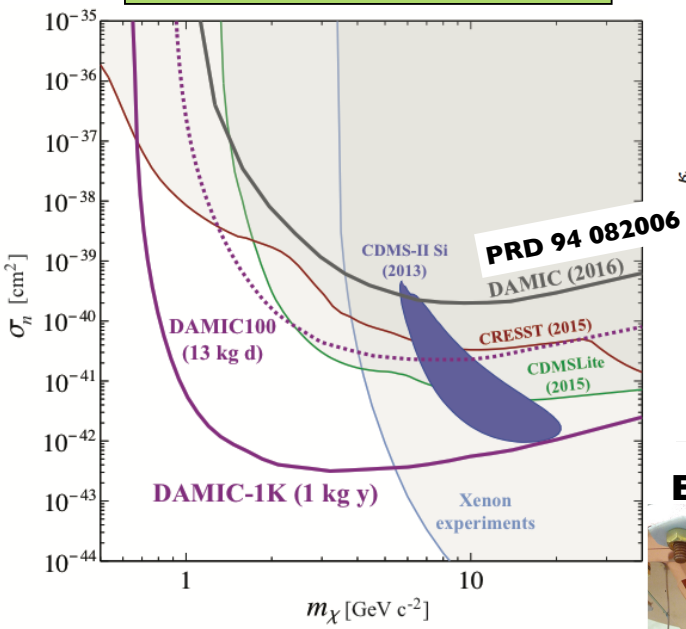


You can also develop the skills in microwave electronics and the operation of quantum sensors that are in high demand in both research and industry

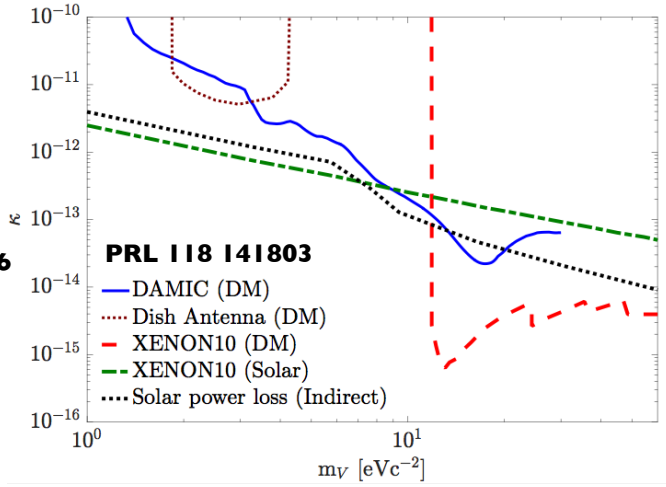
Chavarria Gordienko lab: Imaging detectors for astroparticle and nuclear physics

DAMIC at SNOLAB: CCDs to search for dark matter

Low-mass WIMP search



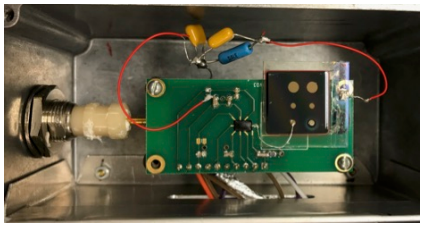
Hidden photon search



Detector R&D!

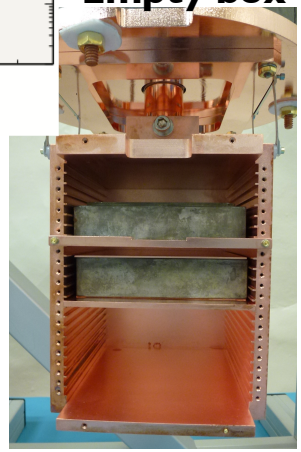
^{82}Se imagers for neutrinoless ββ decay

JINST 12 P03022

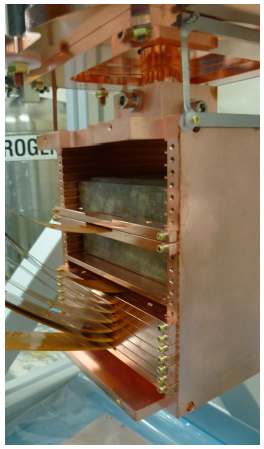


DAMIC-M

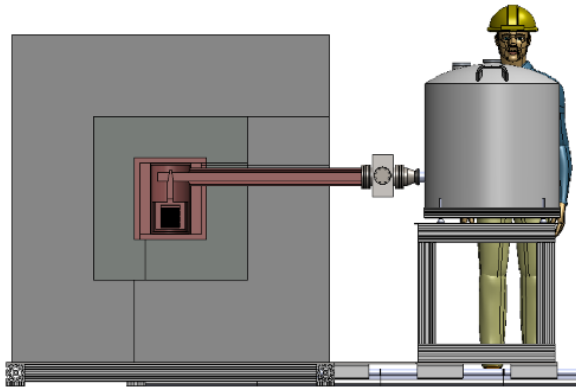
Empty box



With CCDs



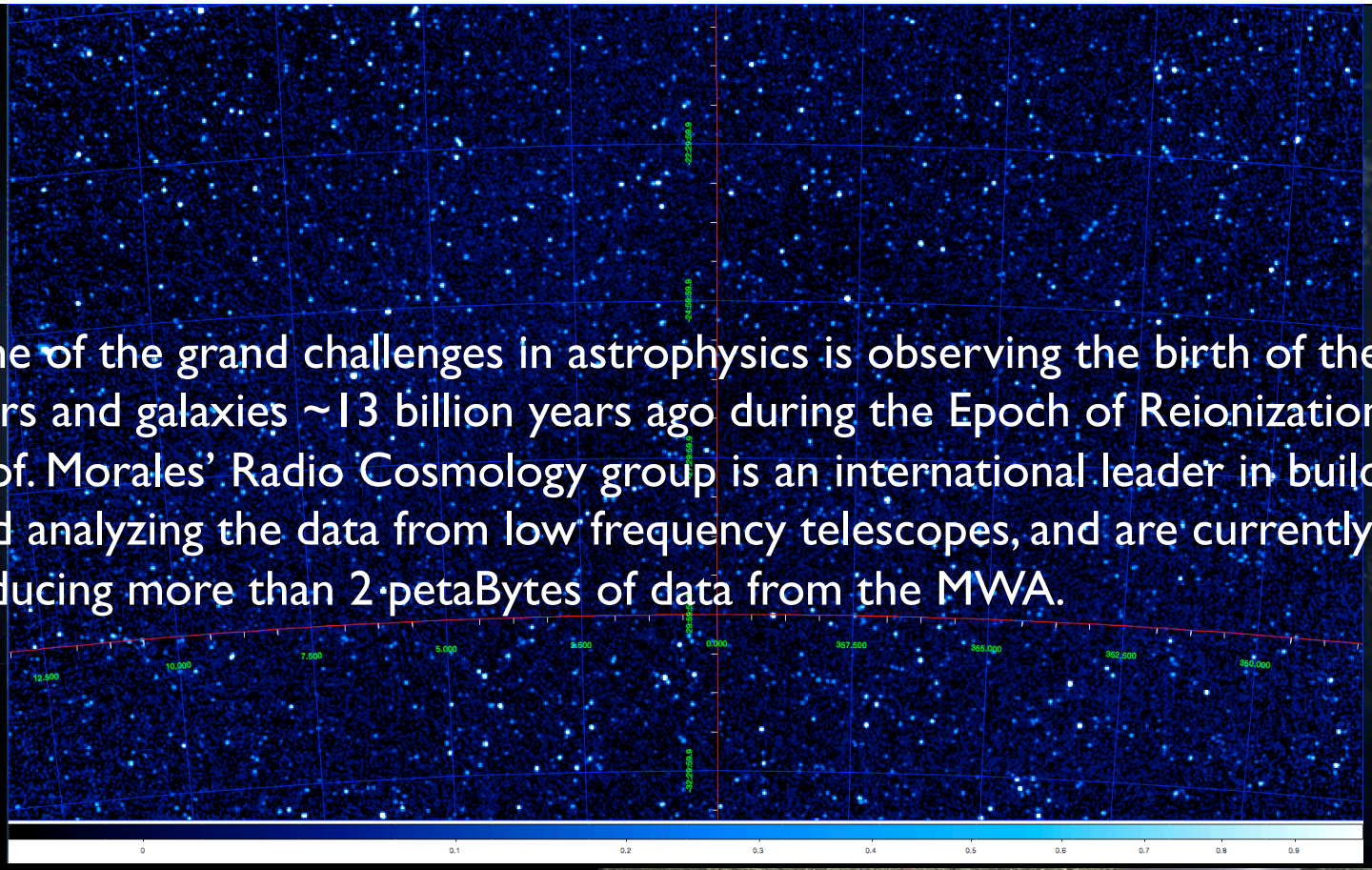
50 CCDs (1 kg target) to be deployed underground in Modane.

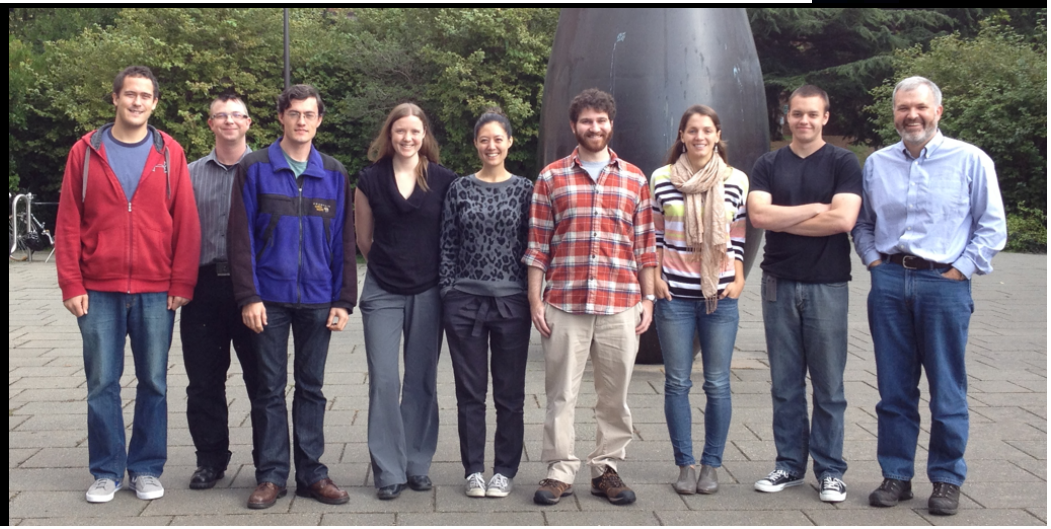


DAMIC SNOLAB taking data!

Installation in Jan 2017
7 CCDs = 40 g at SNOLAB
Ongoing analysis of 13 kg-d!

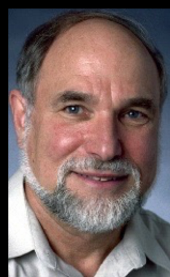
One of the grand challenges in astrophysics is observing the birth of the first stars and galaxies ~13 billion years ago during the Epoch of Reionization. Prof. Morales' Radio Cosmology group is an international leader in building and analyzing the data from low frequency telescopes, and are currently reducing more than 2 petaBytes of data from the MWA.





Morales Radio Cosmology group. Looking for the first stars and galaxies as they turn on ~13 billion years ago.

Dark Universe Science Center (DUSC)



20+ Faculty, interests covering dark matter, dark energy, structure formation

Broad Research areas…

- Astrophysics/Cosmology
- Atomic Physics
- Biological Physics
- Collider/Particle Physics
- Condensed Matter
- Energy Sciences
- Gravitational Physics
- Nanoscale Physics
- Neutrino Physics
- Nuclear
- Precision Measurement
- Physics Education
- Quantum Information