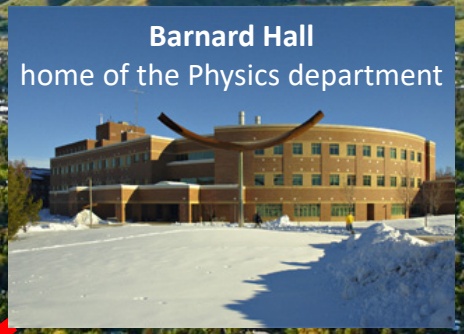
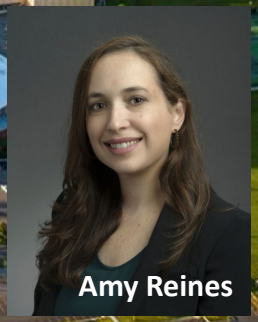
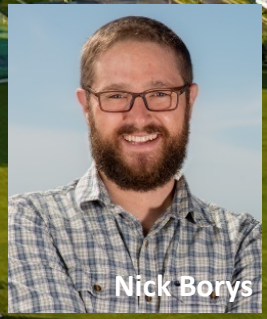
Welcome to Montana State University



Important details

- **Application deadline:** **January 10, 2021**
- **Application fee:** **waived** for participants of this recruiting fair!
- **GREs:** general and subject are **not** required
- **Recommendation letters**: **three** letters required
- More information: http://physics.montana.edu
- Questions: gradphysics@montana.edu





MSU is home to vibrant research & academic communities

2020 Enrollment

- Undergraduates: 14,817
- Graduate students: 1,949
- Total: 16,766

2020 Research Expenditures

$167 Million

Carnegie Classification

R1: very high research activity

- One of only 131 universities in the US.
- Only R1 university in MT, ID, WY, ND, & SD.

Proposal Activity for 2019

1,100 proposals submitted

$485.9 million in awarded grants

Physics Courses

foundational required

423	Electromagnetism I	461	Quantum Mechanics I
425	Electromagnetism II	462	Quantum Mechanics II
427	Advanced Optics	441	Solid State Physics
435	Astrophysics	442	Novel materials for Physics/Engineering
437	Laser Applications	475	Observational Astronomy
501	Advanced Classical Mechanics	531	Nonlinear Optics
506	Quantum Mechanics I	535	Statistical Mechanics
507	Quantum Mechanics II	544	Condensed Matter Physics I
516	Experimental Physics	545	Condensed Matter Physics II
519	Electromagnetic Theory I	555	Quantum Field Theory
520	Electromagnetic Theory II	560	Astrophysics
523	General Relativity I	565	Astrophysical Plasma Physics
524	General Relativity II	566	Mathematical Physics I
525	Current Topics in General Relativity	567	Mathematical Physics II

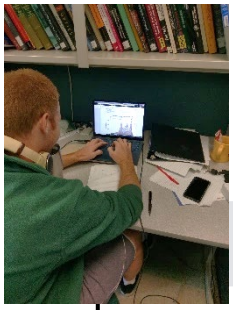
Research Seminars

Teaching	High Energy Astrophysics	Condensed Matter Journal Club
Solid State	Heliophysics Journal Club	Optics Fundamentals
Relativity, Astronomy & Space Physics	Spectrum Lab	Quantum Optics

Additional Graduate Courses in Partner Programs

Chemistry, Materials Science, Electrical Engineering, Computer Science, Math, Statistics, …

Approximate timeline for graduate studies



Time to completion: 5-6 years

Courses

Research

Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6

Year 1:
- Complete first half of core coursework
- Complete any needed foundational classes
- Find a **research** group
- Comprehensive exam

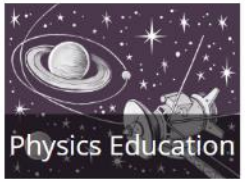
Year 2:
- Complete majority of remaining courses
- Begin thesis-related **research**
- If needed, second comprehensive exam
- Complete oral part of the comprehensive exam

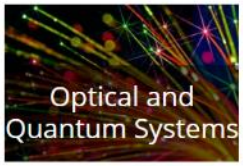
Year 3:
- Complete few remaining courses
- **Research, research, research**!

Years 4-6:
- **Research, research, research**!
- Write, write, write!
- Papers, papers, papers!
- Conference presentations.
- Find job!
- PhD defense

The Physics department is very active in research

Annual research expenditures: $5-$6 Million





Faculty by expertise

- 8 faculty members in condensed matter, optics, and quantum systems.
- 5 faculty members in astrophysics and gravity (+1 future hire).
- 4 faculty members in solar and space physics (+1 future hire).
- 2 faculty members in physics education research.

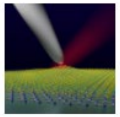
Currently 69 graduate students actively working in all four areas.

Recent News

Nobel announcement inspires black hole researchers
October 9, 2020

NASA grant will aid search for black hole origin
September 25, 2020

MSU nanotech facility wins $3 million grant
September 1, 2020



Nanobubbles may hold a key to quantum technologies
July 15, 2020

MSU astrophysicists study mystery object
June 23, 2020

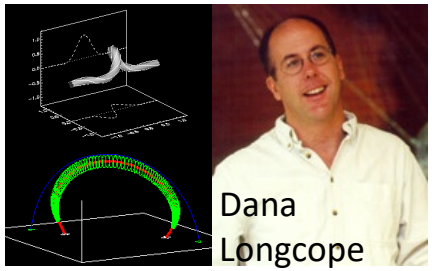
Many opportunities for research in solar and space physics

Extreme UV observations of solar phenomena

Rocket-based instrumentation for solar observations

http://solar.physics.montana.edu/kankel

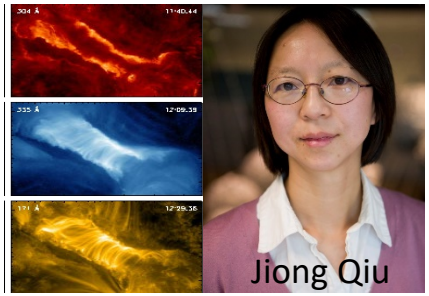
Magnetohydrodynamics & solar physics



Magnetic phenomena and fields on the sun

http://solar.physics.montana.edu/dana

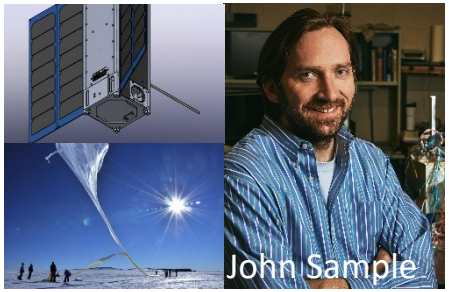
Solar astrophysics



Magnetic reconnection and instabilities on the sun

https://physics.montana.edu/directory/faculty/1524495/jiong-qiu

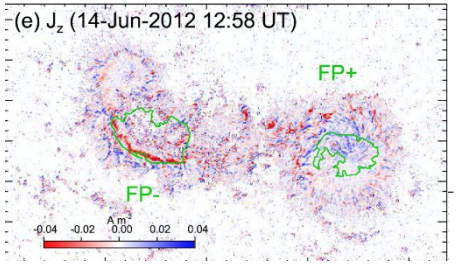
Near-earth high-energy particle phenomena

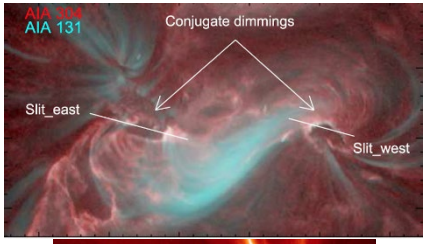


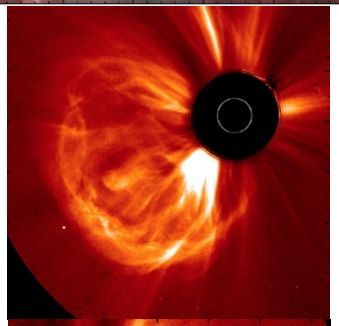
Satellite-based high-energy particle observations

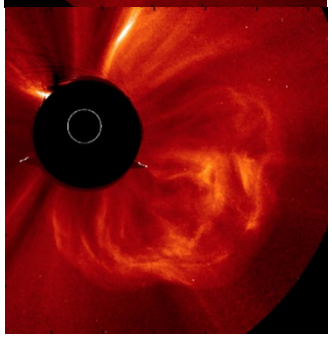
https://physics.montana.edu/directory/faculty/1987181/john-sample

Research in Solar and Space Physics





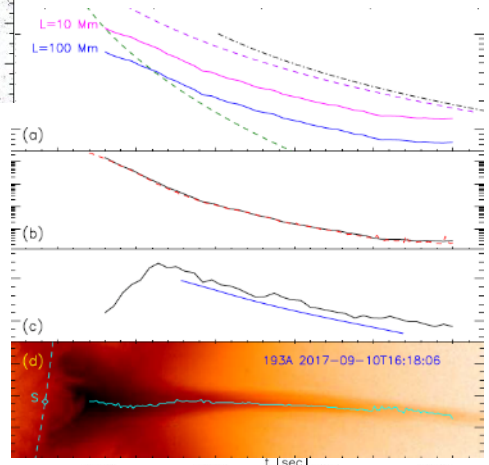


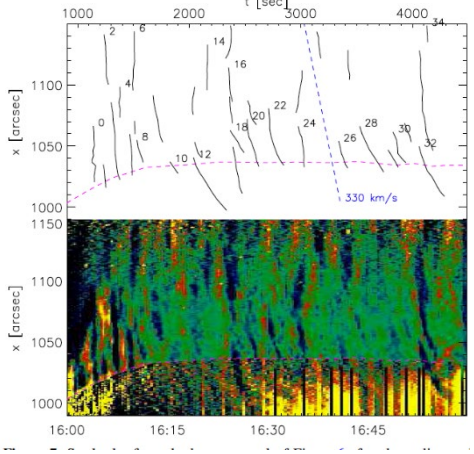


Wang et al. 2019

Observing initiation and propagation of coronal mass ejections

Prof. Jiong Qiu

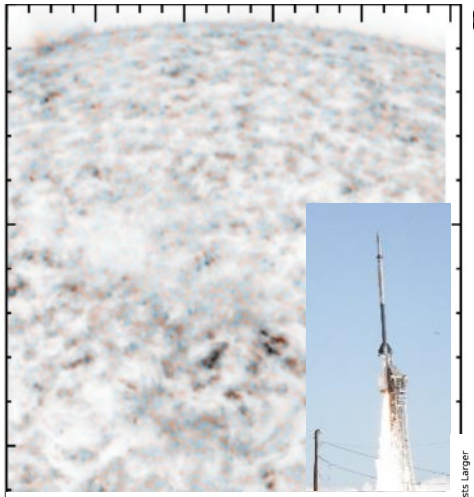


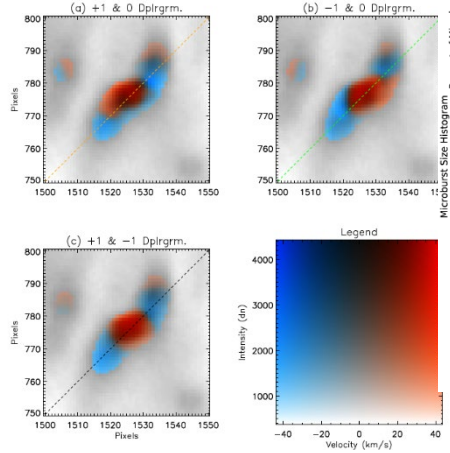


John Unverferth: PhD 2020

Observing and modeling creation and evolution of hot plasma in solar flares

Prof. Dana Longcope

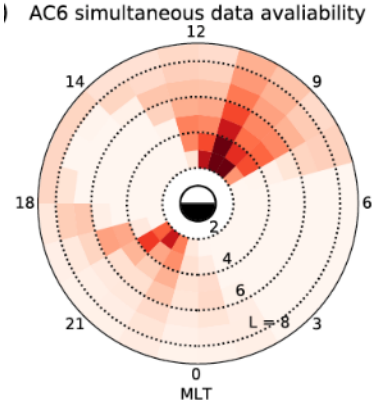


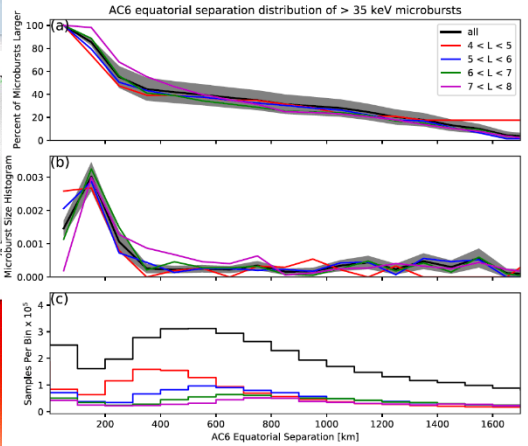


Hans Courier: PhD 2020

``Small'' explosions observed using rocket-borne slitless spectrograph

Prof. Charles Kankelborg

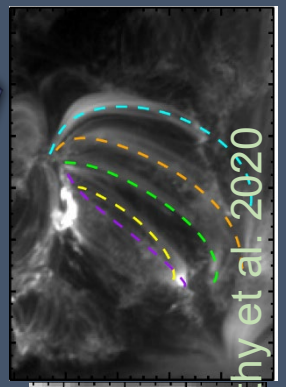




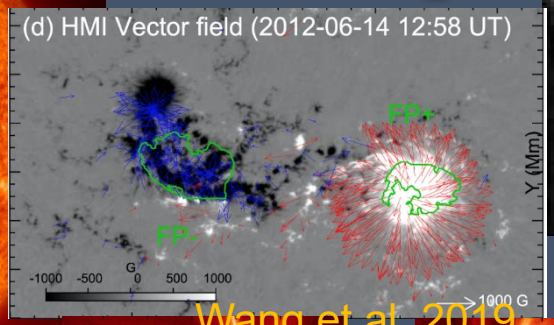
Mike Shumko: PhD 2019

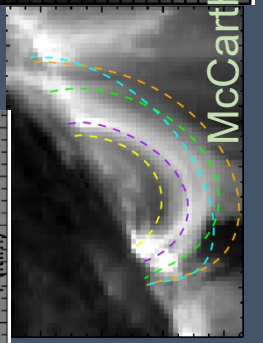
Electron microbursts in Earth's radiation belt, observed by nano-satellites

Prof. John Sample

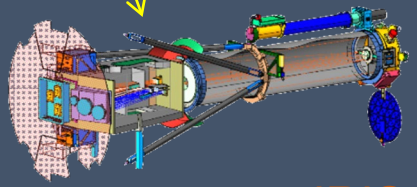


Commanded by students (& faculty) from MSU (264 Barnard Hall)

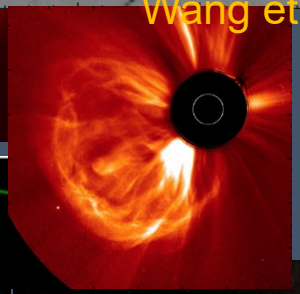


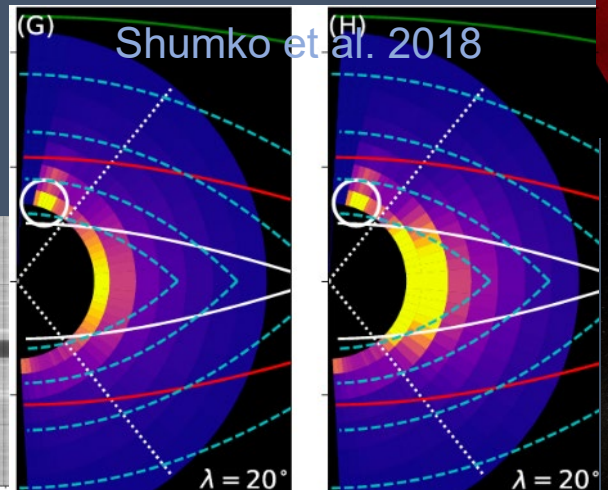


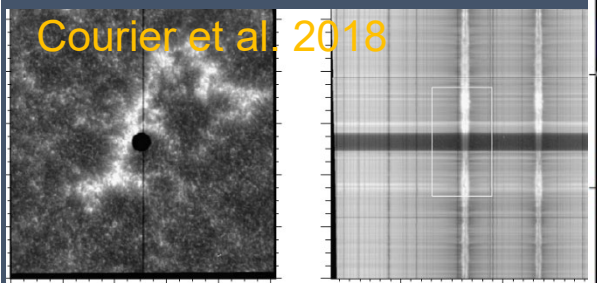
Wang et al. 2019



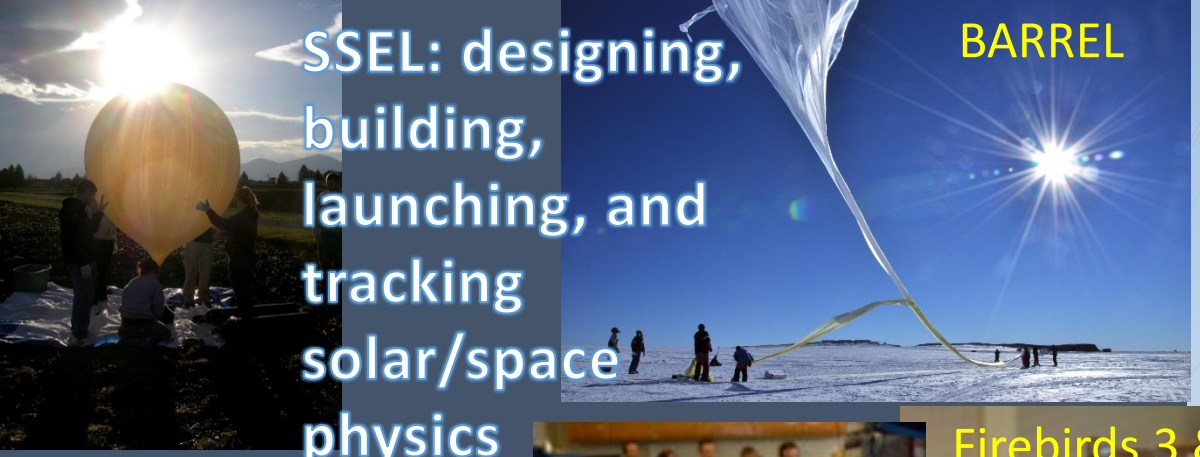
IRIS
(Kankelborg,Co-I)

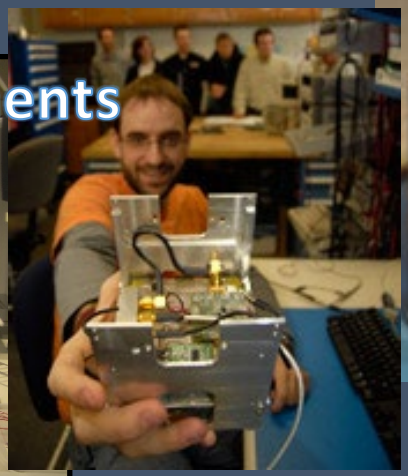


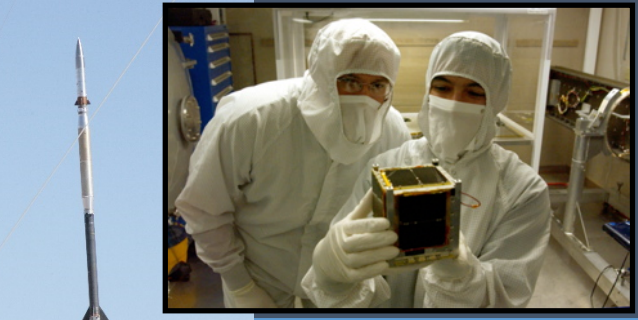


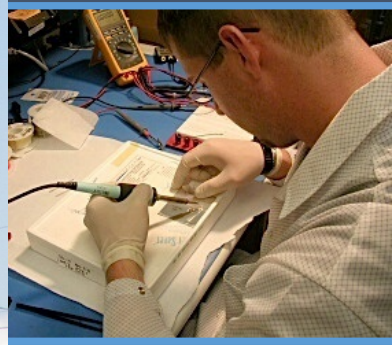


SSEL: designing, building, launching, and tracking solar/space physics experiments





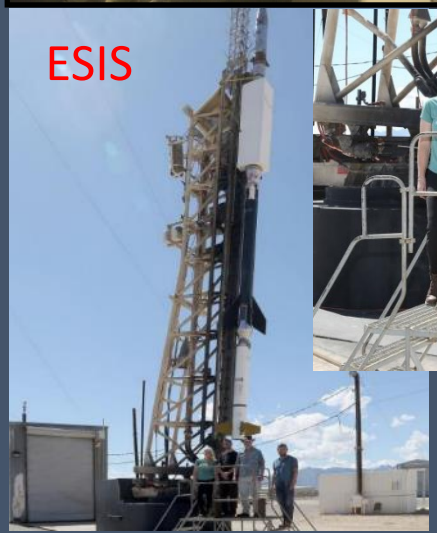




MOSES

Some missions currently under development:

- **REAL**: cube-sat; rad. belt e⁻s
- **BOOMS**: high-alt. balloon payload; rad. belt e⁻s
- **IT-SPINS**: cube-sat; ionospheric imaging
- **FURST**: rocket payload; FUV solar spectrograph

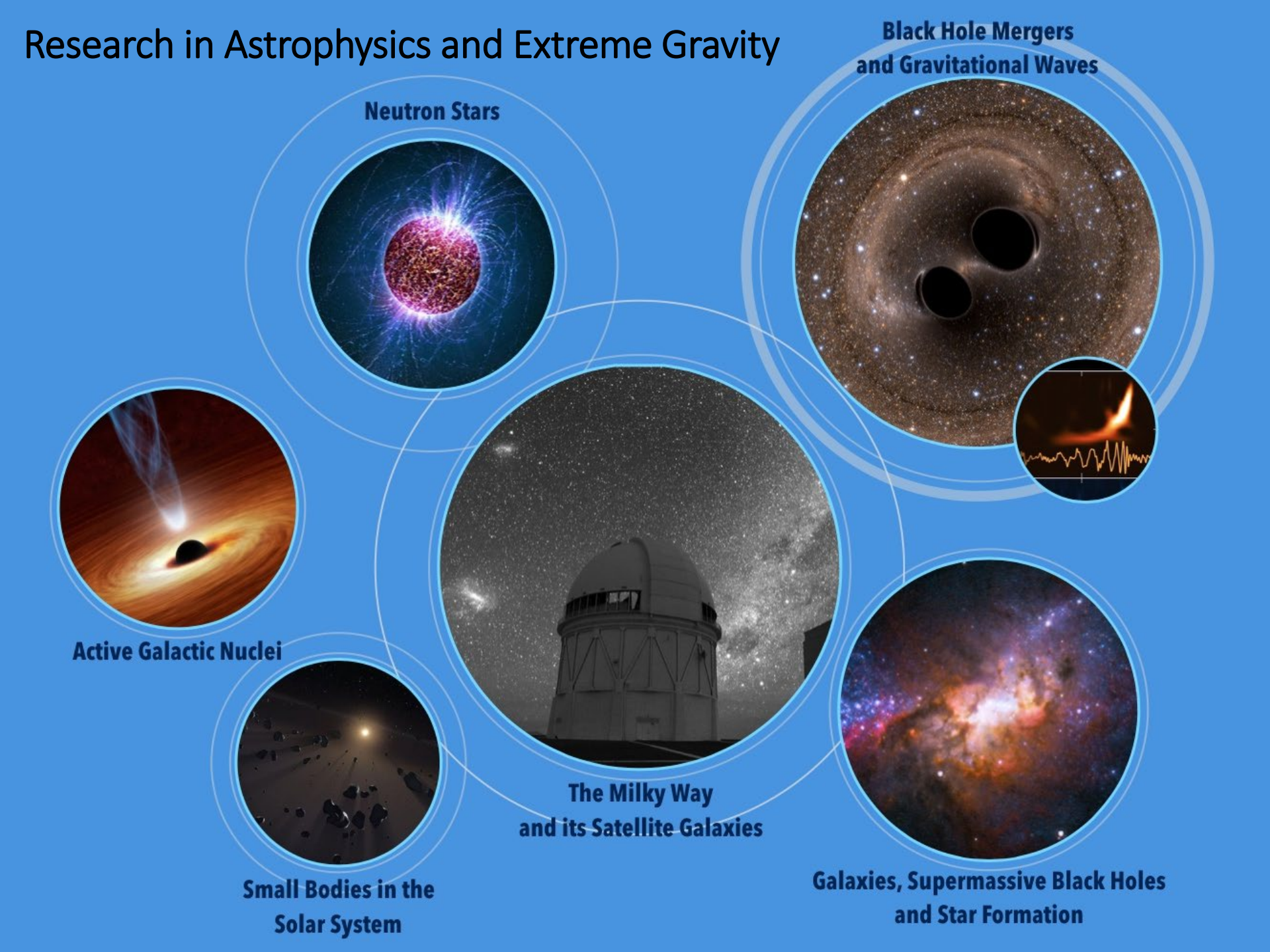


Research in Astrophysics and Extreme Gravity

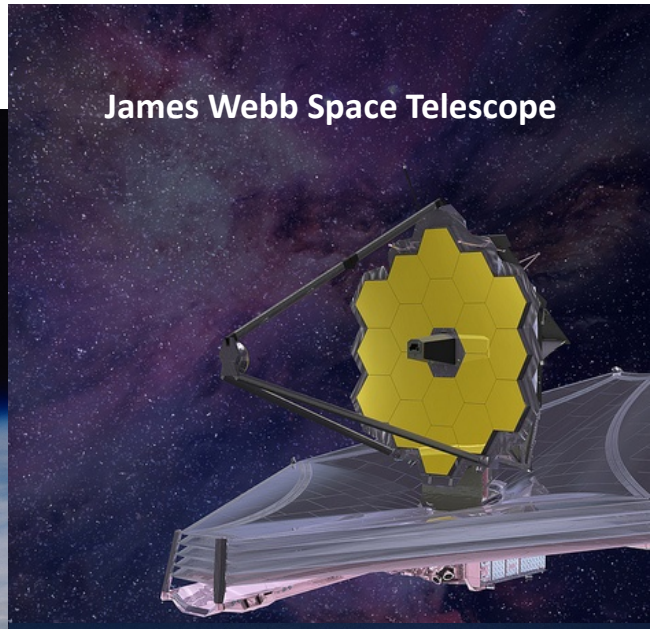
Massive Black Holes, Star Formation, Galaxies

Amy Reines

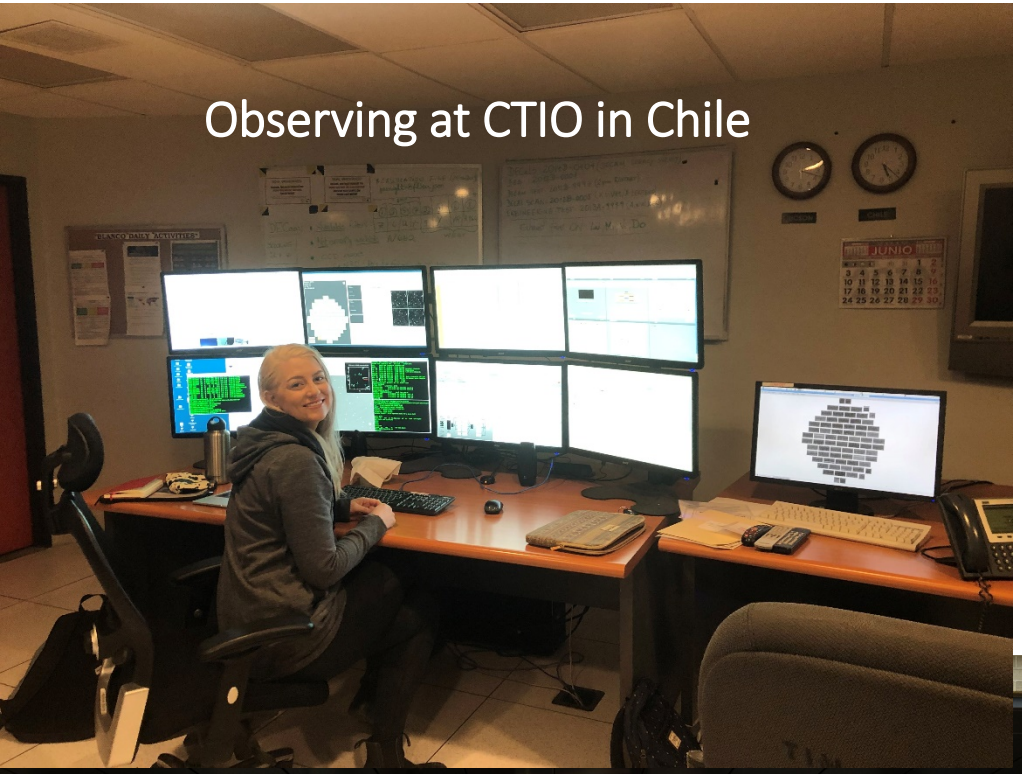
Research in Astrophysics and Extreme Gravity

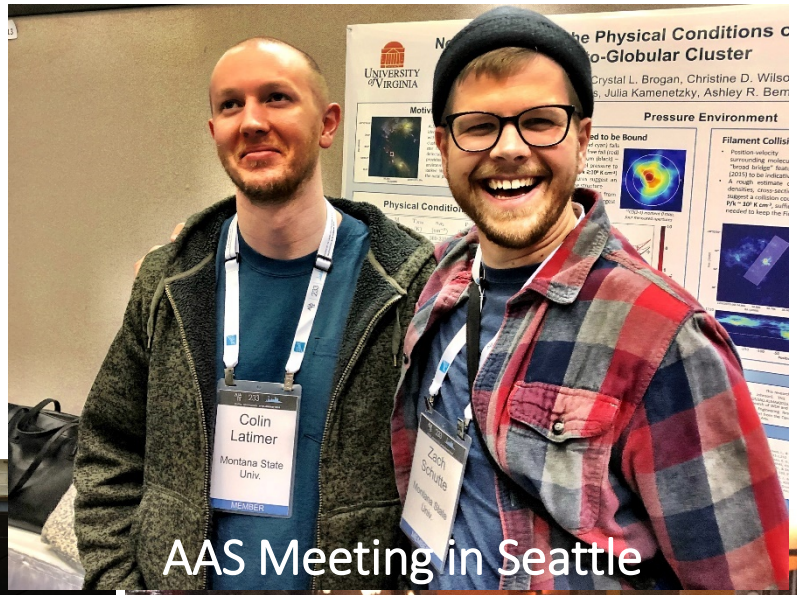


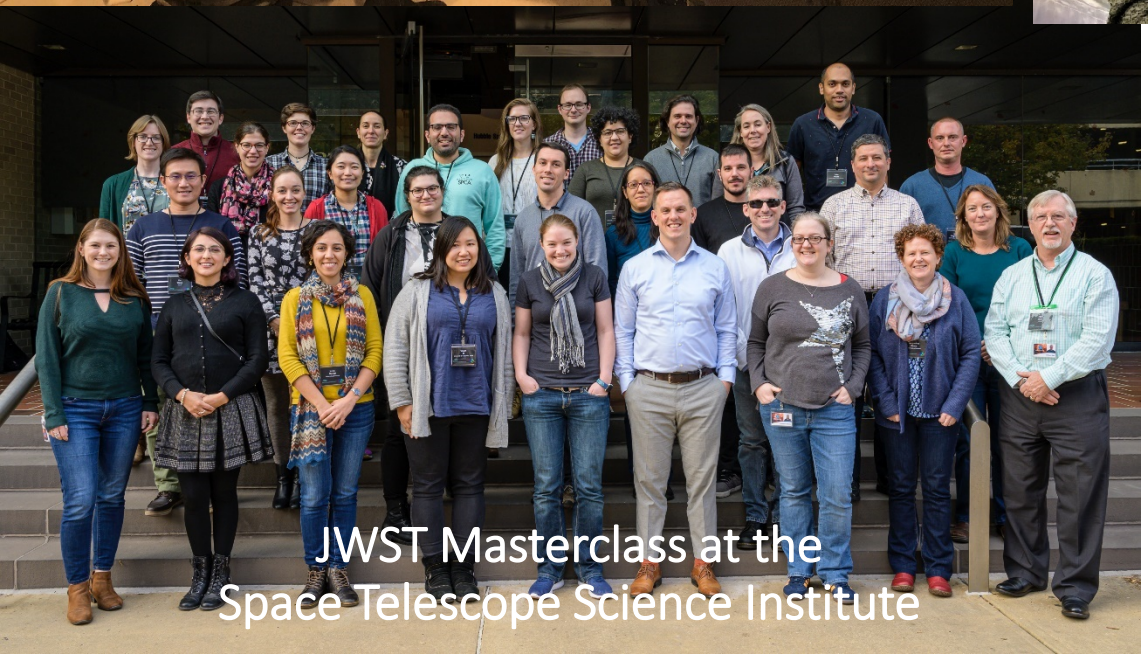
Observatories



Research Activities

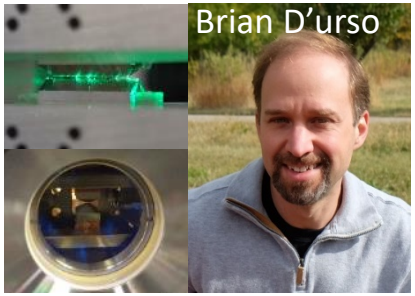






Many opportunities for research in optics, condensed matter and quantum materials/systems

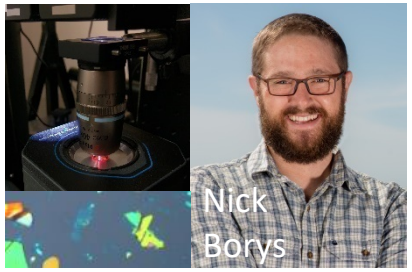
Levitated optomechanics



Precision measurement using quantum systems.

http://www.dursolab.org/

Nano-optics & quantum materials



Quantum phenomena in low-dimensional materials.

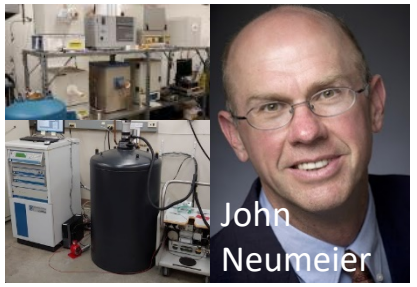
http://www.boryslab.com/

Photonic and imaging

Microwave photonics, LIDAR, & digital holography.

http://spectrum.montana.edu

Quantum materials



Quantum phenomena in condensed matter.

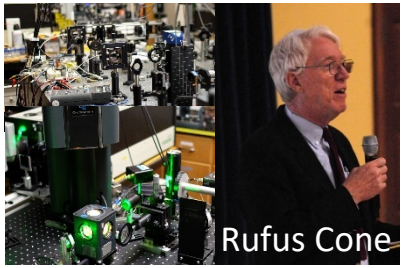
https://sites.google.com/view/neumeier-lab-msu

Ultrafast nonlinear optics

Materials and techniques for nonlinear optics.

http://physics.montana.edu/arebane/research/

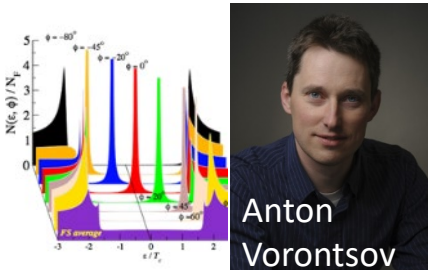
Rare-earth materials for QIS



Fundamental material physics & signal processing

http://physics.montana.edu/directory/faculty/1524001/rufus-cone

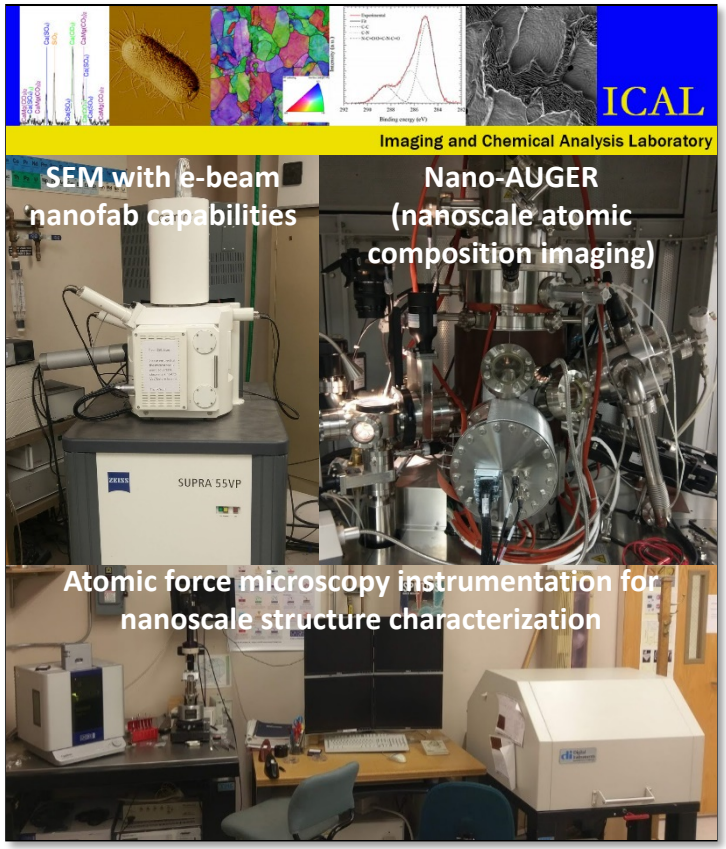
Condensed matter theory



Unconventional super-conductivity & quantum liquids

http://physics.montana.edu/avorontsov

On-campus shared-use facilities to accelerate research

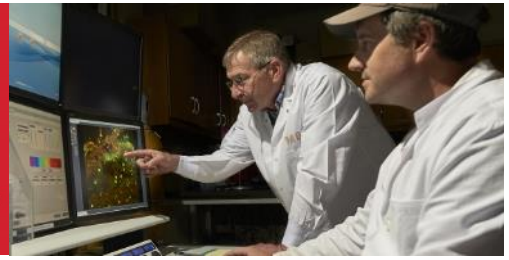


MONTANA STATE UNIVERSITY
Montana Microfabrication Facility

• multiple etchers • thin-film evaporation & sputtering
• optical mask aligner • wafer bonding

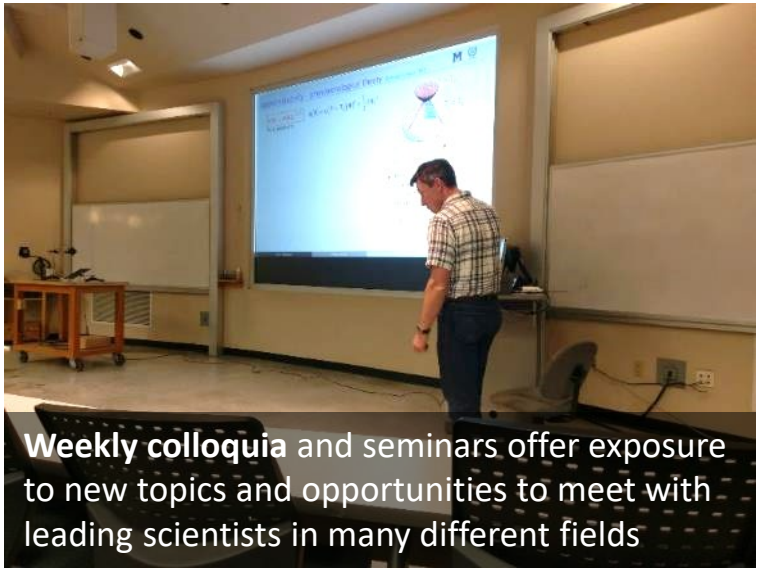
• a new cryogenic-TEM system recently funded

CENTER FOR BIOFILM ENGINEERING



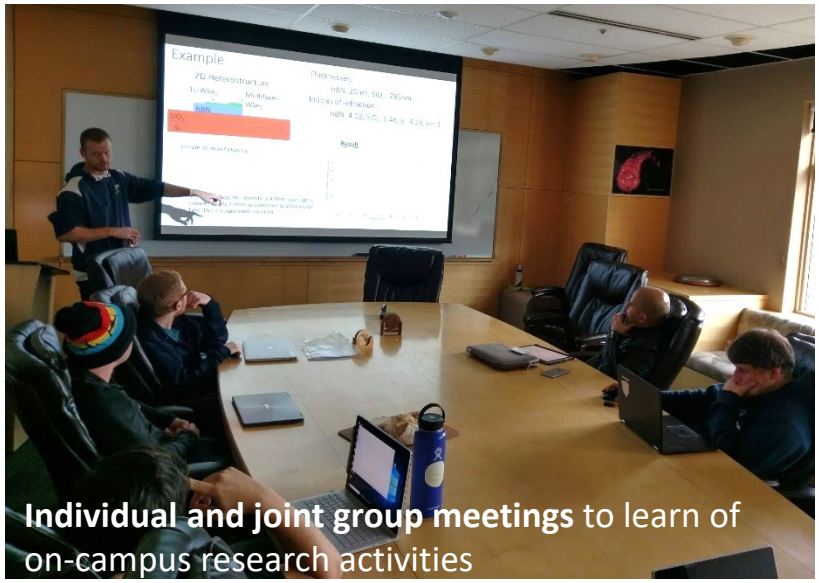
• (User-friendly) Raman and fluorescence microscopy

Many activities for exposure to leading research



Weekly colloquia and seminars offer exposure to new topics and opportunities to meet with leading scientists in many different fields

One-on-one training on sophisticated instruments in shared-use facilities



Individual and joint group meetings to learn of on-campus research activities

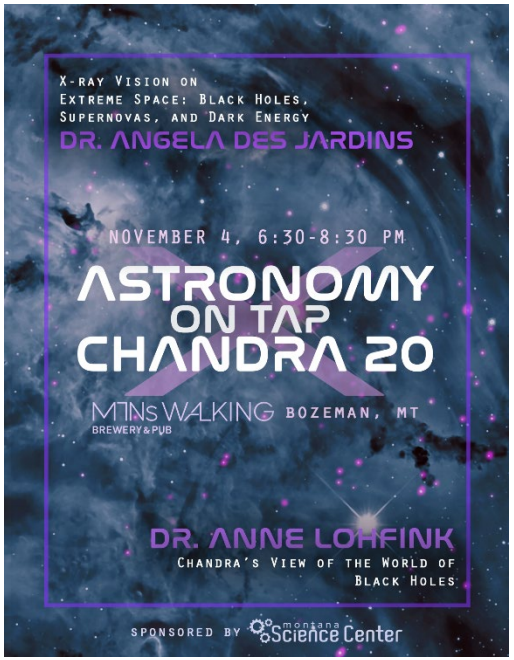
Casual **social gatherings** and dinners

Many opportunities to participate in community outreach

montana Science Center

https://montanasciencecenter.org/

Prof. Brian D'Urso serves on the board of directors.



Organized and run by graduate students

Space Public Outreach Team

Get paid to talk to K-12 groups about space

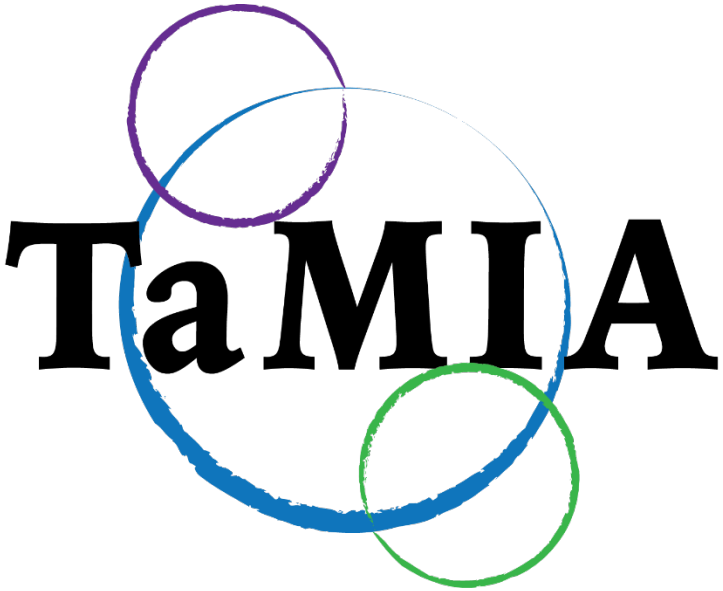
https://spacegrant.montana.edu/spot/index.html

MSGC

Women+ in Physics

"We focus on creating a supportive community and climate of inclusivity with a long term goal of increasing the number of women and underrepresented genders in the field."

https://physics.montana.edu/research/wip/index.html



Towards a More Inclusive Astronomy

http://www.tamiastronomy.org/

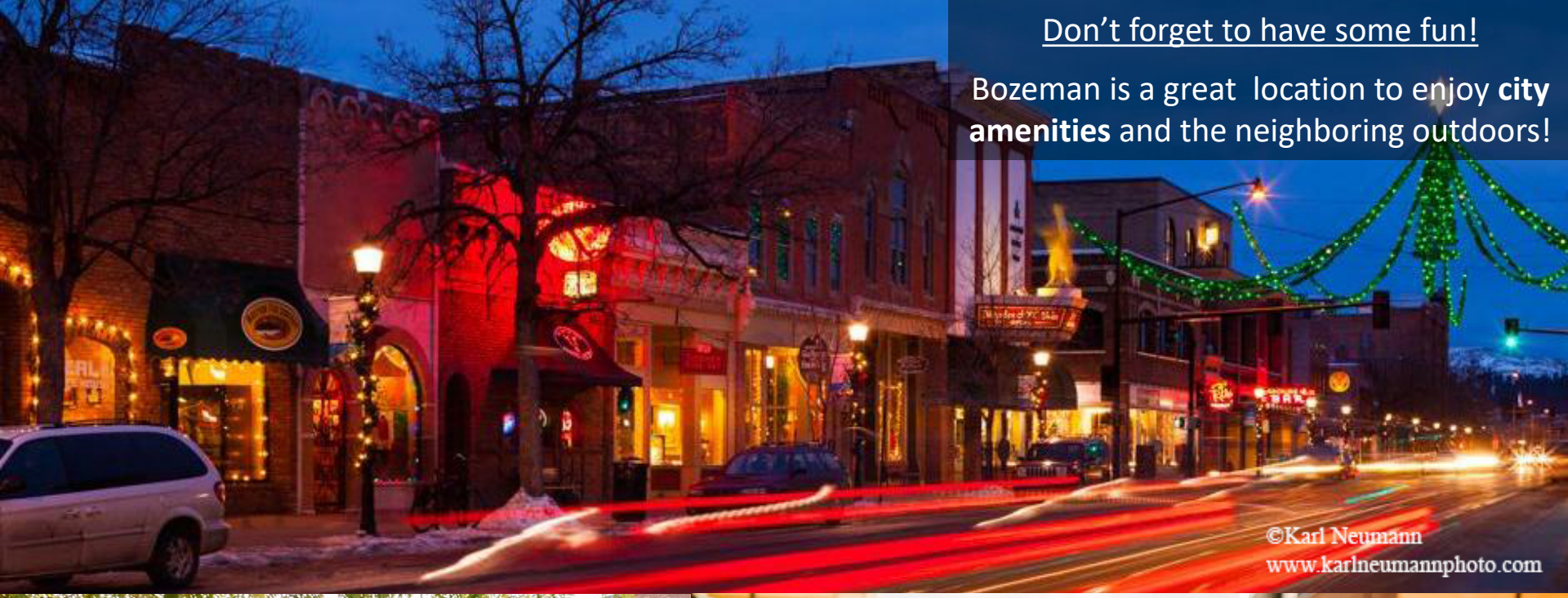
The goal of TaMIA is to create an open and supportive space in which the department can discuss issues of equity and inclusivity, both within our department and in the physics and astronomy communities at large.

Through our TaMIA meetings, we hope to:

- Work together to educate ourselves on the lived experiences of people with different identities from our own;
- Discuss how marginalized identities can affect how people work in physics and astronomy;
- Become better allies

Don’t forget to have some fun!

Bozeman is a great location to enjoy **city amenities** and the neighboring outdoors!



Music on main

Bozeman CVB

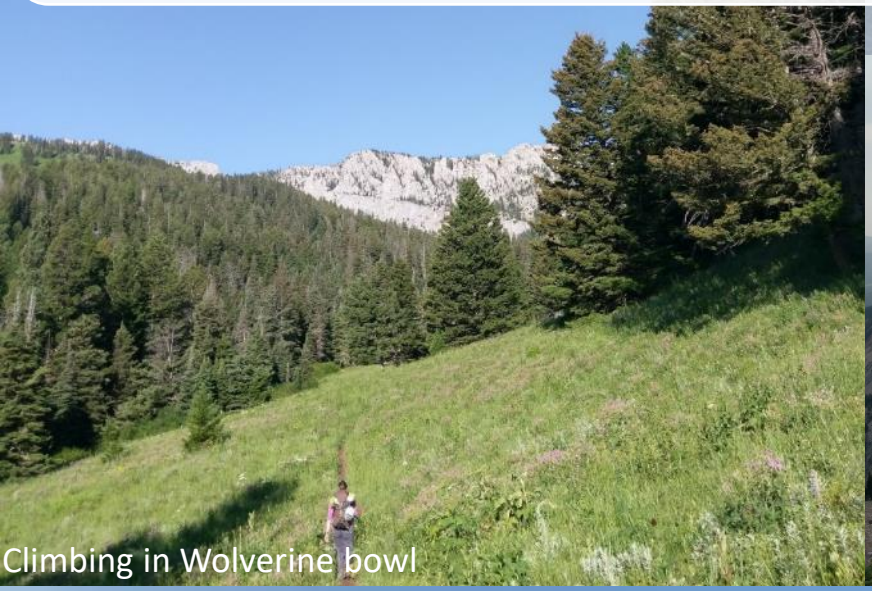
Important details

- **Application deadline: January 10, 2021**
- **Application fee: waived** for participants of this recruiting fair!
- **GREs:** general and subject are **not** required
- **Recommendation letters**: **three** letters required
- More information: http://physics.montana.edu
- Questions: gradphysics@montana.edu

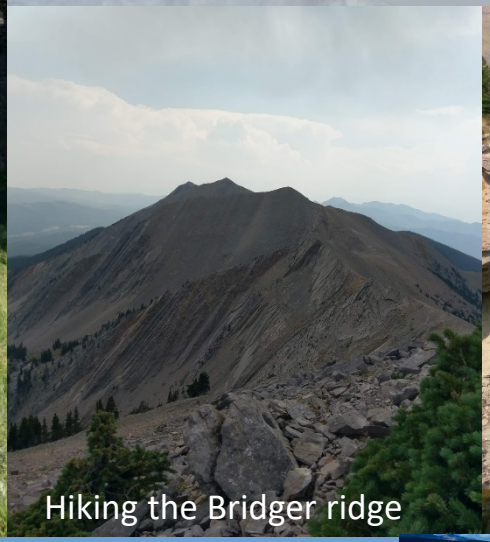
Don't forget to have some fun!

Bozeman is a great location to enjoy city amenities and the neighboring **outdoors**!

Skiing between Big Sky & Yellowstone



Climbing in Wolverine bowl



Hiking the Bridger ridge

Climbing at Natural Bridge Falls

View from the "M"

Yellowstone National Park

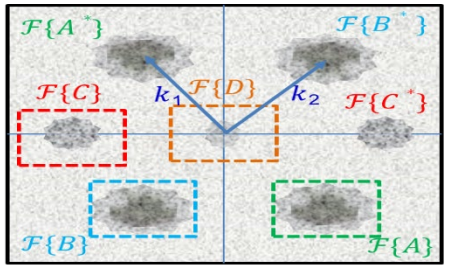
Research group summaries

Prof. Randy Babbitt's Labs w/ Drs. Rupavatharam and Ebbers

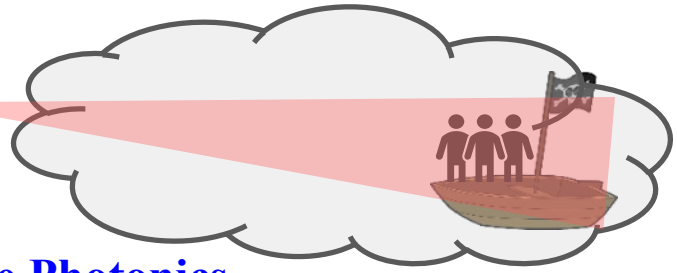
Spectrum LAB
Montana State University

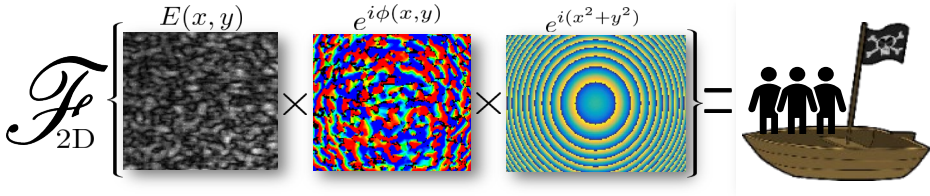
Coherent Lidar and Digital Holography

- Range-Doppler Selective Imaging and Polarimetry
- Active Coherent Imaging Through Fog
- Vibration and Through-Turbulence Imaging



Dig Holo/ Lidar





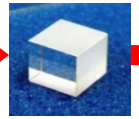
Microwave Photonics

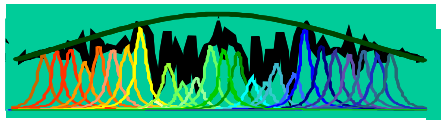
- Spatial-Spectral Holographic Signal Processors
- Broadband Signal Analysis and Geolocation
- Broadband Electro-Optics and Novel Detectors

Laser

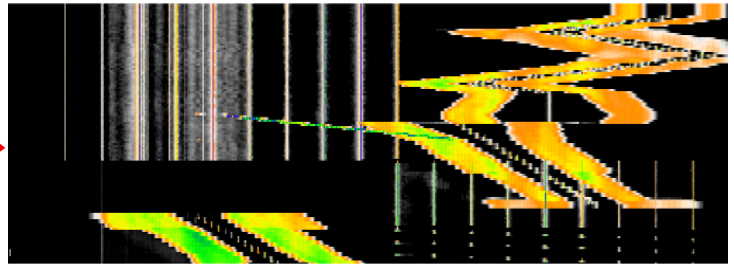
RF Signals

S2 Crystal

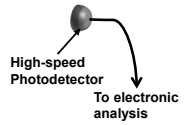




Microwave Spectrogram



Correlators

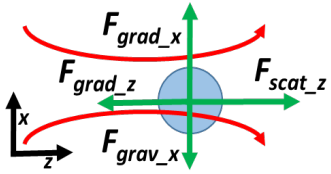


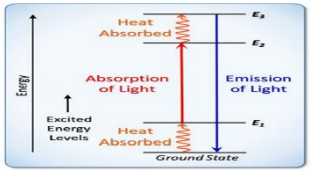
Quantum Networks

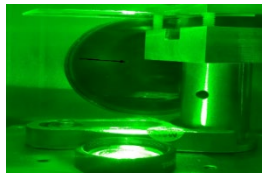
- Quantum Memory and Communications

Optically Levitated Particles

- Laser Cooling
- Precision Gyroscopy







Nano-optics of quantum materials at Montana State

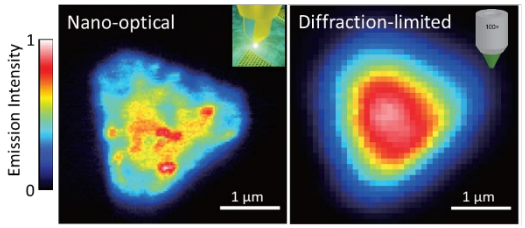
New materials to harness quantum phenomena on ultra-small length scales and ultrashort timescales.

quantum sensing • quantum information science • next-generation optoelectronics
fundamental many-body physics • non-equilibrium systems

Borys Lab – www.boryslab.com – nicholas.borys@montana.edu

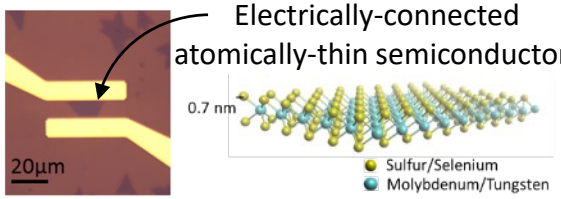
Research Highlights

Optical microscopy & spectroscopy beyond the diffraction-limit



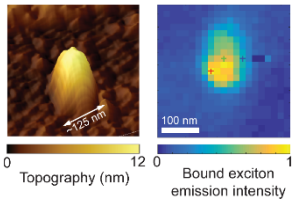
Nat. Commun. **6**, 7993 (2015) • *2D Mater.* **4**, 021024 (2017)
Nature Nano. **15**, 854 (2020)

Nanoscale & ultrafast many-body physics in 2D materials



PRL **119**, 087401 (2017) • *ACS Nano* **11**, 2115 (2017)
Nature Commun. **11**, 1156 (2020) + 1 new sub.

2D material engineering for on-chip quantum photonics



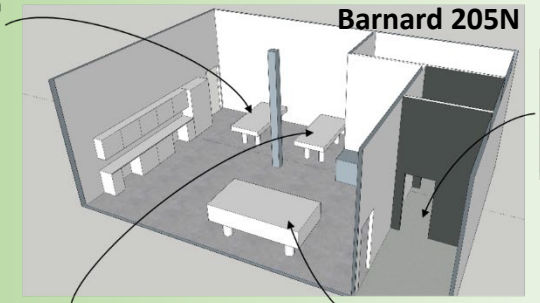
Strain-engineered non-classical light source in a 2D semiconductor!

ACS Nano **13**, 1284 (2019) • *ACS Nano* **13**, 10520 (2019)
J. Phys. Chem C. **124**, 8000 (2020) + 1 new sub.

Experimental facilities

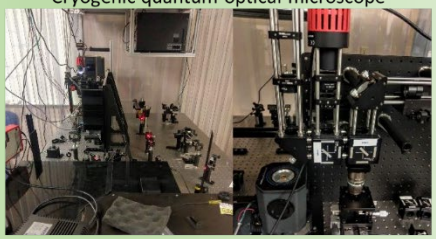
Ultrafast laser system

- Δt=100 fs – 6 ns
- λ=227 – 2000nm



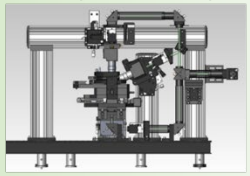
Sample prep, fab, & growth

Cryogenic quantum-optical microscope



T = 3-350 K • Δt≈30 ps • Δx ≈300 nm

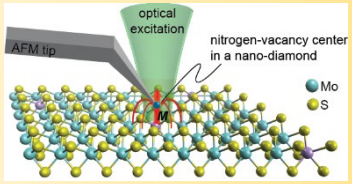
Nano-optical microscope



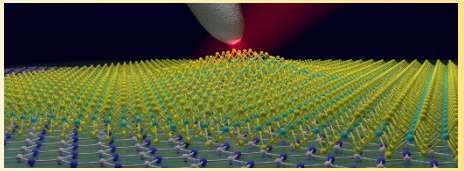
Atomic force & optical microscope
T = 300 K • Δt≈30 ps • Δx < 20 nm

Example Potential Projects

- Nano-optical quantum sensing of nanoscale magnetic moments in interfacial systems.



- Low-temperature and nano-optical investigations of laterally-confined 2D materials (i.e., graphene and hexagonal boron nitride nanoribbons).

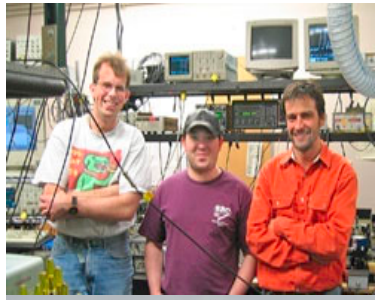


CONE-THIEL GROUP HIGHLIGHTS

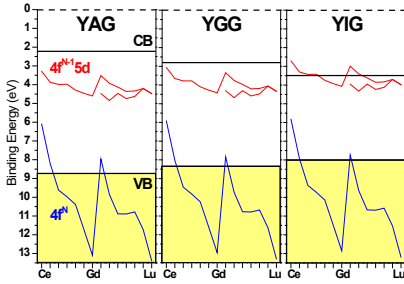
2017 Stibitz Award For Seminal & Pioneering Contributions to Quantum Memory
Fellow of American Physical Society

"From 20 Hz to 200 eV" – a span of 15 orders of magnitude

- Narrowest optical lines observed in any solid – For Quantum Memories & Quantum Computing
- *THE* source for rare earth hole burning and quantum information materials
- Dynamical processes relevant to decoherence in Quantum Information Systems
- Lasers stabilized to spectral holes to 14 Hz – "a hair's breadth out of the earth moon distance" leading to applications including local oscillator in atomic clocks
- New insights from relation of band structure and ionic $4f^n$ levels impact lasers, phosphors, scintillators, and hole burning materials
- Conference organizer: Storage and Manipulation of Quantum Information in Solids; HBSM at MSU, France, and Taiwan; Physics of Quantum Electronics - Jackson Hole and Snowbird



Scientific Materials Corp.



B.S., M.S., and Ph.D. graduates placed in

- Local optics industries – Scientific Materials, Big Sky Lasers, Wavelength Electronics, ILX, Lattice Materials, Resonon, AdvR, Altos, New Wave, S2, FLIR, Quantel, ….
- Universities – University of San Francisco, U. of Wisconsin-Eau Claire, USD, and MIT
- Corning, Hewlett Packard, 3M Research, Rockwell, Ball Research, and Tektronix
- National laboratory –Argonne National Laboratory

Funding DOE (Yale + MSU), NSF (MSU + Caltech + UT-Austin), Boeing, Air Force Research Lab, & others in progress

Collaborations

- Other MSU Physics and ECE groups and MSU Spectrum Lab
- Local Optics Companies (800 employees)
  - Scientific Materials Corporation of Bozeman - collaboration has been highlighted nationally and in Montana
  - S2 Corporation of Bozeman – 4 licensed Cone patents enable their devices
  - AdvR & Montana Instruments
- Yale, Caltech, University of Texas-Austin; Princeton and Harvard
- Groups in France, Canada, Sweden, Switzerland, Australia, and New Zealand

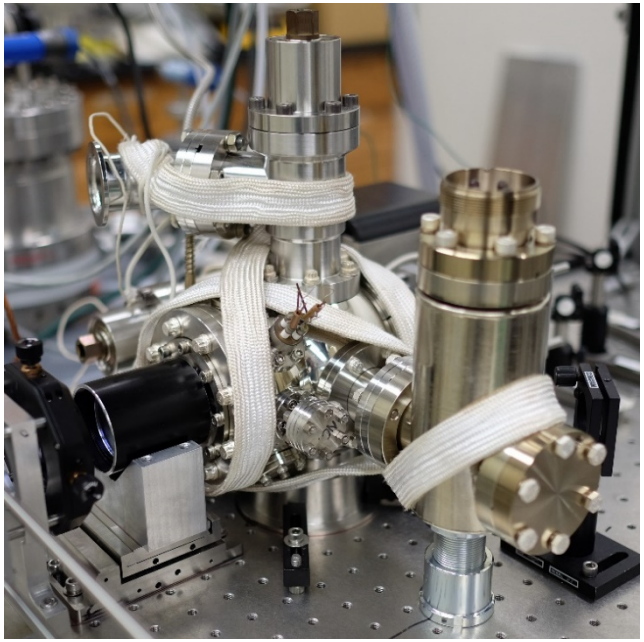
D’Urso Lab - Levitated Quantum Optomechanics

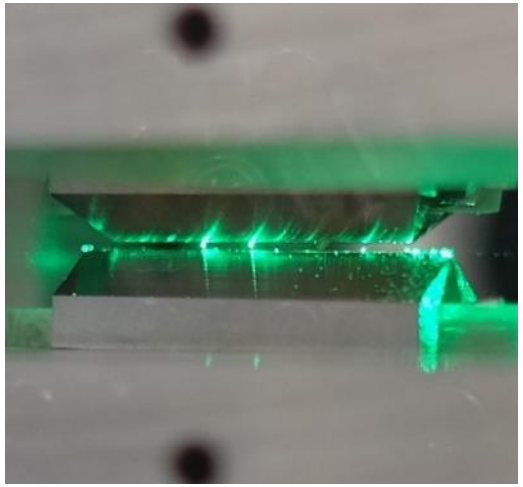
Techniques

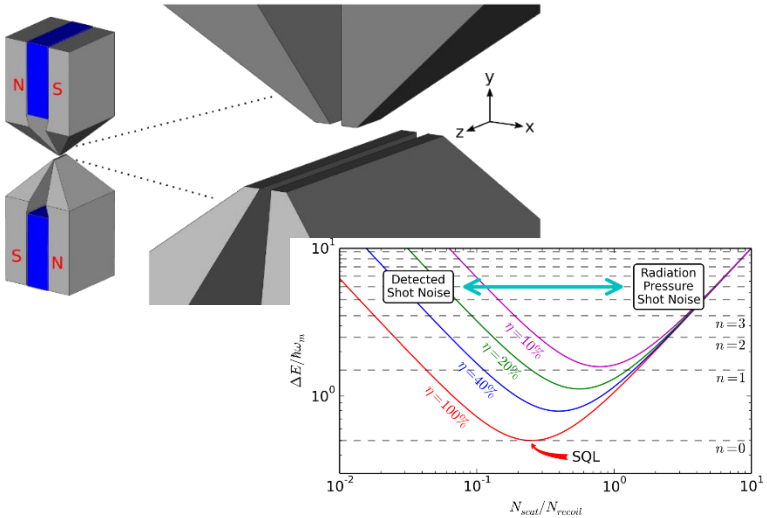
- Magnetic levitation of microparticles.
- Lasers measure particle motion and manipulate particles.

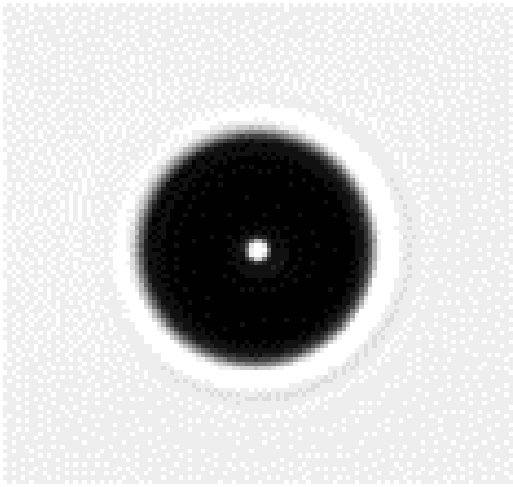
Applications

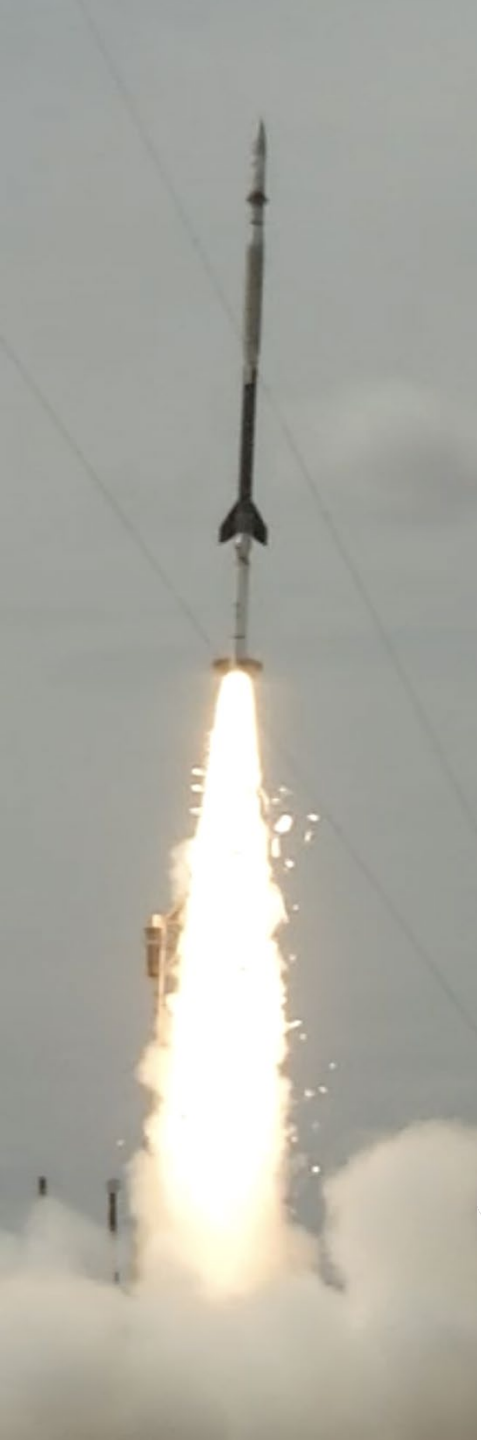
- Probing the limits of quantum mechanics.
- Precision measurements of fundamental constants.
- High-sensitivity accelerometry.





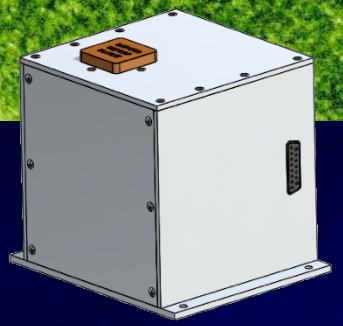






Kankelborg Group Current Projects

- Tomographic Imaging Spectroscopy (MOSES/ESIS rocket, *launched September 2020*)
- FUV spectrum of the Sun as a star (FURST rocket, *2022*)
- Soft X-ray variability in solar flares (Hi-C Flare rocket, *2024*; MUSE satellite, *entering Phase A*)
- FUV/NUV imaging spectroscopy (IRIS satellite, *operational*)



Quantum and Materials Physics

Professor John Neumeier
Ph.D. in Physics, UCSD
Fellow, American Physical Society

1. Magnetic and Electrical Properties of Low-Dimensional Solids

   Electrons in low-dimensional geometries behave differently because of strong interactions. You will study low-dimensional magnetism, superconductivity, and Luttinger-liquid behavior. You will grow *bulk* single crystals of compounds with crystal structures composed of sheets or 1D chains, characterize the compounds, and study their physical properties. *The goal is to search for new physics in new compounds.*

2. Compressibility of H_2O Ice

   Ice's compressibility has only been measured at three temperatures. You will be the first to measure it from 2 K to 270 K. You will need to build a device to measure the compressibility of ice along its principal crystallographic directions. You will also grow single crystals of H_2O and D_2O ice. *The goal is to determine fundamental information about nature's most important solid.*

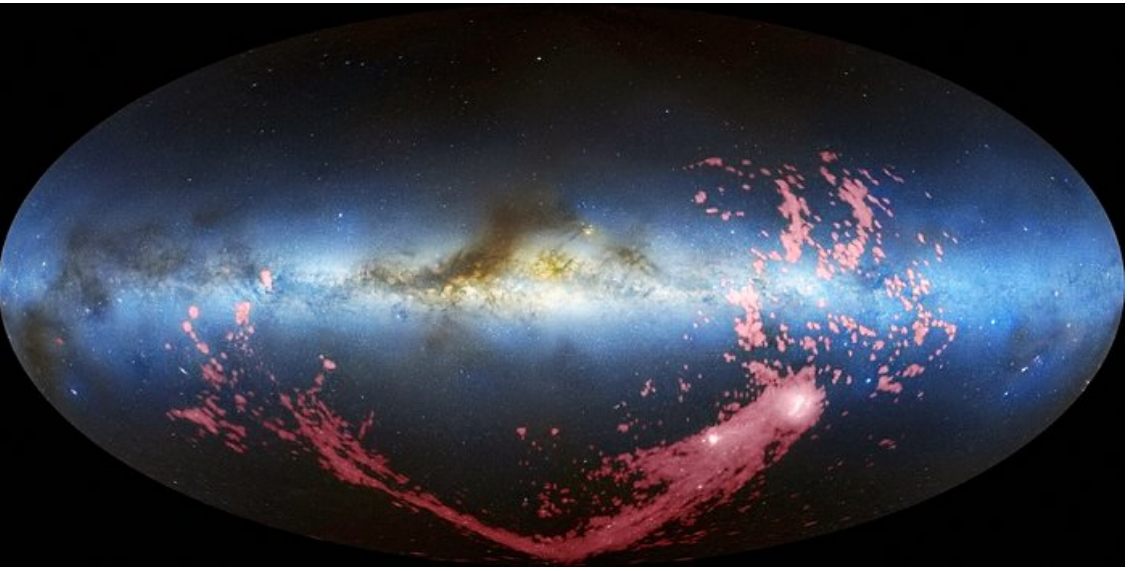
3. Vanadium, Niobium, and Tantalum

   The crystal structures of these elements below ~250 K are unknown. You will be the first to determine their crystal structures, and to measure their physical properties in their low-temperature structures. You will purify the elements, characterize their purity, determine their low-temperature crystal structures, and measure their physical properties. *The goal is to establish fundamental knowledge regarding three elements.*

Nidever Research Group

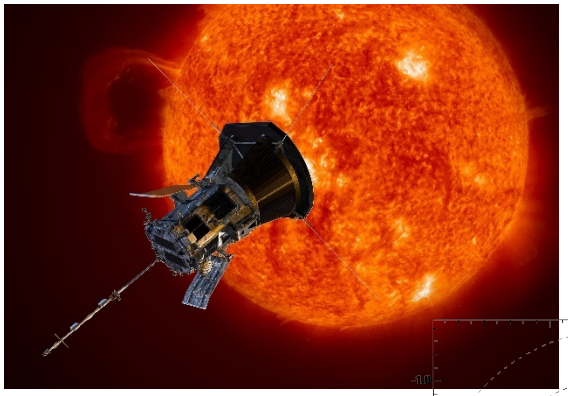
Topics:

- The Milky Way Galaxy – structure, formation and evolution
- Dwarf satellite galaxies
- Large astronomical surveys (commissioning scientist for SDSS-V)
- Small bodies in the solar system



Observations

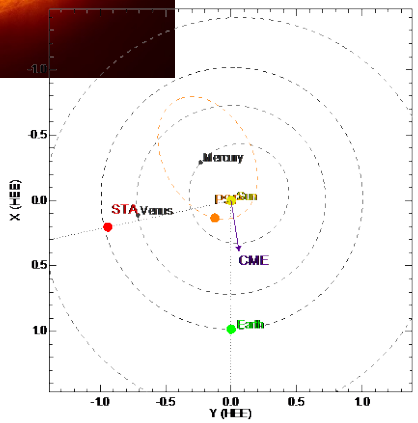
- Ground-based imaging and multi-object spectroscopy at optical and near-infrared wavelengths
- Radio observations of neutral hydrogen gas
- Big Data Astronomy

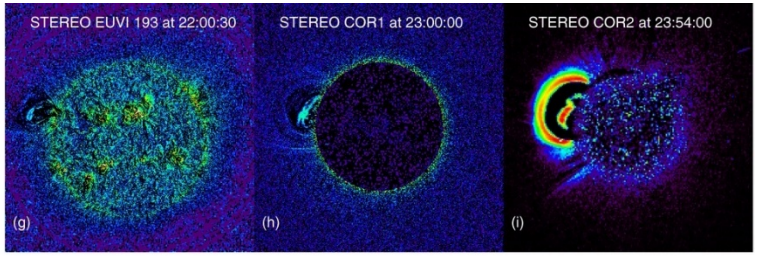


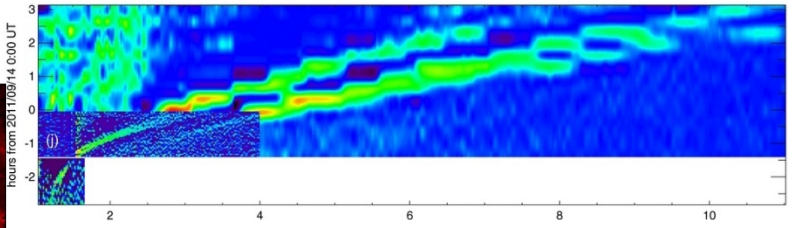
Explosions of solar flares and Coronal Mass Ejections are fueled by magnetic reconnection, a process taking place in many astrophysical environments. We observe flares and CMEs, and study energy release by magnetic reconnection.

Prof. Jiong Qiu

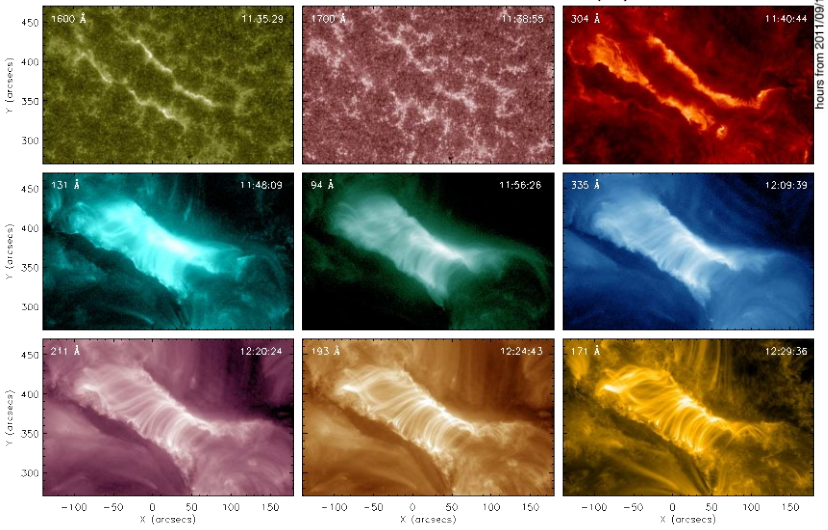
Parker Solar Probe at 0.1 AU from the Sun.



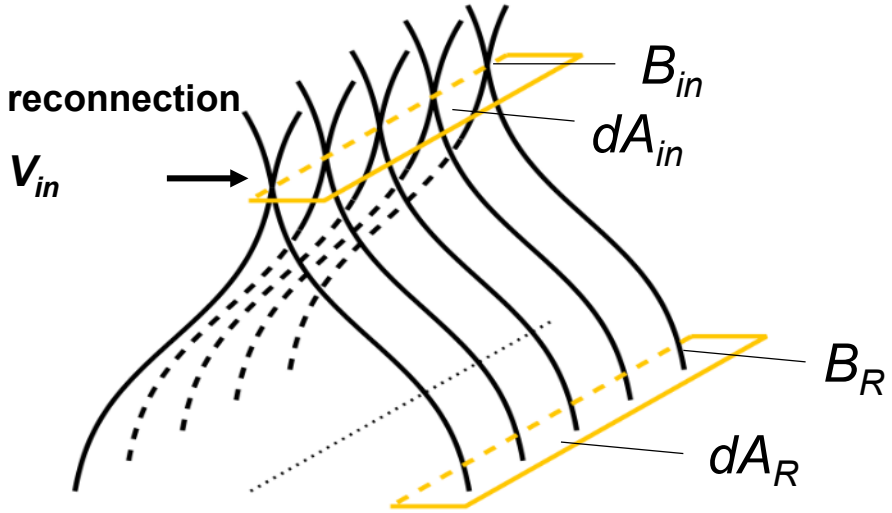




CMEs are released by reconnection and tracked by STEREO spacecraft observing the Sun from side.



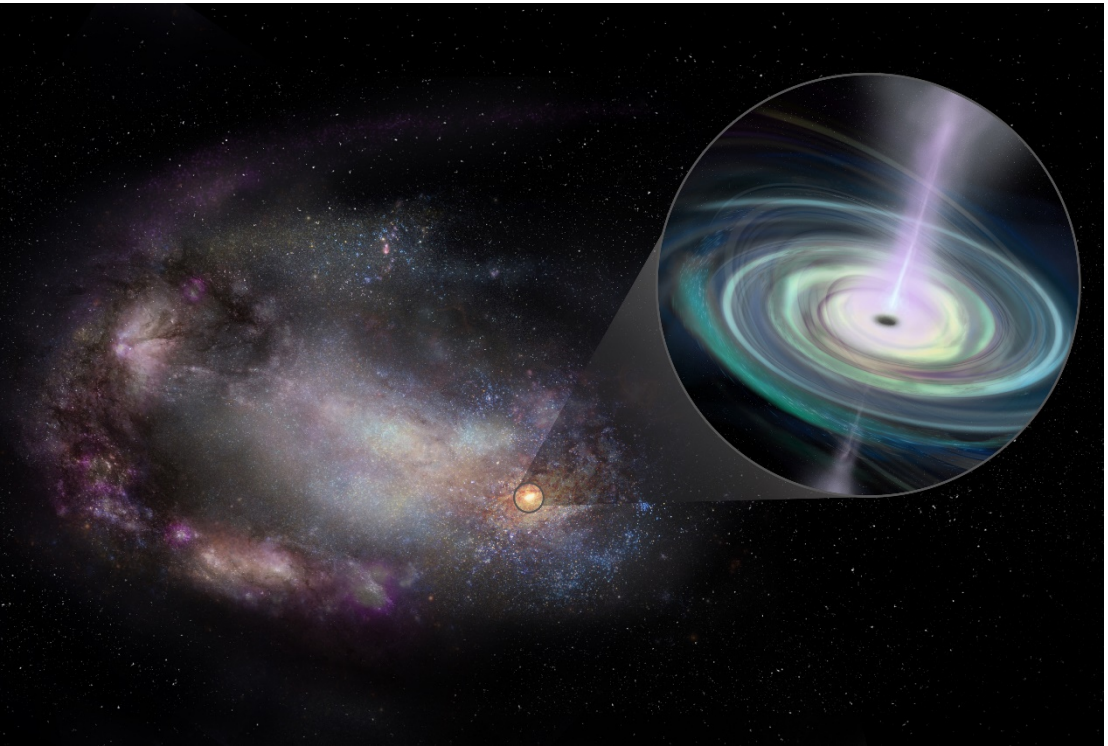
Arcades of flares formed by reconnection, observed by Solar Dynamics Observation



Reines Research Group

Topics:

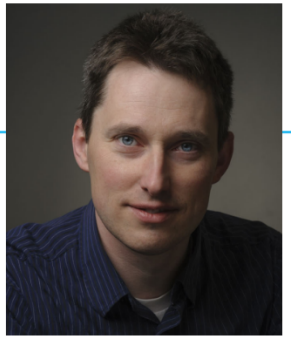
- Massive black holes in dwarf galaxies and the origin of black hole "seeds"
- Active Galactic Nuclei
- Extragalactic Star Formation
- Evolution of galaxies and their massive black holes



Observations:

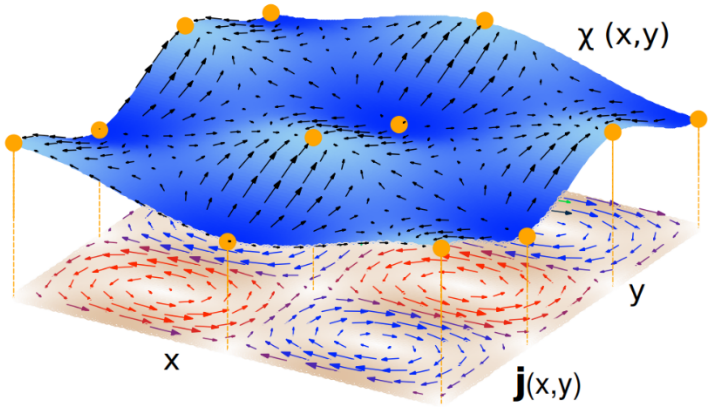
- Multi-wavelength observations spanning radio to X-ray wavelengths
- Large survey data (e.g., SDSS) and dedicated observations (e.g., HST, Chandra, VLA, Gemini)
- Imaging and spectroscopy

Condensed Matter Theory at Montana State



- New states of quantum matter
  e.g. Phase Crystal

$$\Delta(x,y) = \Delta\, e^{i\chi(x,y)}$$



- new symmetries
- new quasiparticles

- Spatially inhomogeneous condensates
- Co-existence and interaction of Superconductivity and Magnetism
- Non-equilibrium processes in quantum liquids: transport, Higgs modes

Fun things

- challenging and beautiful math
- use of advanced Quantum / E&M / Stat mech
- exposure to the large field of Solid State Physics

Methods

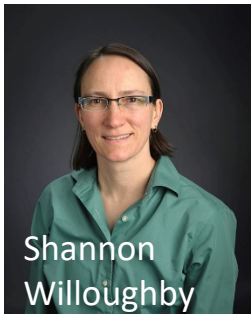
- QFT many-body methods, Feynman diagrams
- Analytical tools (Complex analysis, differential equations, linear algebra, etc)
- Numerical modeling (C, C++, parallel codes GPU / MPI)

Dr. Anton Vorontsov anton.vorontsov@montana.edu http://www.physics.montana.edu/avorontsov/myindex.html

Physics Education Research

Current research interests of the PER group:

- Attitudes and beliefs about science
- Use of statistical tools to better understand concept inventories
- Oral communication skills of STEM graduate students
- Using Minecraft to teach spatial reasoning
- How to better train graduate teaching assistants


Shannon Willoughby