Undergraduate Research Opportunities in Physics (2020)

Mentor: **Jeong-Young Ji, *Plasma kinetic/fluid theory***

Possible projects:

(1) Develop a plasma fluid model capturing kinetic effects
(2) Develop a kinetic/fluid theory for strongly coupled plasmas

Skills: Mathematical Physics and Programming

Mentor: **Jim Wheeler, *Quantum field theory, general relativity, gauge theory, mathematical physics***

Current topics of interest include: Gauge field theories of gravity, twistor string theory, supersymmetry, quantum field theory, general relativity, Hamiltonian and quantum mechanics as conformal gauge theories. The last of these is most suitable for undergraduate involvement.

Prerequisite tools include multivariate calculus, differential equations, and linear algebra. Advance tutoring in differential forms, differential geometry, Lie groups, and Lie algebras is desirable.

Mentor: **Oscar Varela, *String theory and supergravity***

While gravity was the first fundamental interaction to be understood at the classical level, its quantisation remains an outstanding problem in theoretical physics. String theory is a candidate theory of quantum gravity that encompasses as a bonus all other fundamental interactions. Research in this topic includes the construction of solutions to the underlying supergravity equations and applications of the AdS/CFT correspondence.

Prerequisites include classical and quantum mechanics and good math skills.

Mentor: **Titus Yuan, *LIDAR***

My current research projects are focusing on optical remote sensing of the upper atmosphere, the boundary area between the well-mixed neutral atmosphere and geospace. The major instrument is an advanced lidar (light detection and ranging) system that measures the temperature and winds in the altitude range of ~ 80 km – 110 km. It takes advantage of the laser induced fluorescence by the Sodium atoms in this region (meteor ablation). The complexity of atmospheric dynamic and chemical processes in the mesosphere makes it extremely difficult for precise model simulations and, thus, requires large amount of observations to help scientists' understandings of these fundamental processes and how they affect the coupling between the lower and upper atmosphere.

I am interested in hiring students with some basic optics knowledge and experimental skills, since the above projects are all laser/optical physics related. To understand these measurements, I am also studying atmospheric dynamics and ion-neutral coupling in the upper atmosphere, so students would be involved in some projects that require data analysis and calculations of some critical parameters. Thus, programing skill (no requirement for the tools) would be desired.

Mentor: **Boyd Edwards, *Nonlinear Dynamics, Microfluidics***

I model the dynamics of charged and neutral bodies in response to applied electric, magnetic, and gravitational fields. The motion of charged particles in solution in response to applied electric fields have applications to forensic analysis in microfluidic lab-on-a-chip devices. The motion of a magnet sphere in response to the magnetic field of a second sphere has applications to collections of small neodymium magnet spheres used as desk toys. The motion of a hockey puck on the surface of the earth in response to gravitational, Coriolis, and centrifugal forces has application to meteorology, oceanography, and long-range ballistics. I am particularly interested in chaotic and nonlinear periodic motion. My approach is to get as far as I can with closed form and approximate mathematical solutions that explore the physical origins of the motion, and then to supplement these as needed with numerical solutions.

Skills: Interest in electromagnetism and classical mechanics, and strong mathematical and programming skills.

Mentor: **T.-C. Shen, *Nanotechnology***

(1) Carbon nanotubes: we have successfully grown CNTs on Al_2O_3 nanoparticles. The 3-dimensional CNT structures are ~10 mm tall and very porous. The high porosity could enhance gas-phase chemical reactions with catalyst nanoparticles on the CNT sidewalls. We plan to reduce the CNT density further and to develop a chemical vapor deposition scheme to deposit nanoscale catalyst particles uniformly in the CNT structure.

(2) Metasurfaces in photonics: matter-light interaction at nanometer scale was not included in the Maxwell's equations. As a result, it is now possible to use nanostructures to manipulate light and create integrated photonics on Si chips for sensors and actuators. Using the fabrication facility at NDL, we can pattern CNTs to absorb EM waves up to mid-IR. We plan to continue making darker surfaces and metallic patterns on surfaces to manipulate light.

(3) Graphene growth and devices: we are investigating low temperature (~300 ºC) graphene growth and pattern graphene layers with prefabricated Si structures to test their electro-mechanical responses.

Mentor: **David Peak, *Complex Systems***

My interests involve modeling and analyzing "complex dynamical systems" and "complex materials." By "complex" I mean systems consisting of many elementary pieces whose collective activity results in unexpected and surprising behavior. I am especially interested in how biological systems (plants, colonial organisms, brains) process information, reallocate resources, and correct errors through complex dynamics, and whether such processes can be mimicked in nanoscale electronic circuits to help them function better than more conventional strategies.

My research is highly interdisciplinary, is partly computational and partly theoretical, and is centered in experimental data. Students interested in working with me/us should have (or acquire) (a) some programming skills (e.g., Python) or some familiarity with Mathematica, Maple, Mathcad, or Matlab, and (b) good familiarity with calculus and algebra.

Mentor: **Charles Torre, *Gravitation, Mathematical Physics, and Algebraic Computation***

Research opportunities are based upon a large collaborative research project involving development and scientific applications of algebraic computing software. The applications include topics in gravitation, relativistic field theory, and geometrical methods in mathematical physics.

This research is for those who enjoy working with the computer and learning about new mathematics. Good computer and advanced math skills are required.

Mentor: **Jan Sojka, *Ionospheric Physics and Space Weather***
Contact email: janjsojka@usu.edu
Other team members: Don.rice@usu.edu, David.smith@usu.edu

The ionosphere, extending from 50 km to an altitude of 1000km, forms a plasma shield around the Earth. Space weather causes auroral storms radio communication problems, and even disruptions in the power grid and GPS positioning accuracy.

The USU Ionospheric Research Group has projects for students interested in modeling, computation, data analysis, and equipment management associated with space weather will lead to presentation opportunities, meet research requirements, and maybe even authorship.

1. **Ionospheric computer models**: Both the Time Dependent Ionospheric Model (TDIM) and Bottomside Ionosphere with Winds, X-Rays, and Metals (BIWXM) model are based on first principle physics with an introduction to plasma physics not just on Earth, but also on exoplanets. Potential studies may include solar storms, meteoric debris such as sodium metal content at 100 km altitude, and protecting the lower atmosphere from Solar Energetic Protons (SEP).
2. **Bear Lake Observatory (BLO) Ionosonde**: This VIPIR ionosonde operates like a radar but at radio high frequencies (HF). Its echoes come from the ionosphere above BLO and contain information about the structure and dynamics of the ionosphere. Ionosonde operation, hands-on experimentation, and data analysis are the focus of this project.
3. **SEP penetration at air craft altitudes:** This project pertains to the adverse impact on both technology and humans. SEP events associated with solar storms require the airline industry to reroute flights away from the polar regions to protect passengers and crew from increased radiation. SEP ionospheric events also cause havoc on radio communications. Team

members and HAM radio amateurs David Smith and Don Rice study how SEPs affect HAM radio communication. Research in SEP penetration also involves development of predictive models that would be of value to the NOAA space weather forecasters.

Mentor: **Mark Riffe,** ***Solid State Physics—Experiments, Data Analysis, and Modeling***

My current research interest is vibrational dynamics of solids. Vibrations impact a number of physical properties, including the transport of heat and charge through a material. A main goal of this research is to understand how vibrations at single-crystal surfaces differ from vibrations inside the material. We model vibrational structure using an embedded-atom-method (EAM) theory, which is implemented in Fortran and Python computer code.

Formal experience with another programming language, such as C++, should be sufficient for a student to get started on this project.

Mentor: **Eric Held,** ***Theoretical/computational plasma physics—Stability and transport in magnetically confined plasmas***

My major goal as a theoretical plasma physicist is to contribute to the realization of controlled magnetic fusion in a terrestrial reactor. The Fusion Theory and Computation group at USU participates in this effort by coupling high-fidelity solutions to the plasma kinetic equation (a reduced Boltzmann equation) into plasma fluid codes such as NIMROD (https://nimrodteam.org/). At its heart, we seek to unify the continuum (fluid) and multi-particle (kinetic) descriptions of the fourth state of matter in a consistent, hybrid framework. Dr. Held invites promising physics undergrads to participate in projects such as:

(1) exploring relativistic corrections to plasma kinetic theory,
(2) studying particle, momentum and heat transport in magnetized fusion plasmas, and,
(3) developing novel numerical treatments to improve the efficiency of hybrid fluid/kinetic plasma codes.

Our research is partly theoretical and partly computational. If you are interested in working with the Fusion Theory and Computation group, it might be helpful to have (a) a solid background in mathematics (*i.e.*, you get giddy about calculus, differential equations and linear algebra), (b) some programming skills (preferably Fortran and Python, but we can work with what you got), (c) some familiarity with packages such as Maple or Mathcad, and (d) a desire to learn how to run and diagnose complicated computer programs in a high-performance computing environment.

Mentor: **Ludger Scherliess,** ***Space Physics - Space Weather Modeling, Data Analysis***

Our sun is the main source of space weather, which can affect Earth and the rest of the solar system. Sudden bursts of energetic particles and large magnetic field structures from the Sun's atmosphere called coronal mass ejections (CME) together with sudden bursts of radiation (solar flares) can cause space weather effects here on Earth. At its worst, it can damage satellites and cause electrical blackouts on Earth, but also is the cause for the beautiful auroral lights.

My interests involve what is broadly referred to as understanding and modeling the effects of space weather on our upper atmosphere – a region where satellites fly. I am particularly interested in the Earth's ionosphere and in the development of space weather models for this region. These models are much like the ones that are used for our daily weather forecasts. As an undergraduate student you can be involved in the development and testing of these models, in the monitoring and analysis of the day- to-day space weather, or in the study of ionospheric weather over regions like North America, Europe, or Asia.

Large quantities of data are also available from observations made by NASA and ESA satellites that give us information about Earth's upper atmosphere. As an undergraduate student you can be involved in the analysis and interpretation of this data and can compare the data with results from our space weather models. This work will provide you with a good understanding of the physical processes that are at work in our upper atmosphere. During your project you will also have the opportunity to learn or to improve your programming skills in languages like Python, C and Fortran that we use for our everyday work.