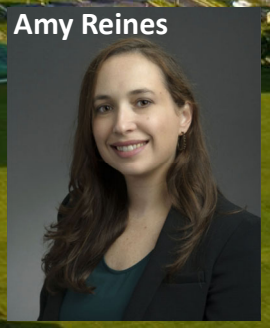
Physics @ Montana State University

Downtown

Barnard Hall
home of the Physics department

Important details

- **Application deadline: January 10, 2022**
- **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

2021 Enrollment

- Undergraduates: 14,668
- Graduate students: 2,173
- Total: 16,841

2021 Research Expenditures

$193 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 2021

672 new grants awarded

$121 million in awarded grants

The Physics department is very active in research

Annual research expenditures: $5.9 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 80 graduate students actively working in all four areas.

Recent News

Letters and Science poster slam set for Oct. 8
October 1, 2021

MSU awarded $20M for quantum tech development
September 2, 2021

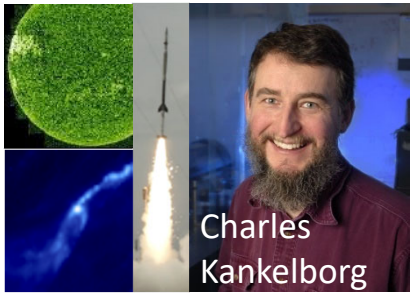
Mallory Molina awarded Ford Fellowship
July 16, 2021

Collaboration finds black hole-neutron star merger
July 1, 2021

Students, faculty and staff honored in CLS awards
June 10, 2021

Many opportunities for research in solar and space physics

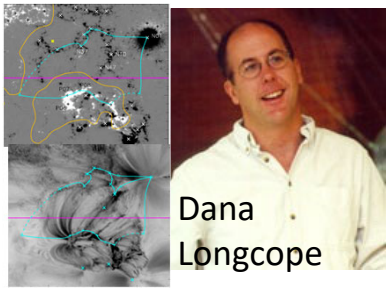
Extreme UV observations of solar phenomena



Rocket-based instrumentation for solar observations

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

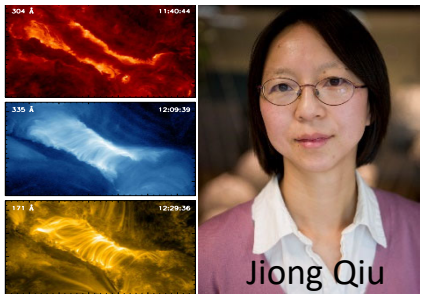
Magnetohydrodynamics & solar physics



Magnetic phenomena and fields on the sun

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

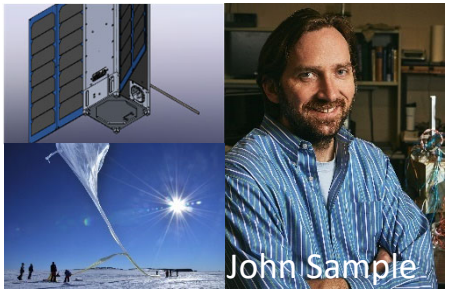
Solar astrophysics



Magnetic reconnection and instabilities on the sun

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

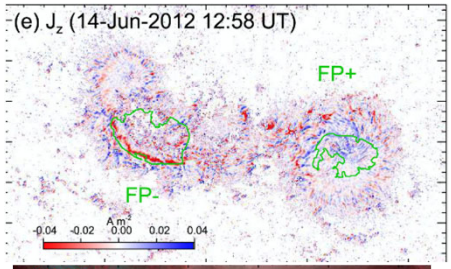
Near-earth high-energy particle phenomena

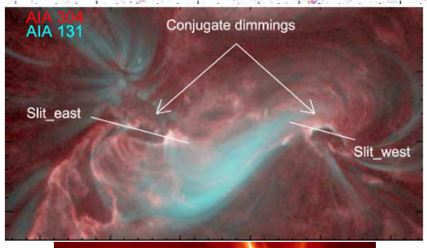


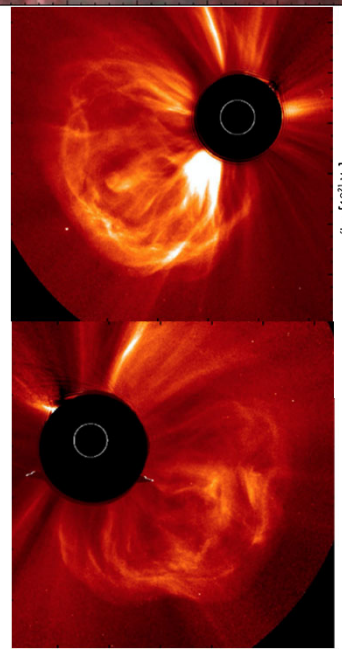
Satellite-based high-energy particle observations

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

Research in Solar and Space Physics



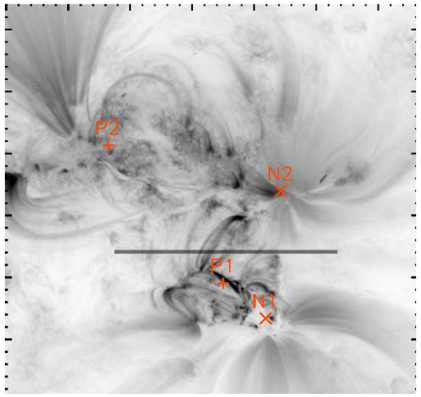


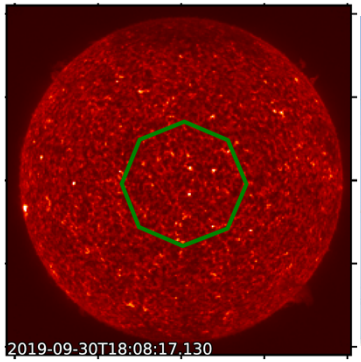


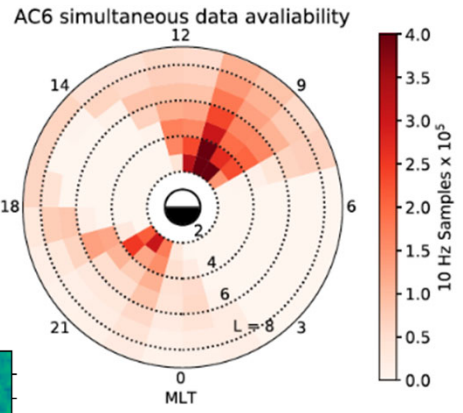
Wang et al. 2019

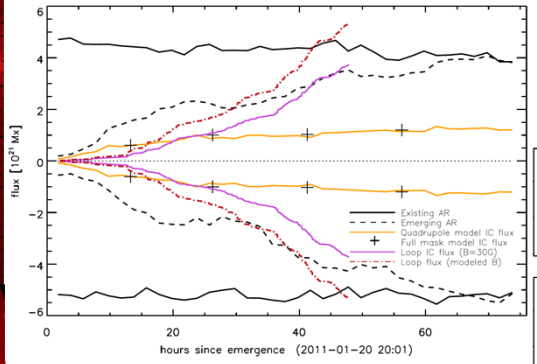
Observing initiation and propagation of coronal mass ejections

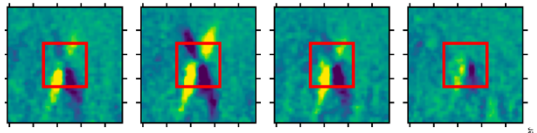
Prof. Jiong Qiu

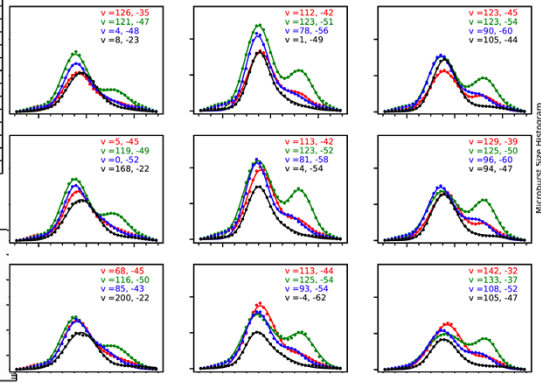


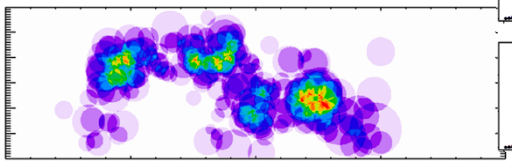


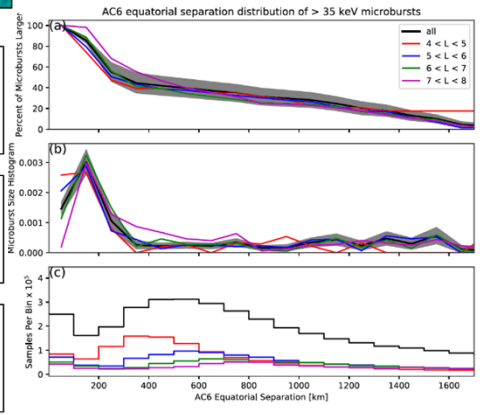












Marika McCarthy: PhD 2021

Observing and modeling magnetic reconnection in the solar corona

Prof. Dana Longcope

Jake Parker: PhD 2021

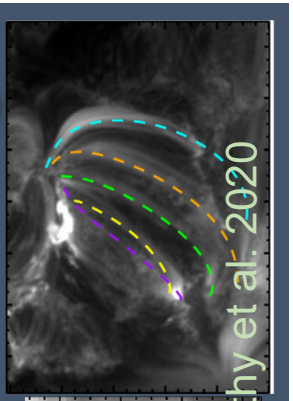
``Small'' explosions observed using rocket-borne slitless spectrograph

Prof. Charles Kankelborg

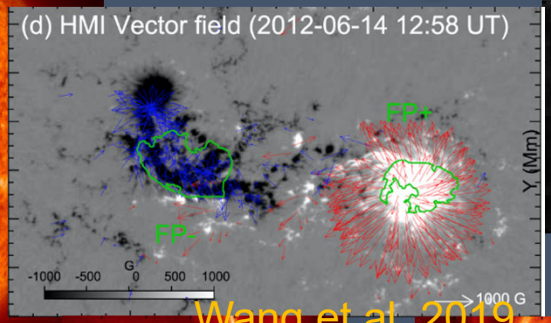
Mike Shumko: PhD 2019

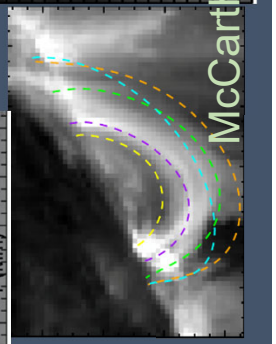
Electron microbursts in Earth's radiation belt, observed by nano-satellites

Prof. John Sample

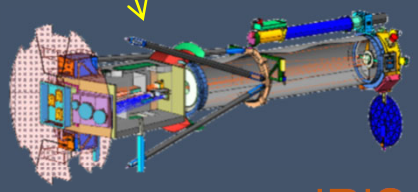


Commanded by students (& faculty) from MSU (264 Barnard Hall)

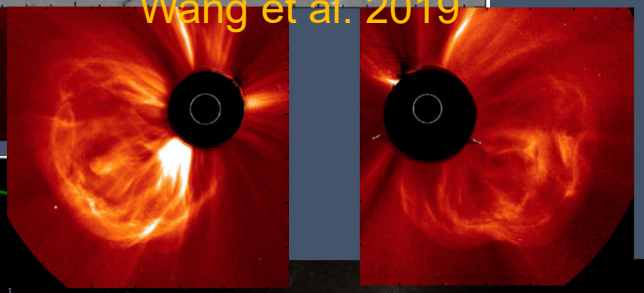


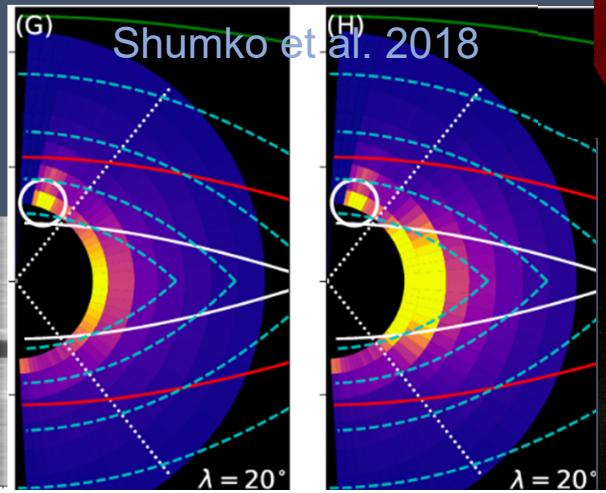


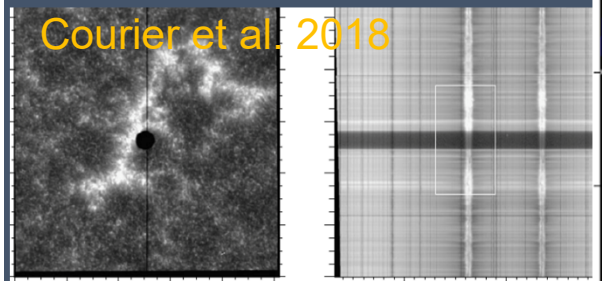
Wang et al. 2019



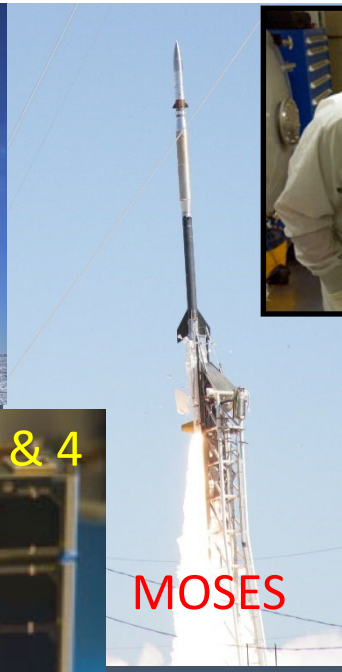
IRIS
(Kankelborg,Co-I)

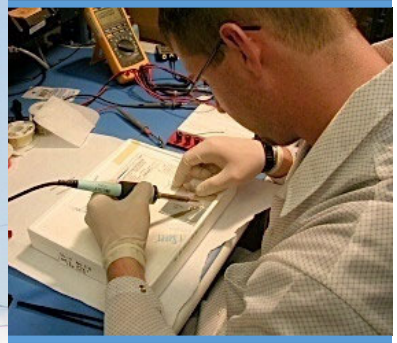


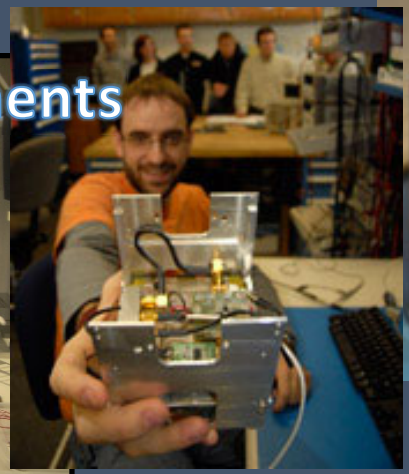




SSEL: designing, building, launching, and tracking solar/space physics experiments

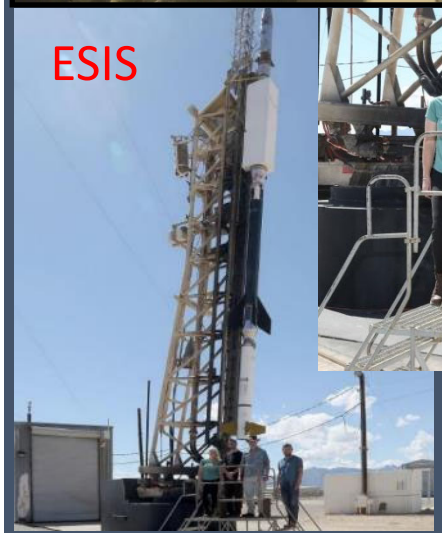






Some missions currently under development:

- **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

Extreme Gravity, Gravitational Waves

Neil Cornish

Neutron Star Composition, Dynamics and Evolution

Bennett Link

Active Galactic Nuclei Accretion and Jets

Anne Lohfink

Galaxy Evolution, Local Group Surveys & Big Data

David Nidever

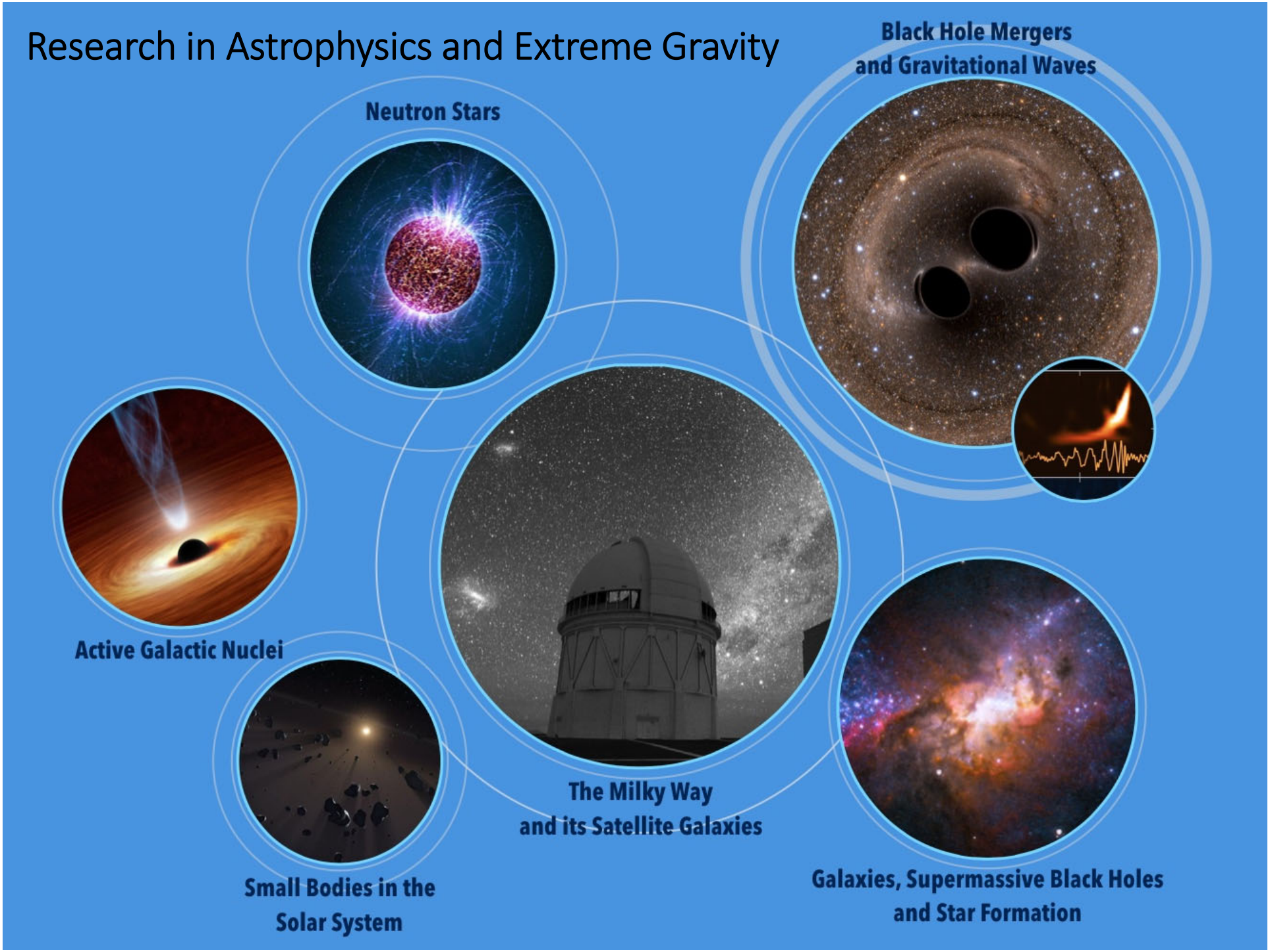
Massive Black Holes, Star Formation, Galaxies

Amy Reines

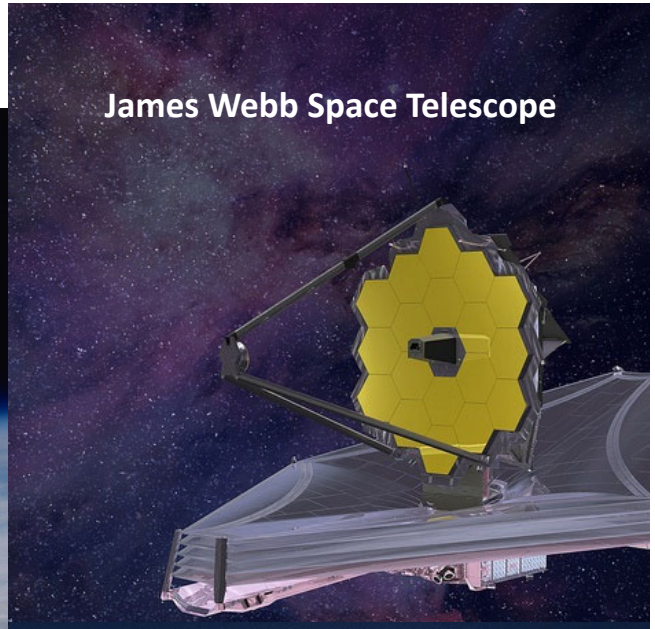
Compact Objects

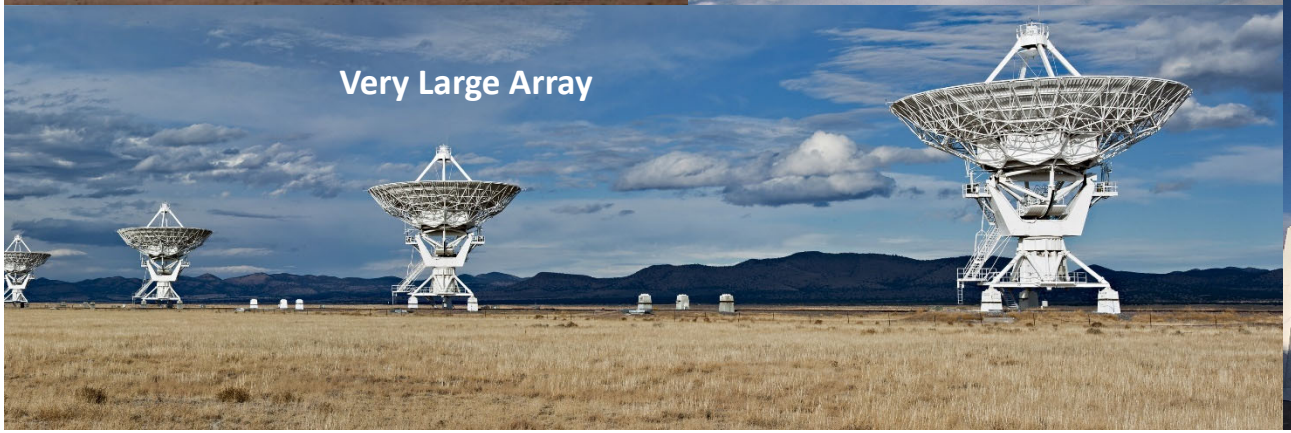
Sachiko Tsuruta

Research in Astrophysics and Extreme Gravity



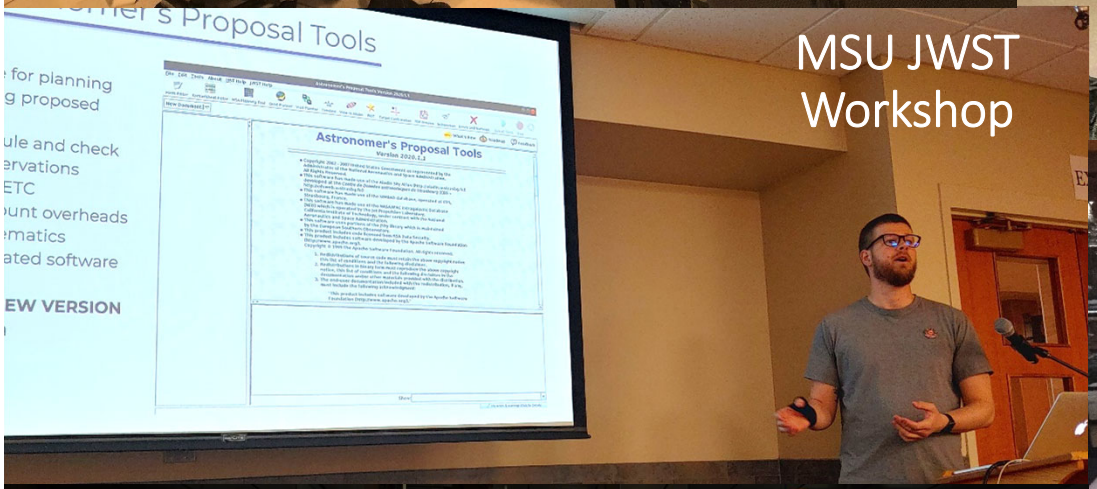
Observatories

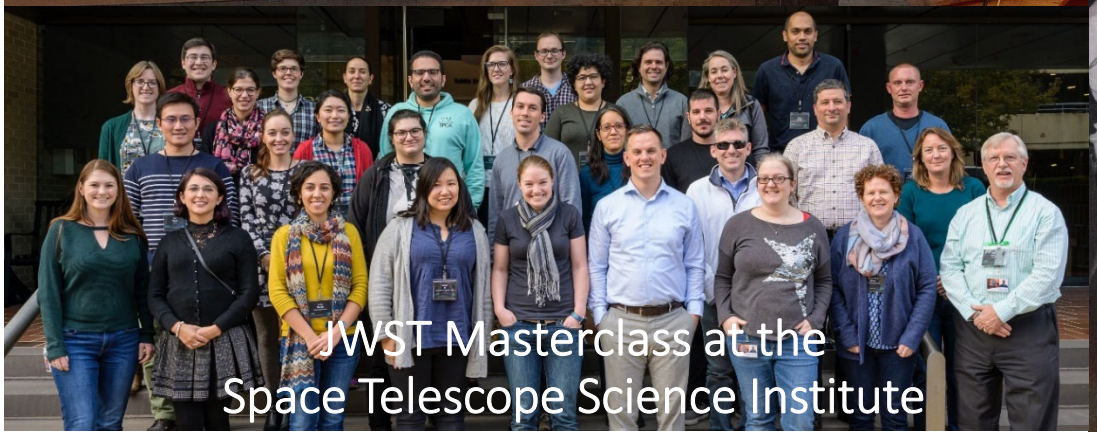




Research Activities


Observing at CTIO in Chile

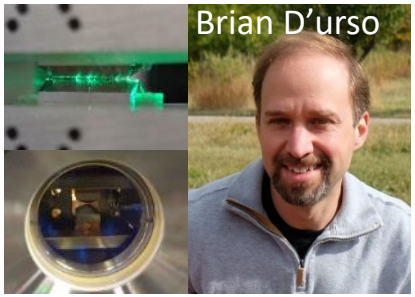



JWST Masterclass at the
Space Telescope Science Institute


SMASH Workshop Dinner
in Bozeman

Research in optics, condensed matter and quantum materials/systems

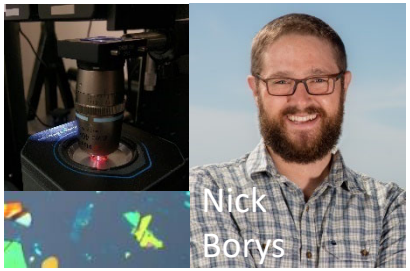
Levitated optomechanics



Precision measurement using quantum systems

http://www.dursolab.org/

Nano-optics & quantum materials



Quantum phenomena in low-dimensional materials

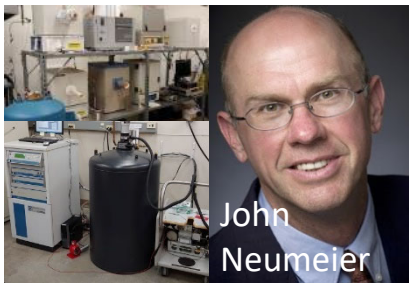
http://www.boryslab.com/

Photonic and imaging

Microwave photonics, LIDAR, & digital holography

http://spectrum.montana.edu

Quantum materials



Quantum phenomena in condensed matter

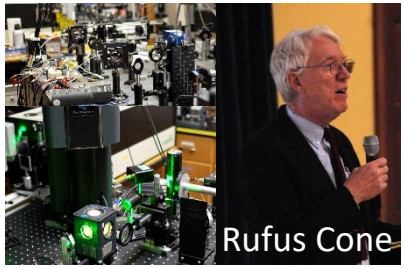
https://sites.google.com/view/neumeier-lab-msu

Ultrafast nonlinear optics

Materials and techniques for nonlinear optics

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

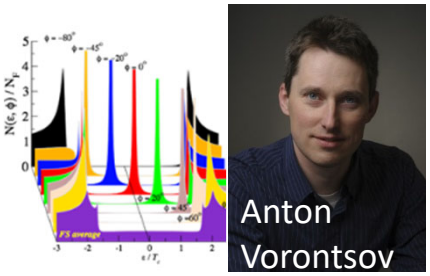
Rare-earth materials for QIS



Fundamental material physics & signal processing

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

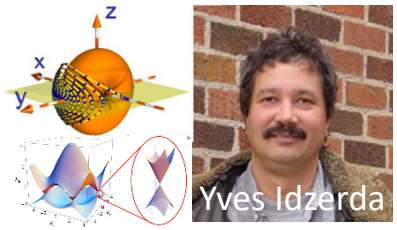
Condensed matter theory



Unconventional super-conductivity & quantum liquids

http://physics.montana.edu/avorontsov

Magnetism and spin structures



Spin phenomena in nano-structured materials

http://physics.montana.edu/directory/faculty/1524200/yves-idzerda

We lead an NSF foundry for 2D quantum materials research

($20M, six-year program -- only two in the nation!)

MonArk Quantum Foundry
A NATIONAL NETWORK OF 2D-QMaPs
www.monarkfoundry.org

MONTANA STATE UNIVERSITY

UNIVERSITY OF ARKANSAS

NSF

MonArk Leadership Team & Collaborators

Yves Idzerda
Director

Hugh Churchill
Asst. Dir., UA

Nick Borys
Asst. Dir., MSU

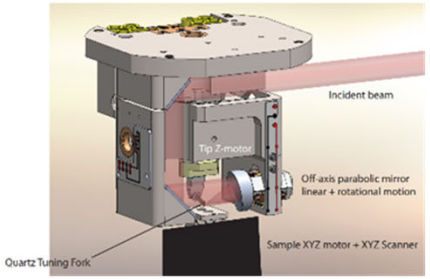
Salvador Barraza-Lopez
Theory Lead

MonArk Scientific Thrusts

- 2D quantum emitters & quantum interconnects
- 2D quantum dots and qubits.
- 2D nonlinear media
- 2D magnetism quantum spin liquids
- + more!

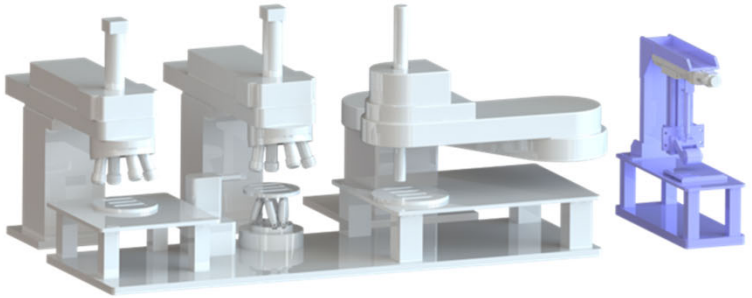
MonArk Infrastructure Development

- 4 K nano-optics (MSU)

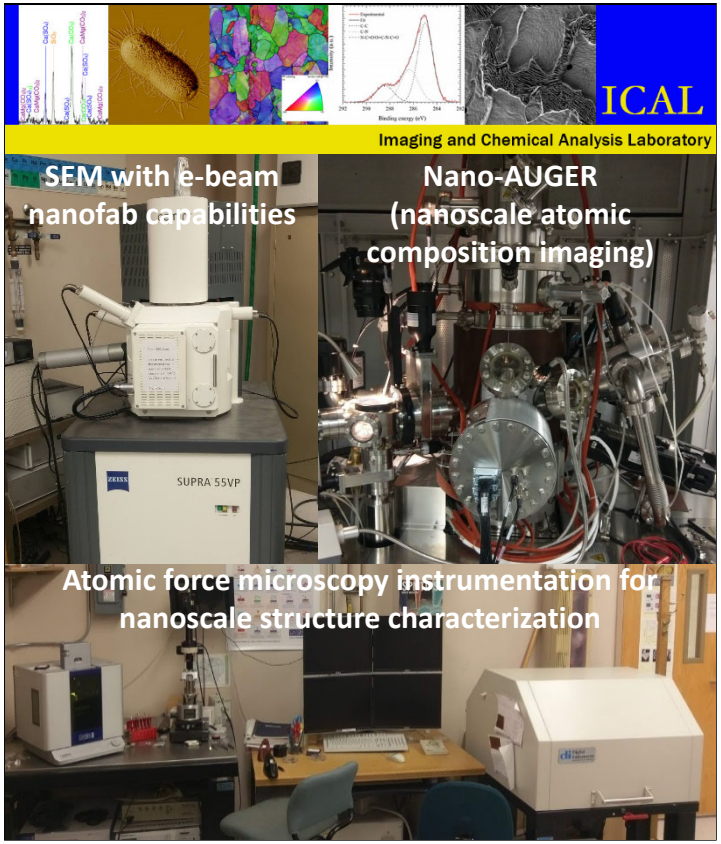


- mK qubit characterization (UA)

- Automated 2D material exfoliation and device fabrication (MSU and UA)



On-campus shared-use facilities to accelerate research



MONTANA STATE UNIVERSITY | Montana Microfabrication Facility

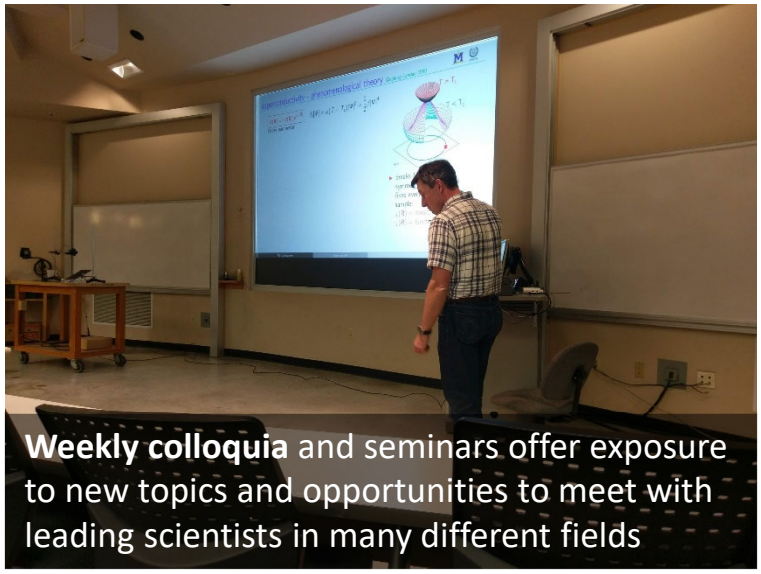
• multiple etchers • thin-film evaporation & sputtering
• optical mask aligner • wafer bonding

• a new cryogenic-TEM system recently funded

CENTER FOR BIOFILM ENGINEERING

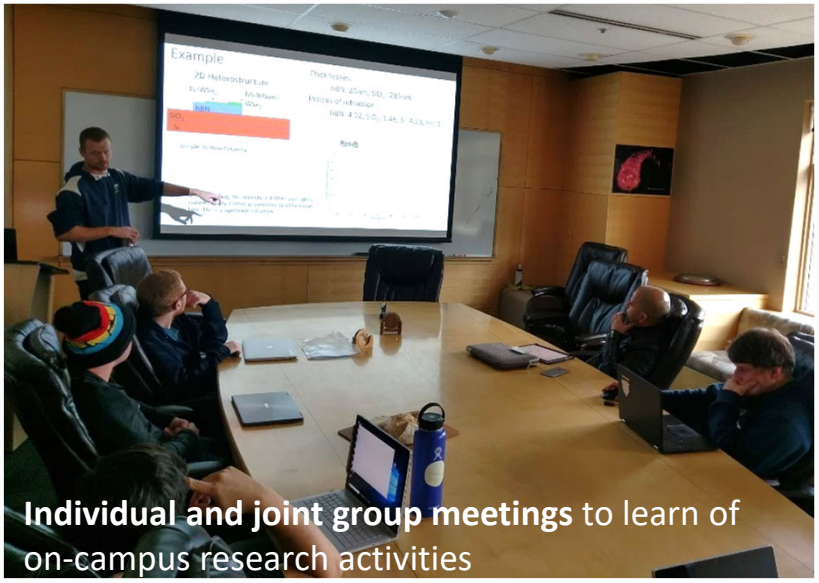
• (User-friendly) Raman and fluorescence microscopy

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

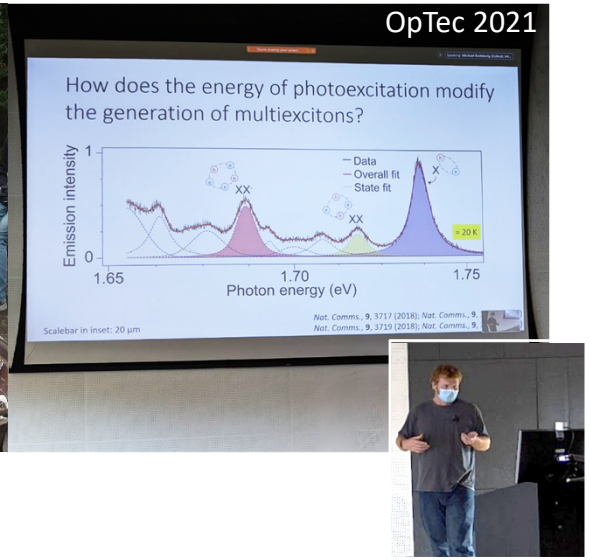


Individual and joint group meetings to learn of on-campus research activities

Social gatherings

Fall party

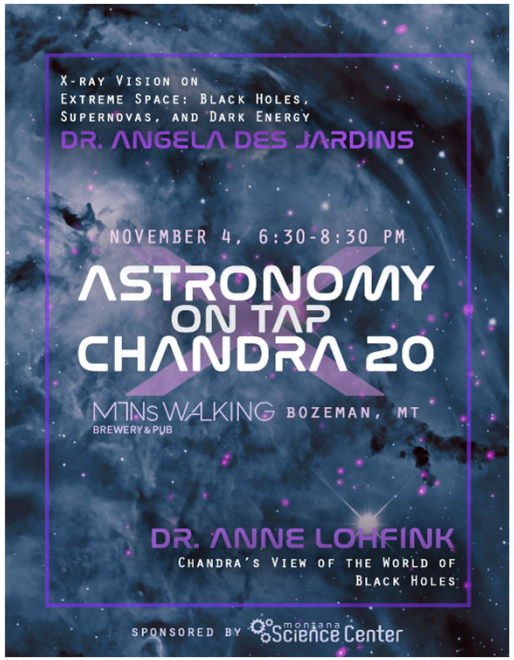
On-campus conferences



Many opportunities to participate in community outreach

montana Science Center

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

Practical matters: approximate PhD timeline

Time to completion: 5-6 years

Courses

Research

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

<u>Year 1:</u>

- Complete first half of core coursework
- Complete any needed foundational classes
- Find a **research** group
- Qualifying exam (two attempts)

<u>Year 2:</u>

- Complete majority of remaining courses
- Begin thesis-related **research**
- Qualifying exam (two attempts, if needed)
- Oral comprehensive exam (on research)

<u>Year 3:</u>

- Complete few remaining courses
- **Research, research, research**!

<u>Years 4-6:</u>

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

Qualifying exam information: https://physics.montana.edu/grad/qualifyingexam.html

Practical matters: financial support

Financial support

1. Year 1: guaranteed teaching assistantships (TAs) for the Fall, Spring and Summer semester
    1. 12 month appointment.
2. Beyond Year 1:
    1. TAs are reliably available for students who need them.
    2. We encourage you to find a research assistantship (RA).
    3. Financial support is available throughout your PhD.
3. 2020/2021 base stipends:
    1. Minimum stipend: $23,020/year

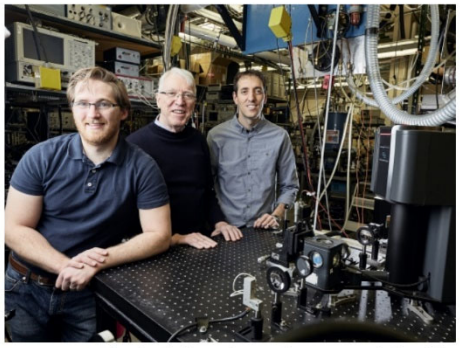
External fellowships and grants:

1. Discuss fellowship opportunities with the prospective PIs
    1. Deadlines can be in the late fall/winter of the first semester
2. A few example opportunities:
    1. Montana Space Grant Consortium Fellowships
    2. NSF Graduate Fellowship
    3. NASA FINESST
    4. DoD NDSEG Fellowship
    5. Frannie & John Hertz Foundation
    6. Graduate Fellowships for STEM Diversity
    7. Ford Foundation Fellowship Program
    8. See also: MSU Graduate School Fellowship Opportunities

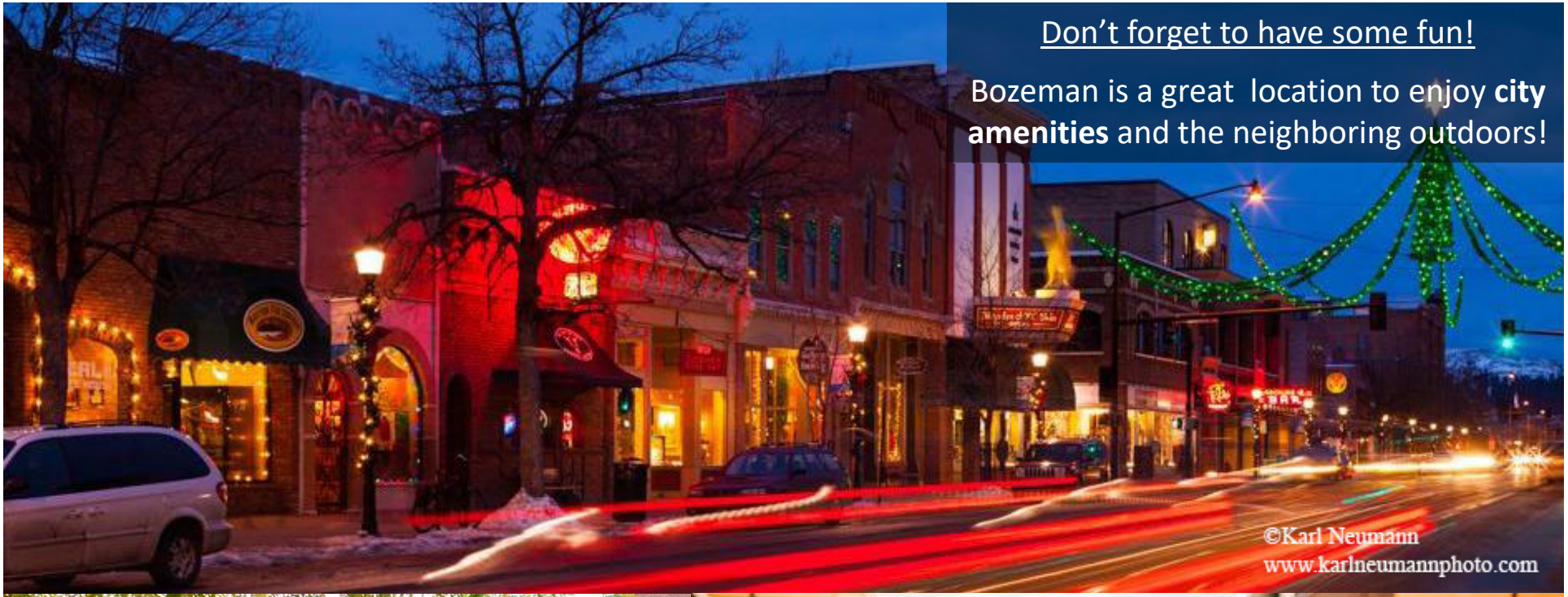
MSU grad student receives NSF award to further refine super-cold refrigerator

Evelyn Boswell for the MSU News Service

FEBRUARY 5, 2019



Montana State University physics graduate student Aaron Marsh, from left, Rufus Cone, professor of physics in the College of Letters and Science at MSU, and Josh Doherty, product development scientist at Montana Instruments, have been working together to develop a cryostat to reach temperatures near absolute zero. MSU Photo by Adrian Sanchez-Gonzalez



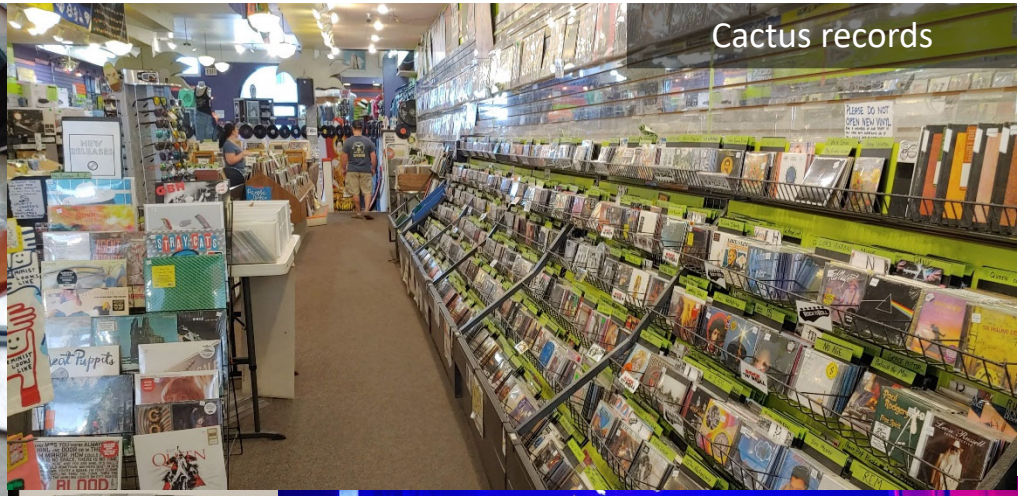
Don’t forget to have some fun!

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

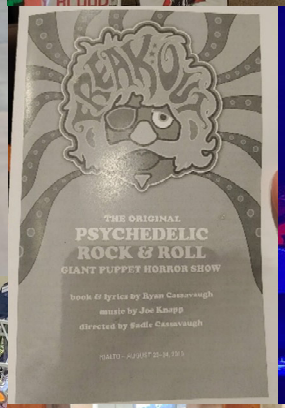
Music on main

Bozeman CVB

Ramen from
Hokkaido Ramen



Cactus records



Musical and Musical program at Rialto

Sweet Pea Festival

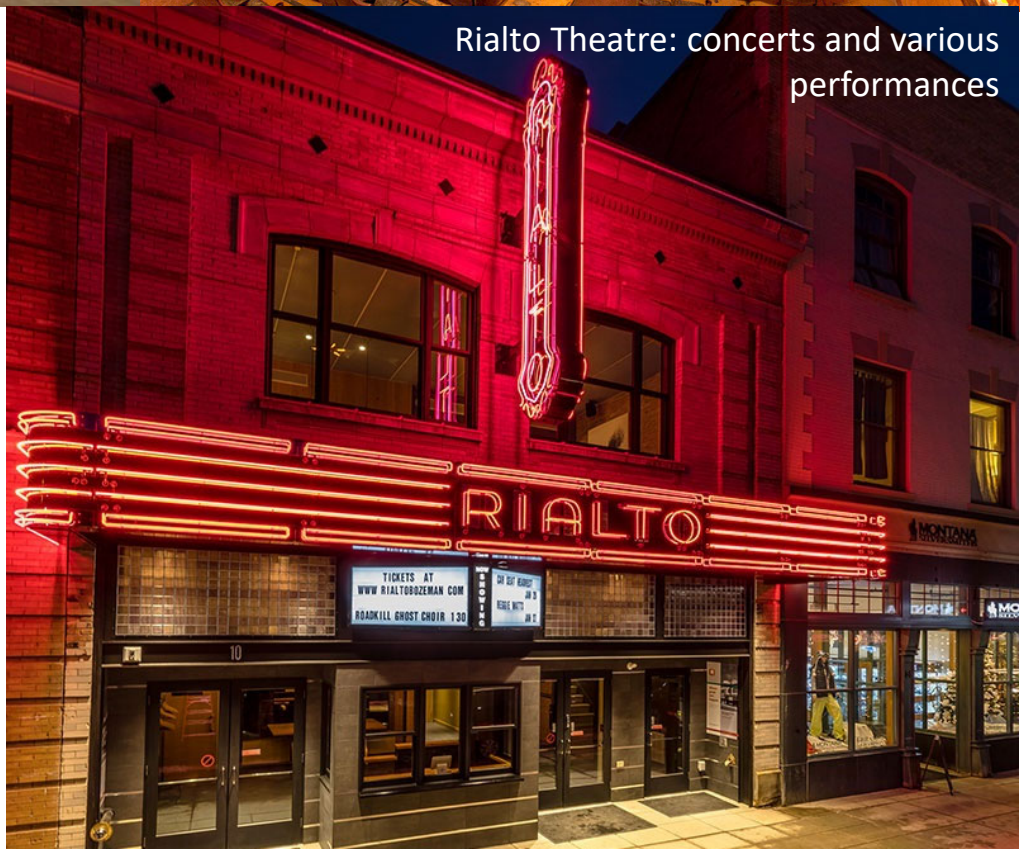
Airport bears!

One of two escape rooms in Bozeman

Emerson Center for the Arts and Culture:
The museum hosts art exhibits.

Ellen Theatre: musicals/shows and various performances here.

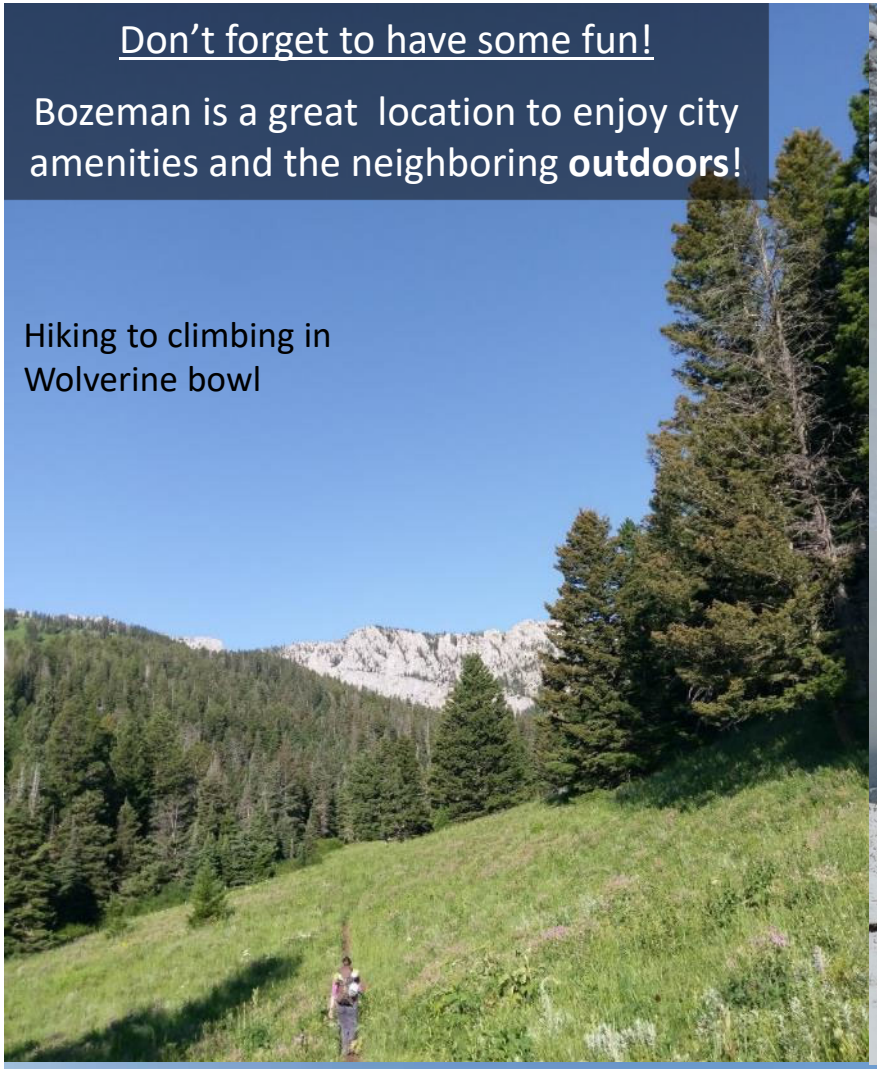
Year-round Farmer's market



Rialto Theatre: concerts and various performances

Don’t forget to have some fun!

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



Hiking to climbing in Wolverine bowl

Skiing between Big Sky & Yellowstone

Mallory Molina’s dog enjoying winter

Climbing at Natural Bridge Falls

View from the “M”

Yellowstone National Park

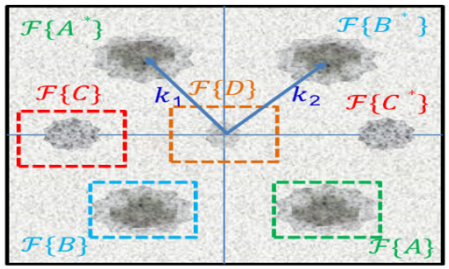
Research group summaries
(in alphabetical order)

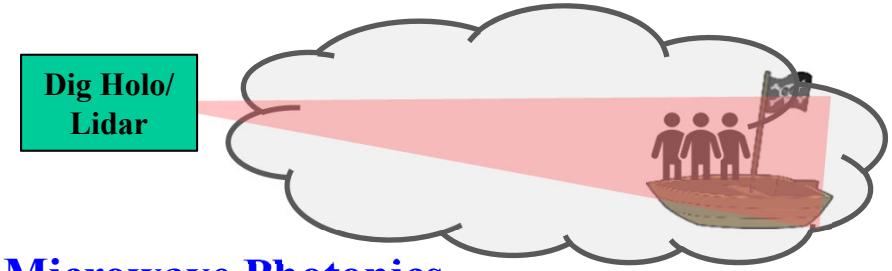
Prof. Randy Babbitt's Labs w/ Drs. Rupavatharam and Ebbers

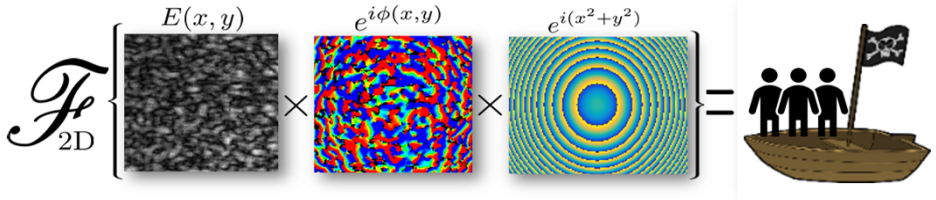
Spectrum LAB
Montana State University

Coherent Lidar and Digital Holography

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

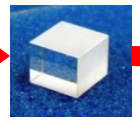


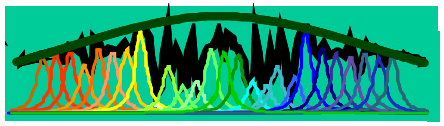




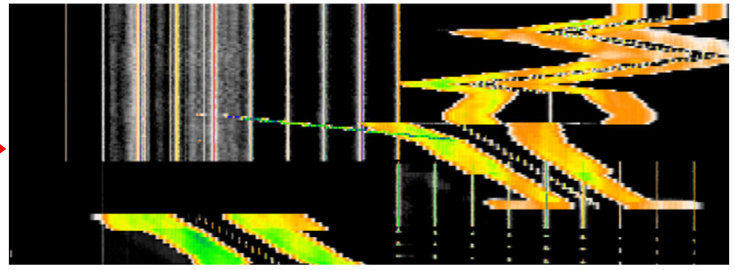
Microwave Photonics

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

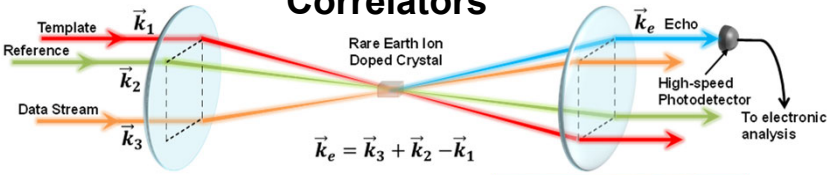




Microwave Spectrogram



Correlators

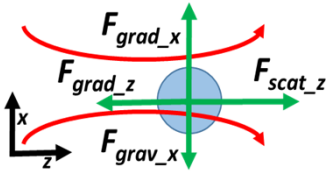


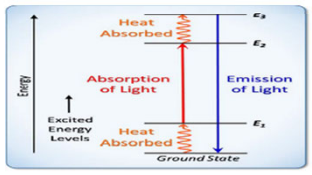
Quantum Networks

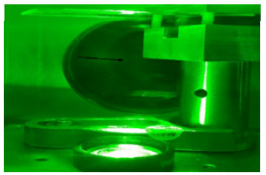
- Quantum Memory and Communications

Optically Levitated Particles

- Laser Cooling
- Precision Gyroscopy







Nano-optics of quantum materials at Montana State

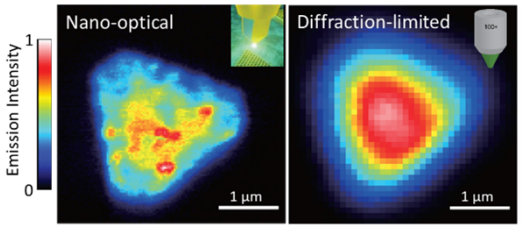
New materials to harness quantum phenomena on ultra-small length scales and ultrashort timescales.

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

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

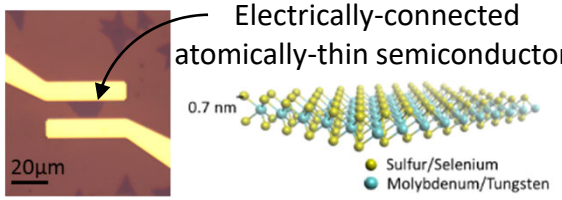
Research Highlights

Optical microscopy & spectroscopy beyond the diffraction-limit



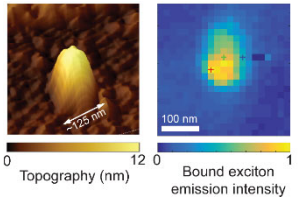
Nat. Commun. **6**, 7993 (2015) • *2D Mater.* **4**, 021024 (2017)
Nature Nano. **15**, 854 (2020)

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



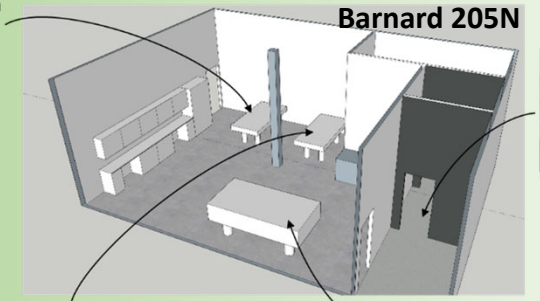
Strain-engineered non-classical light source in a 2D semiconductor!

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

Experimental facilities

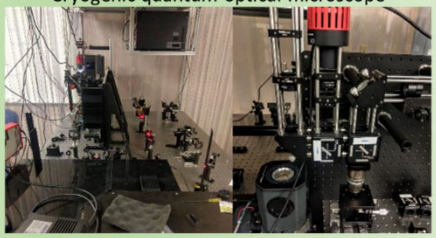
Ultrafast laser system

- Δt=100 fs – 6 ns
- λ=227 – 2000nm



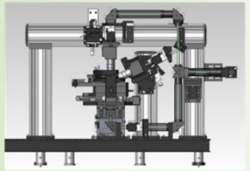
Sample prep, fab, & growth

Cryogenic quantum-optical microscope



T = 3-350 K • Δt≈30 ps • Δx ≈300 nm

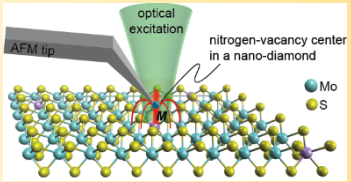
Nano-optical microscope



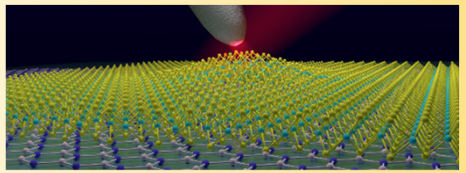
Atomic force & optical microscope
T = 300 K • Δt≈30 ps • Δx < 20 nm

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

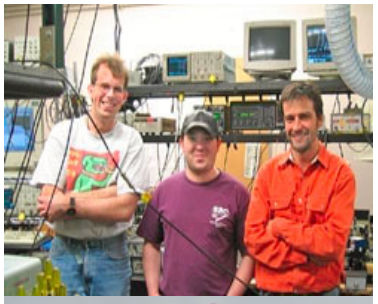
B.S., M.S., and Ph.D. graduates placed in

- 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

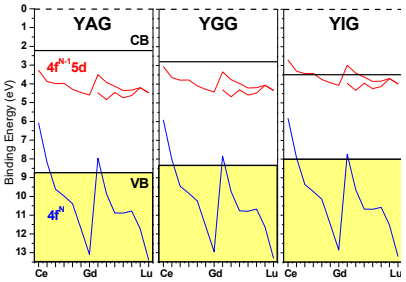
Funding DOE (Yale + MSU), NSF (MSU + Caltech + UT-Austin), Boeing, Air Force Research Lab, & others in progress

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



Scientific Materials Corp.



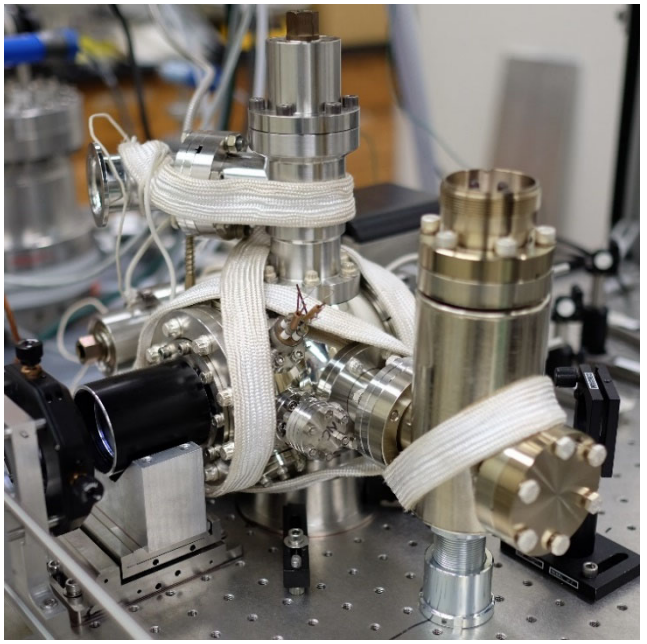
D’Urso Lab - Levitated Quantum Optomechanics

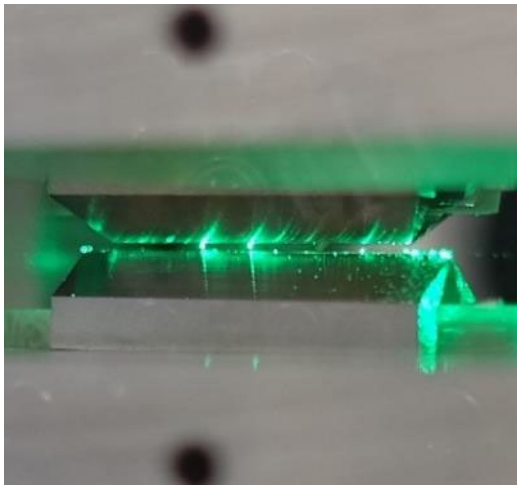
<u>Techniques</u>

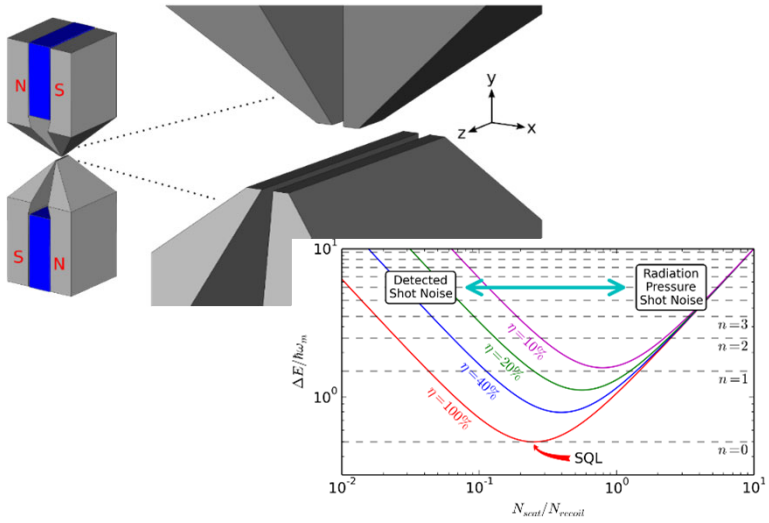
- Magnetic levitation of microparticles.
- Lasers measure particle motion and manipulate particles.

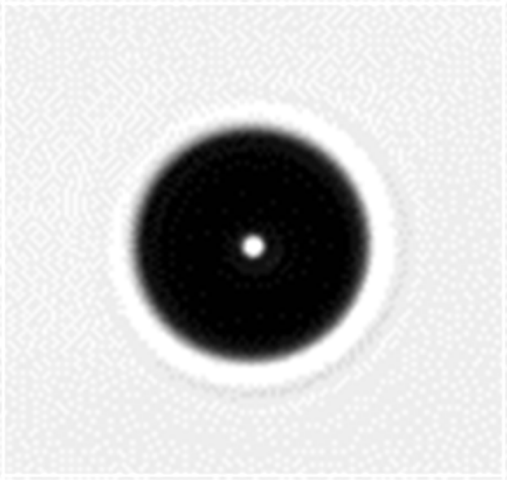
<u>Applications</u>

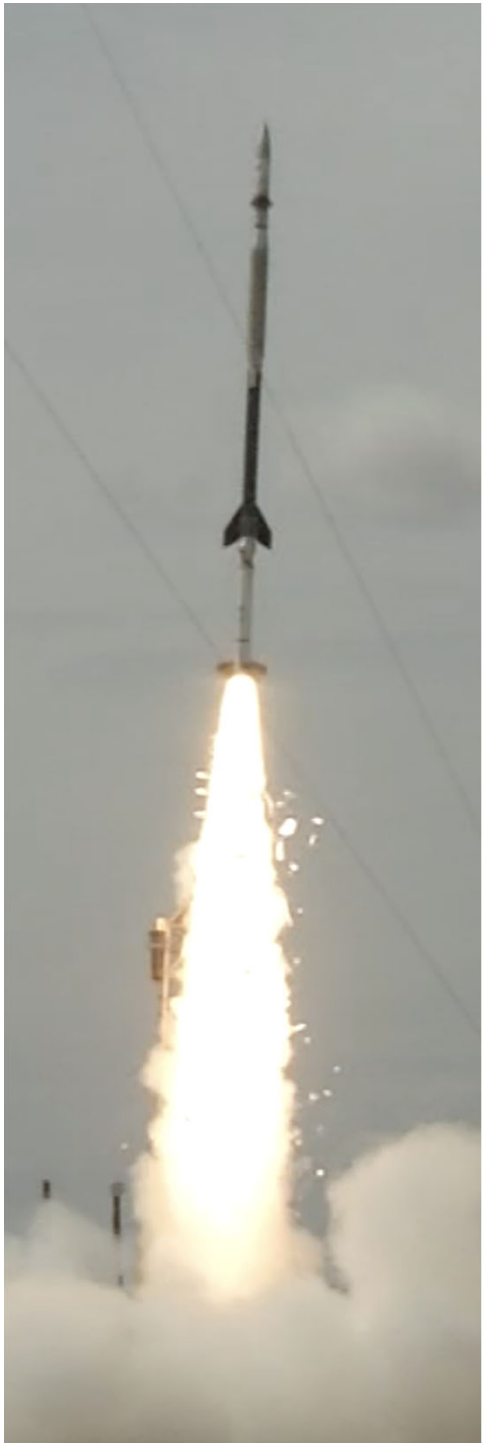
- Probing the limits of quantum mechanics.
- Precision measurements of fundamental constants.
- High-sensitivity accelerometry.





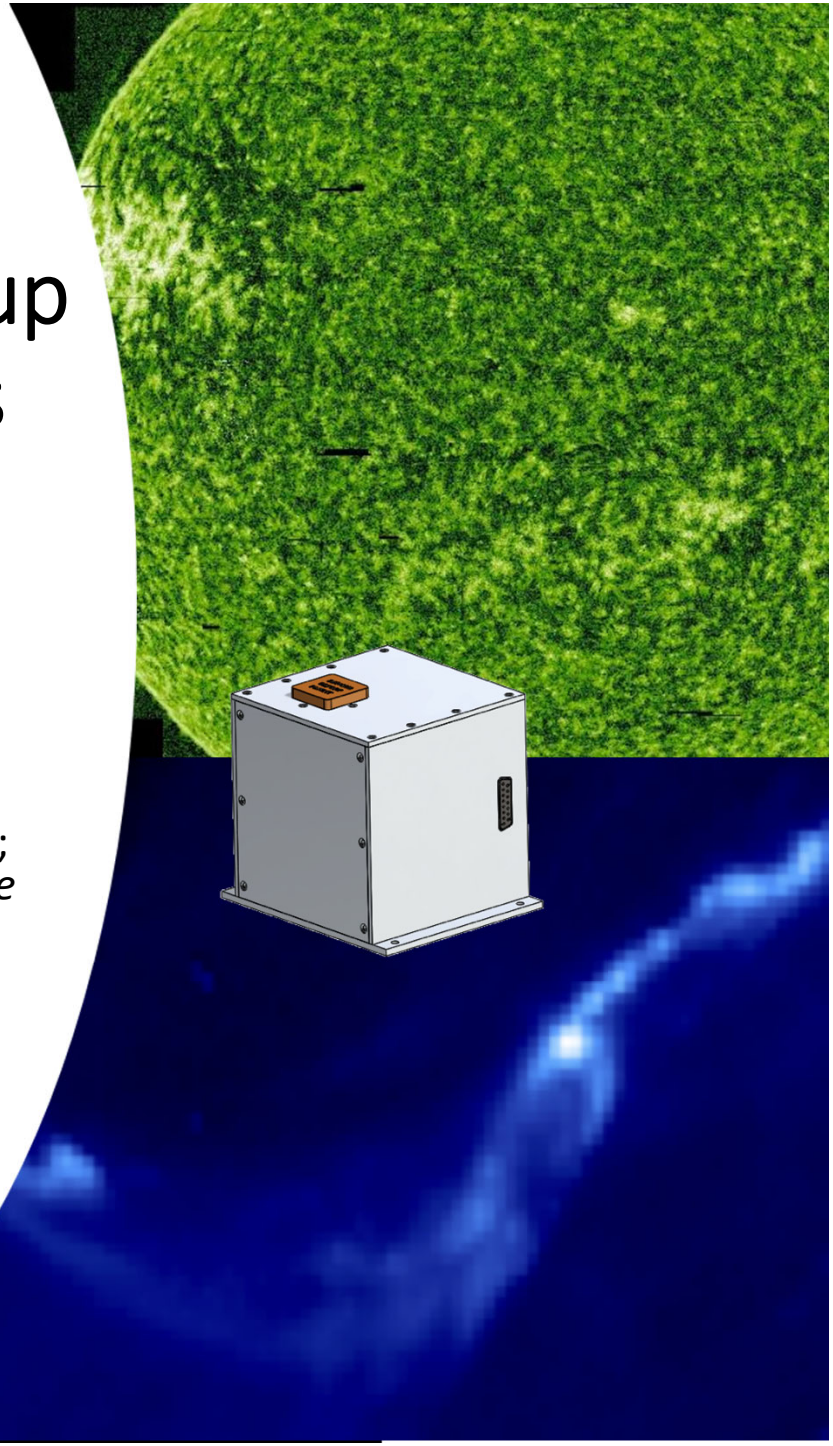






Kankelborg Group Current Projects

- 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.*

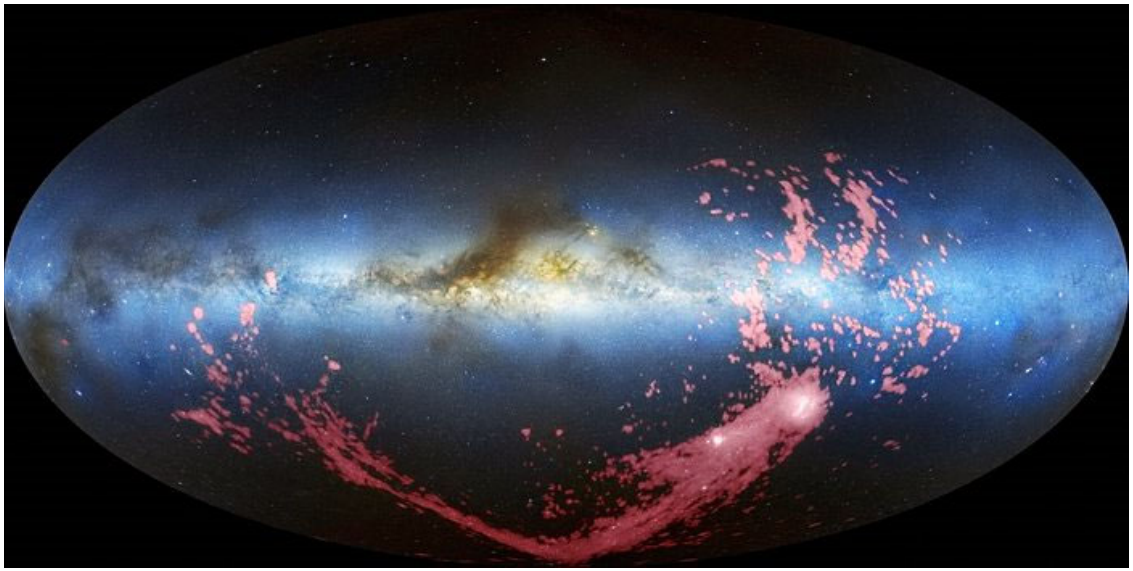
3. Vanadium, Niobium, and Tantalum

   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

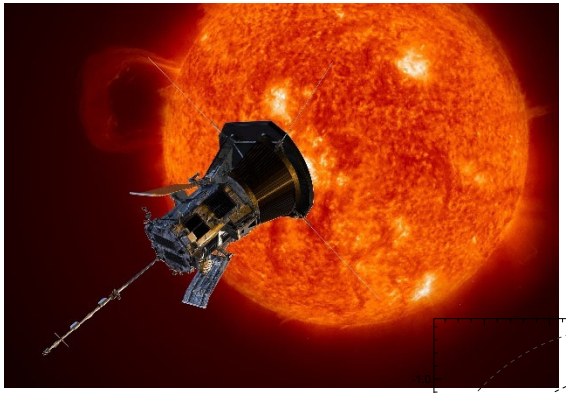
Topics:

- 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

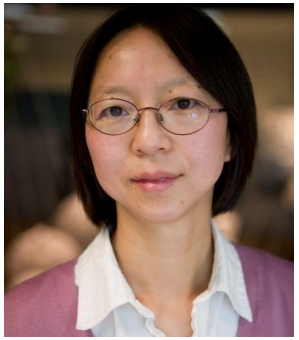


Observations

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

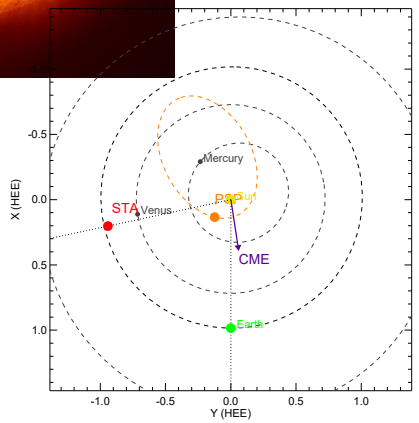


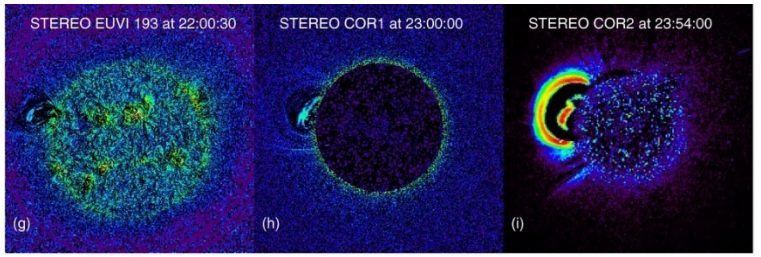
Explosions of solar flares and Coronal Mass Ejections are fueled by magnetic reconnection, a process taking place in many astrophysical environments. We observe flares and CMEs, and study energy release by magnetic reconnection.

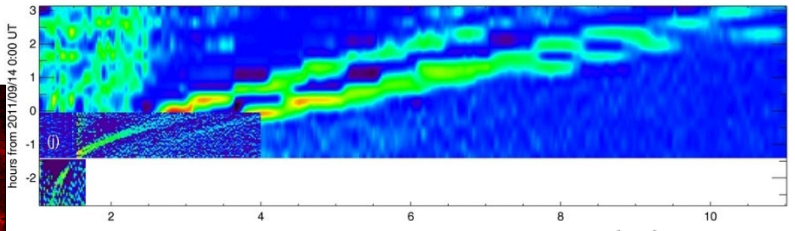


Prof. Jiong Qiu

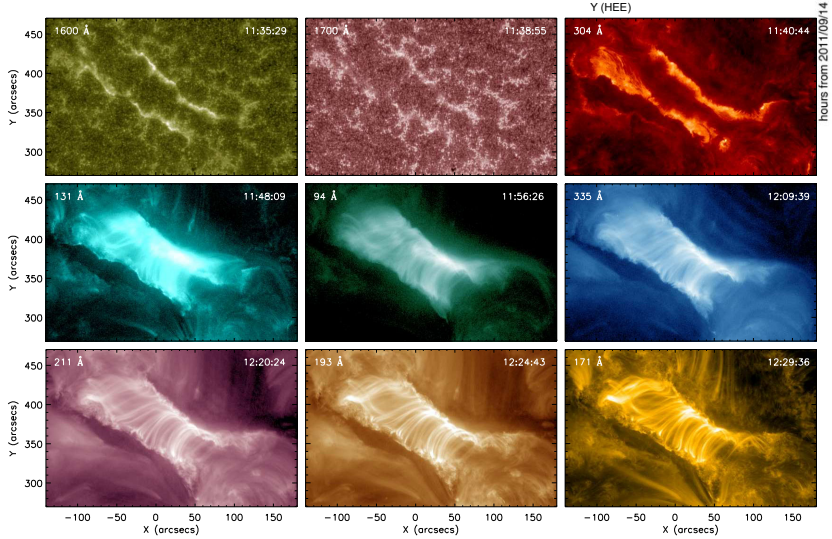
Parker Solar Probe at 0.1 AU from the Sun.



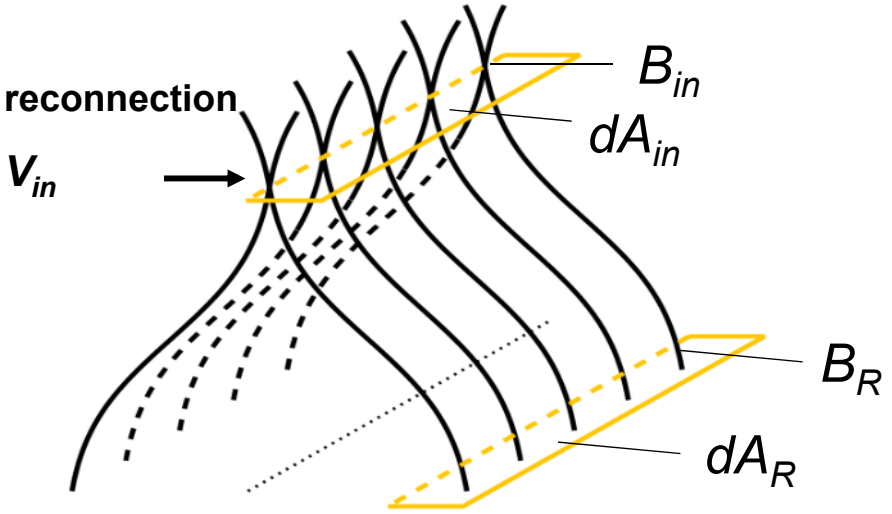




CMEs are released by reconnection and tracked by STEREO spacecraft observing the Sun from side.



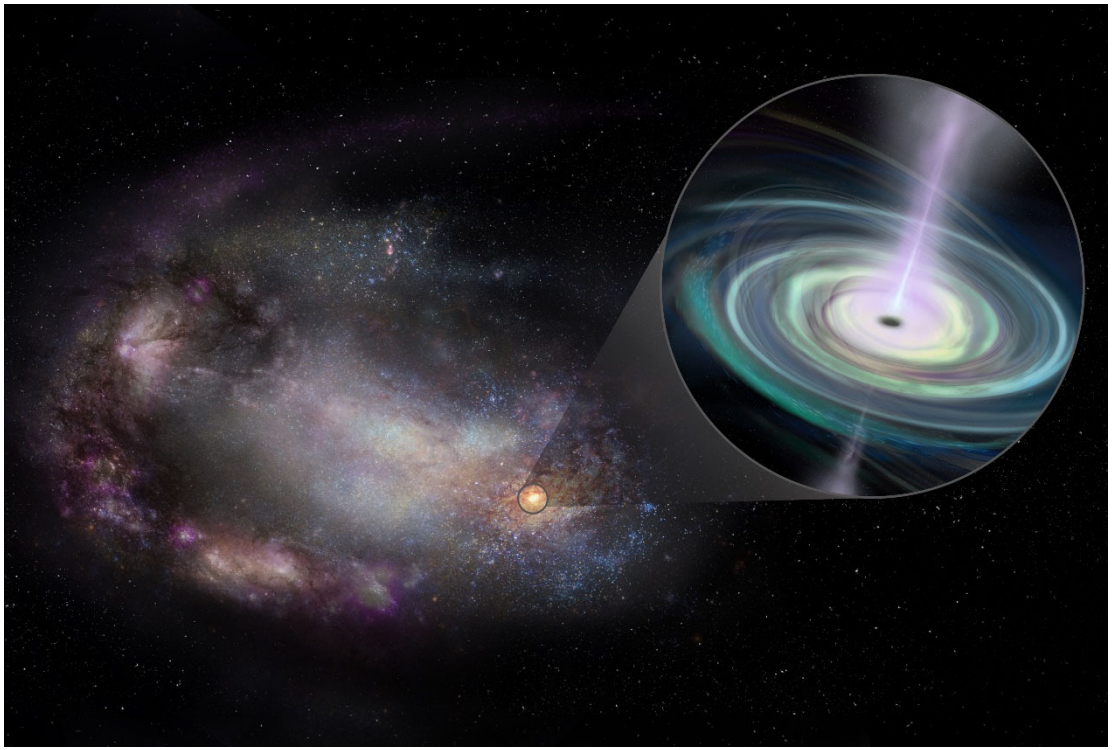
Arcades of flares formed by reconnection, observed by Solar Dynamics Observation



Reines Research Group

Topics:

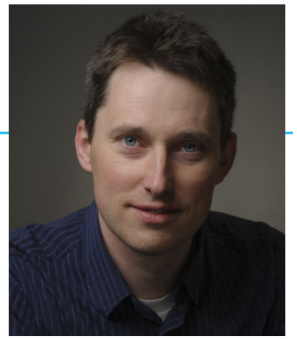
- Massive black holes in dwarf galaxies and the origin of black hole "seeds"
- Active Galactic Nuclei
- Extragalactic Star Formation
- Evolution of galaxies and their massive black holes



Observations:

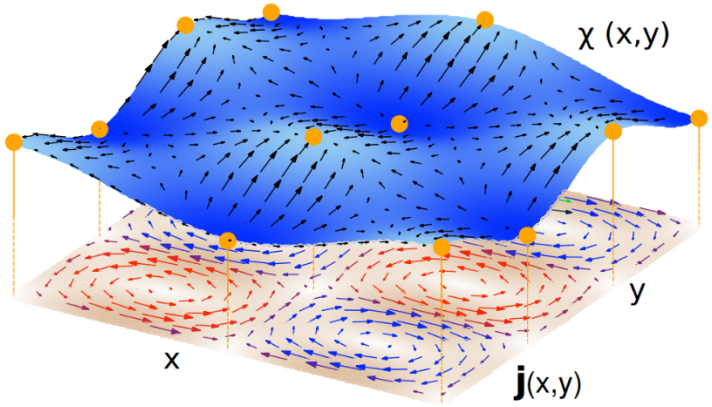
- Multi-wavelength observations spanning radio to X-ray wavelengths
- Large survey data (e.g., SDSS) and dedicated observations (e.g., HST, Chandra, VLA, Gemini)
- Imaging and spectroscopy

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

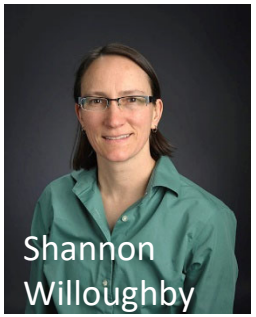
Methods

- 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