Physics Department Staff

Margaret Jarrett
Graduate coordinator

Stephanie McLaren
Business operations manager

Elicia Palmer
Academic services coordinator

Norm Williams
Machine shop supervisor

Shane Mayer-Gawlik
Instructional lab supervisor
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
$138.6 million in awarded grants
### Physics Courses

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

### 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

**Faculty by expertise**
- 8 faculty members in condensed matter, optics, and quantum systems.
- 6 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 68 graduate students actively working in all four areas.

**Annual research expenditures:** $5.9 Million

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**Recent News**

- **Cornish and Creel to give joint talk on March 24**
  *March 8, 2022*

- **MSU research shows creative side of black holes**
  *January 24, 2022*

- **Molina pioneering method to search for black holes**
  *January 10, 2022*

- **Cornish, Creel named CLS distinguished professors**
  *November 9, 2021*

- **Brian D’Urso to give Nov. 16 provost's lecture**
  *November 5, 2021*

- **MSU researchers receive $6 million to advance quantum internet**
  *March 16, 2020*

- **MSU awarded $20M grant for quantum technology development**
  *September 2, 2021*

- **Teaching the teachers: Gregory Francis awarded Millikan Medal for physics teaching**
  *March 25, 2021*
Many opportunities for research in solar and space physics

**Extreme UV observations of solar phenomena**
- Charles Kankelborg
- Rocket-based instrumentation for solar observations
  - [http://solar.physics.montana.edu/kankel](http://solar.physics.montana.edu/kankel)

**Magnetohydrodynamics & solar physics**
- Dana Longcope
- Magnetic field and flares on the Sun
  - [http://solar.physics.montana.edu/dana](http://solar.physics.montana.edu/dana)

**Solar astrophysics**
- Jiong Qiu
- Magnetic reconnection and instabilities on the sun
  - [https://physics.montana.edu/directory/faculty/1524495/jiong-qiu](https://physics.montana.edu/directory/faculty/1524495/jiong-qiu)

**Near-earth high-energy particle phenomena**
- John Sample
- Satellite-based high-energy particle observations
  - [https://physics.montana.edu/directory/faculty/1987181/john-sample](https://physics.montana.edu/directory/faculty/1987181/john-sample)

**New hire in space physics**
- [http://solar.physics.montana.edu/directory/faculty/1987181/john-sample](http://solar.physics.montana.edu/directory/faculty/1987181/john-sample)
Research in Solar and Space Physics

Observing initiation and propagation of coronal mass ejections
Wang et al. 2019
Prof. Jiong Qiu

``Small'' explosions observed using rocket-borne slitless spectrograph
Jake Parker: PhD 2021
Prof. Charles Kankelborg

Observing and modeling magnetic reconnection in the solar corona
Marika McCarthy: PhD 2021
Prof. Dana Longcope

Electron microbursts in Earth’s radiation belt, observed by nano-satellites
Mike Shumko: PhD 2019
Prof. John Sample
Hinode
Commanded by students (& faculty) from MSU (264 Barnard Hall)

Van Allen Probes

SDO

IRIS (Kankelborg, Co-I)

Parker Solar Probe

We work with data from space

Shumko et al. 2018

Coming soon: MUSE (Kankelborg Co-I)

STEREO
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
- **Hi-C-flare**: rocket payload; X-ray monitor of solar flares
- **IMPRESS**: cube-sat; hard X-ray spectra of solar flares
- **MUSE**: NASA MIDEX; imaging EUV solar spectrograph
Research in Astrophysics and Extreme Gravity

- **Extreme Gravity, Gravitational Waves**
  - Neil Cornish

- **Neutron Star Composition, Dynamics, & Evolution**
  - Bennett Link

- **Active Galactic Nuclei Accretion & Jets**
  - Anne Lohfink

- **Galaxy Evolution, Local Group Surveys & Big Data**
  - David Nidever

- **Massive Black Holes, Star Formation, Galaxies**
  - Amy Reines

- **Compact Objects**
  - Sachiko Tsuruta

- **New Area in Extreme Gravity/Astrophysics**
Research Activities

NANOGRAV Conference @ Vanderbilt University

Observing at CTIO in Chile

JWST Masterclass at the Space Telescope Science Institute

MSU JWST Workshop

SMASH Workshop Dinner in Bozeman
## Research in optics, condensed matter and quantum materials/systems

### Levitated optomechanics
- **Brian D’urso**
  - Precision measurement using quantum systems
  - [http://www.dursolab.org/](http://www.dursolab.org/)

### Nano-optics & quantum materials
- **Nick Borys**
  - Quantum phenomena in low-dimensional materials
  - [http://www.monarkfoundry.org](http://www.monarkfoundry.org)

### Photonic and imaging
- **Randy Babbitt**
  - Microwave photonics, LIDAR, & digital holography
  - [http://spectrum.montana.edu](http://spectrum.montana.edu)

### Quantum materials
- **John Neumeier**
  - Quantum phenomena in condensed matter
  - [https://sites.google.com/view/neumeier-lab-msu](https://sites.google.com/view/neumeier-lab-msu)

### Ultrafast nonlinear optics
- **Aleks Rebane**
  - Materials and techniques for nonlinear optics
  - [http://physics.montana.edu/arebane/research/](http://physics.montana.edu/arebane/research/)

### Rare-earth materials for QIS
- **Rufus Cone**
  - Fundamental material physics & signal processing
  - [http://physics.montana.edu/directory/faculty/1524001/rufus-cone](http://physics.montana.edu/directory/faculty/1524001/rufus-cone)

### Condensed matter theory
- **Anton Vorontsov**
  - Unconventional superconductivity & quantum liquids
  - [http://physics.montana.edu/avorontsov](http://physics.montana.edu/avorontsov)

### Magnetism and spin structures
- **Yves Idzerda**
  - Spin phenomena in nano-structured materials
  - [http://physics.montana.edu/directory/faculty/1524200/yves-idzerda](http://physics.montana.edu/directory/faculty/1524200/yves-idzerda)
  - [http://www.monarkfoundry.org](http://www.monarkfoundry.org)
On-campus shared-use facilities to accelerate research

Nanoscale fabrication and characterization
- Multiple AFMs • 3 SEMs (2 w/nanofab capabilities
- Nano-AUGER • XRD • Optical microscopes • Etc.

Cleanroom and nanoscale fabrication
- Multiple etchers • thin-film evaporation & sputtering
- Optical mask aligner • wafer bonding

Cryo-EM Facility
- Transmission electron microscopy at cryogenic temperatures and room temperature

(User-friendly) Raman and fluorescence microscopy
Goal: accelerate 2D materials research to solve challenges in quantum information science and technology

$22.2M for six years – 18 research groups in Montana and Arkansas
MSU Quantum Network Project

Features
- Hybrid network for classical (ECE) and quantum communications (Spectrum)
- Entangled photon pair generation (AdvR, Spectrum)
- Photon based entanglement transport through fibers and free-space links (Spectrum)
- Spatial spectral materials for multimode quantum memory (Physics Dept.)
- Quantum frequency conversion and quantum functionality eg., Sensing (Spectrum, Physics)

https://spectrum.montana.edu/
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.

**On-campus workshops and conferences**

**Casual social gatherings**

**Research group hikes!**

**OpTec 2021**

Emerald Lake
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: Jessica Myron (grad)
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.tamiastonomy.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
Grad Students: Bethany Garver, Michael Mingyar, Jessica Myron, Seth Kimbrell, Katherine Bruce, Erica Chwalik
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
- First and second attempt at qualifying exam

**Year 2:**
- Complete majority of remaining courses
- Begin thesis-related research
- If needed, second comprehensive exam
- Third and fourth qualifying exam attempts
- 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

Courses

Research
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. **2021/2022 base stipends**:
   1. Minimum stipend: $25,330/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](#)
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)

4. Qualifying exam:
   1. First attempt: at the beginning of the fall semester.
   2. Second attempt: at the beginning of the spring semester

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!)

3. It helps to have passed one or more subjects on the qualifying exam after your second attempt to get a firm commitment from an adviser.
Practical matters: housing

1. **On-campus:** 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 at any time
   - Application fee is returned if you do not accept our 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)

* Assumes a $347 tax credit estimated using a $25k/year income. Priced for a 22 y/o male; no tobacco use.

Additional resources

- MSU Graduate School Guidance on Healthcare
- ACA Navigator (non-profit program for choosing health insurance in Montana)
- HealthCare.gov
Don’t forget to have some fun!
Bozeman is a great location to enjoy city amenities and the neighboring outdoors!
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!

Skiing in Beehive Basin

Hiking on the “M”

Physics Grads hiking Drinking Horse!

Climbing at Natural Bridge Falls

“Kayaking” around Hyalite reservoir with Buster

Yellowstone National Park
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

Nanoscale & ultrafast many-body physics in 2D materials

2D material engineering for on-chip quantum photonics

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 $4f^n$ 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
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$_2$O 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$_2$O and D$_2$O 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.

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

**Methods**

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

**Fun things**

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