Welcome to Montana State University

Barnard Hall
home of the Physics department

Nick Borys
Dana Longcope

Bridger Bowl
Barnard Hall
home of the Physics department

Downtown

Mallory Molina
Anne Lohfink
Nick Borys
Dana Longcope
2nd floor of Barnard Hall
Physics Department Staff

Margaret Jarrett
Graduate coordinator

Norm Williams
Machine shop supervisor

Stephanie McLaren
Business operations manager

Shane Mayer-Gawlik
Instructional lab supervisor
Physics Department Staff

Halloween 2019
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

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</tbody>
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### 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
- ...
The Physics department is very active in research

Annual research expenditures: $6.6 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

- **MSU satellite launched to space station**
  
  February 19, 2021

- **Montana State's Dana Longcope wins Arctowski Medal**
  
  January 26, 2021

- **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
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

Charles Kankelborg

**Magnetohydrodynamics & solar physics**

Magnetic phenomena and fields on the sun

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

Dana Longcope

**Solar astrophysics**

Magnetic reconnection and instabilities on the sun

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

Jiong Qiu

**Near-earth high-energy particle phenomena**

Satellite-based high-energy particle observations

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

John Sample
Research in Solar and Space Physics

Observing initiation and propagation of coronal mass ejections
Prof. Jiong Qiu

Observing and modeling creation and evolution of hot plasma in solar flares
Prof. Dana Longcope

``Small'' explosions observed using rocket-borne slitless spectrograph
Prof. Charles Kankelborg

``Small'' explosions observed using rocket-borne slitless spectrograph
John Unverferth: PhD 2020

Electron microbursts in Earth’s radiation belt, observed by nanosatellites
Prof. John Sample

Wang et al. 2019

Hans Courier: PhD 2020

Mike Shumko: PhD 2019
Hinode
Commanded by students (& faculty) from MSU (264 Barnard Hall)

We work with data from space

Parker Solar Probe

IRIS (Kankelborg, Co-I)

McCarthy et al. 2020
Shumko et al. 2018
Wang et al. 2019

SDO

Van Allen Probes

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

Firebirds 3 & 4

Barrel

Bozeman

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

- Neutron Stars
- Black Hole Mergers and Gravitational Waves
- Active Galactic Nuclei
- The Milky Way and its Satellite Galaxies
- Small Bodies in the Solar System
- Galaxies, Supermassive Black Holes and Star Formation
Observatories

- Chandra X-ray Observatory
- Laser Interferometer Gravitational-Wave Observatory (LIGO)
- Very Large Array
- Hubble Space Telescope
- James Webb Space Telescope
- Cerro Tololo Inter-American Observatory
Research Activities

AAS Meeting in Seattle

Observing at CTIO in Chile

MSU JWST Workshop

SMASH Workshop Dinner in Bozeman

JWST Masterclass at the Space Telescope Science Institute
# Research in optics, condensed matter and quantum materials/systems

## Levitated optomechanics
Levitated optomechanics

**Brian D’urso**

**Precision measurement using quantum systems**


## Nano-optics & quantum materials
Quantum phenomena in low-dimensional materials

**Nick Borys**

**Randy Babbitt**

**Quantum phenomena in condensed matter**


[http://spectrum.montana.edu](http://spectrum.montana.edu)

## Photonic and imaging
Microwave photonics, LIDAR, & digital holography

**http://www.dursolab.org/**

## Quantum materials
Quantum phenomena in condensed matter

**John Neumeier**

[https://sites.google.com/view/neumeier-lab-msu](https://sites.google.com/view/neumeier-lab-msu)

## Ultrafast nonlinear optics
Materials and techniques for nonlinear optics

**Aleks Rebane**

**Rufus Cone**

**Unconventional superconductivity & quantum liquids**

[http://physics.montana.edu/directory/faculty/1524001/rufus-cone](http://physics.montana.edu/directory/faculty/1524001/rufus-cone)

## Rare-earth materials for QIS
Fundamental material physics & signal processing

**Anton Vorontsov**

**Spin phenomena in nano-structured materials**

[http://physics.montana.edu/directory/faculty/1524200/yves-idzerda](http://physics.montana.edu/directory/faculty/1524200/yves-idzerda)

## Condensed matter theory

**Yves Idzerda**

## Magnetism and spin structures
On-campus shared-use facilities to accelerate research

- **SEM with e-beam nanofab capabilities**
- **Nano-AUGER** (nanoscale atomic composition imaging)
- Atomic force microscopy instrumentation for nanoscale structure characterization
- Multiple etchers, thin-film evaporation & sputtering
- Optical mask aligner, wafer bonding
- (User-friendly) Raman and fluorescence microscopy
- A new cryogenic-TEM system recently funded
Physics machine shop for custom experimental projects
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.

Casual social gatherings and dinners.

Individual and joint group meetings to learn of on-campus research activities.
Many opportunities to participate in community outreach

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
Women+ in Physics

Dedicated to creating a supportive community climate of inclusivity with a long-term goal of increasing the number of women and underrepresented genders in the field.

On-Going Projects of MSU W+iP:
1. Mentorship program for undergraduate and graduate students
2. Library of Physics books for undergraduate and graduate students

Leaders:
President: Katie Fasbender (Grad), VP: Elizabeth Vinson (undergrad)
Co-Advisors: Amy Reines (faculty), Mallory Molina (postdoc)
Towards a More Inclusive Astronomy

National organization with the goal of creating inclusive environments within physics and astronomy departments (www.tamiastronomy.org/)

Goals of TaMIA Chapter at MSU Physics:
1. Cultivate Discussion about inclusion and climate in the department
2. Create a supportive environment for marginalized people within TaMIA meetings and the entire department

MSU Leaders (always open to new leaders):
Postdocs: Mallory Molina, Remya Nair
Grad Students: Bethany Garver, Michael Mingyar, Jessica Myron
Practical matters: approximate PhD timeline

Time to completion: 5-6 years

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
**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](https://www.spacegrant.org/montana)
   2. [NSF Graduate Fellowship](https://www.gsgnmsu.edu/)
   3. [NASA FINESST](https://finest.nasa.gov/)
   4. [DoD NDSEG Fellowship](https://www.naval.nps.navy.mil/)
   5. [Frannie & John Hertz Foundation](https://www.hertz.org/)
   6. [Graduate Fellowships for STEM Diversity](https://www.stemdiversity.org/)
   7. [Ford Foundation Fellowship Program](https://www.fordfoundation.org/)
   8. See also: [MSU Graduate School Fellowship Opportunities](https://graduate.montana.edu/financialaid/fellowships/)

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

Evelyn Boswell for the MSU News Service
FEBRUARY 5, 2019
Practical matters: first-year expectations

Classes and teaching responsibilities

1. Classes:
   1. Fall: Classical Mechanics, Quantum I, Math Physics I
   2. Spring: Quantum II, E&M I, Statistical Mechanics
   3. You will meet with an adviser when you arrive to discuss your specific coursework plan

2. Teaching: 19 hrs/week
   1. Assignments vary (labs, grading, etc.)

3. Research: few hrs/week (as much as possible)

Finding a research group

1. Email professors with research that you find interesting now! We all want to hear from you and talk about potential projects

2. Get involved with research activities as soon as possible
   1. Use small projects to try-out a lab
   2. Attend weekly group meetings (ask first!)
Practical matters: housing

1. **On-campus**: once you accept, get on the graduate student housing waiting list immediately to increase your chances of getting a spot
   - Rates: [see listings on MSU FGH site](#)
   - Officially no pets*
   - You may only apply if you have accepted an offer
   - Offer some of the best views

2. **Off-campus**: roommates make the rent affordable
   - Many options around campus and near downtown
   - Margaret will facilitate introductions so that you can look for housing with other first-year students

Resources:
1. [MSU Family and Graduate Housing – Prospective Tenants](#)
2. [MSU Off-Campus Housing Market Place](#)
Practical matters: health insurance

1. As a graduate student, you have full access to the Montana State University Health Services*
   1. Provide: primary care, pharmacy services, vaccinations, x-rays, acute care, clinical laboratory services, counseling services, etc.
   2. Cost:
      1. Basic services covered by the University Health Fee
      2. Additional fees may apply for prescriptions, lab-work, x-rays, etc.

2. In addition, you are required by MSU to have insurance:
   1. Affordable health insurance is available through the Montana market place (MSU’s student insurance is expensive ($385/mo)).

Sample plans on HealthCare.gov* ($1/mo - $200/mo)

Additional resources

• MSU Graduate School Guidance on Healthcare
• ACA Navigator (non-profit program for choosing health insurance in Montana)
• HealthCare.gov

* Assumes a $307.18 tax credit estimated using a $20k/year income. Priced for a 22 y/o male; no tobacco use.
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

Sweet Pea Festival

Cactus records

Musical and Musical program at Rialto

One of two escape rooms in Bozeman

Airport bears!
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’s dog enjoying winter

Climbing at Natural Bridge Falls

Yellowstone National Park

View from the “M”
Research group summaries
(in alphabetical order)
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

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

Optical microscopy & spectroscopy beyond the diffraction-limit

Optical microscopy & spectroscopy beyond the diffraction-limit

Nanomaterials & ultrafast many-body physics in 2D materials

Electrically-connected atomically-thin semiconductor!

2D material engineering for on-chip quantum photonics

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

- 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).

Research Highlights

- Optical microscopy & spectroscopy beyond the diffraction-limit
- Nanoscale & ultrafast many-body physics in 2D materials
- 2D material engineering for on-chip quantum photonics

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).
“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 4fn 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
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 H₂O 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 H₂O and D₂O 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.

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

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