UNDERGRADUATE RESEARCH OPPORTUNITIES IN PHYSICS

The Physics Department at Utah State University has a long record of successfully involving its undergraduate students in research and extracurricular scholarly activities. Learning what science is requires more than just doing homework and taking exams: it requires getting involved in the pursuit of knowledge that is not yet in any textbook. Below are some of the Department's mentors and the research projects they have available for undergraduate participation. Most of these projects list the skills necessary to fully contribute.

Fundamental Theory Group: Fields, Astrophysics, and Spacetime Theory (FAST)

Mentor: **Maria Rodriguez** ***General Relativity and Black Hole Physics***

My research focuses on theoretical aspect of black holes - which are one of the most fascinating objects in the Universe - and the astonishing effects they have in the surrounding space-time. In the frontier of theoretical relativity, string theory and astrophysics over the past years I have been studying and finding new black hole solutions of Einstein's Theory, deciphering patterns of the emitted signals as objects fall into the black holes and investigating the mechanisms by which black holes generate the most energetic beams captured by mankind after the Big Bang.

Skills: Programming skills and some level of differential geometry are desirable.

Mentor: **Charles Torre** ***Gravitation, Relativity, Field Theory, Mathematical Physics, Geometrical Methods in Physics***

Research opportunities are based upon a large collaborative research project involving development and applications of algebraic computing software for analysis of gravitation and relativistic field theory.

Good computer and math skills are a must.

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: **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.

Surface Physics Group: Center for Surface Analysis and Applications (CSAA)

Mentor: **JR Dennison** ***Experimental Solid State Physics***

The Materials Physics Group studies properties of materials and their interaction with electron, ion and photon beams. A particular emphasis has been characterization of materials used in spacecraft construction and the prediction and mitigation of spacecraft charging due to interactions with the space plasma environment for projects funded through NASA and private companies. Projects can involve instrumentation development and construction, computer automation, data acquisition, data modeling and analysis, and theoretical calculations. Topics include:

(1) *Electron Transport* in highly insulating materials: investigates the conductivity, luminosity, polarizability, and electrostatic breakdown of highly insulating thin film polymer, ceramic and composite materials. The focus is to understand the physics underlying the changes in electron transport that occurs over long time periods, and in response to variations in temperature, electron flux, charge accumulation and radiation damage.

(2) *Electron Emission* studies: involves measurement and data analysis of the number, energy and angle of electrons emitted from materials as a result of incident electron, ion and photon beams. A recent emphasis has been electron emission from charged and uncharged insulators.

Skills: Experience in experimentation and techniques such as electronics, computer interfacing, vacuum physics, cryogenics, surface physics methods, data and error analysis, and scientific writing are useful, but can also be acquired or enhanced during the course of the project. Skills in numerical methods and programming are useful for data analysis and transport simulations.

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 MatLab computer code.

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

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

(1) Carbon nanotubes: Many applications involving carbon nanotubes require metallic substrates, but CNTs are notoriously difficult to grow on metals. This research involves exploring new catalyst deposition techniques to nucleate nanoparticles for CNT growth on copper, stainless steel, aluminum, and perhaps diamond.

(2) Functional devices: Digital computation devices have improved our productivity tremendously. With the development of new materials and paradigms many other types of devices at micro to nanometer scale can improve our lives too. This research involves patterning and functionalizing vertically aligned carbon nanotubes for chemical and biological sensing.

Students who are responsible, creative, curious, patient, and careful and with some programming experience (LabVIEW preferred) are welcome to apply.

Space Physics Group: Center for Atmospheric and Space Science (CASS)

Mentor: **Maura Hagan** ***Connections between meteorological weather and space weather***

There is increasing evidence that deep convective storms in the tropics generate waves that propagate upward in the Earth's atmosphere and affect prevailing space weather conditions. Research opportunities include diagnosing numerical model simulations and comparing the model results with ground-based or satellite-borne observations of the Earth's upper atmosphere and ionosphere.

Desirable Skills: Computer programming experience; experience with manipulation and visualization of large data sets.

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

My interests involve what is broadly referred to as space weather. I am particularly interested in the Earth's ionosphere and in the development of weather models for this region. These models are much like the ones that are used for our daily weather forecasts. Undergraduate students 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.

Data Analysis: Large quantities of ionospheric data are available on a daily basis from observations on the ground and from satellites. I use this data to study physical processes that are active in the ionosphere. Undergraduate students can be involved in the analysis and interpretation of this data and/or can compare the data with output from numerical/theoretical models of the ionosphere.

Skills: Programming skills (C, Fortran, etc.) and a basic knowledge of data and error analysis are of advantage, but can also be acquired during the course.

Mentor: **Jan Sojka** ***Space physics***

My specific interests include instruments to monitor the upper atmosphere, from both the ground and from satellites, data analysis and interpretation of measurements obtained from such instruments, development of computer and analytic models of the upper atmosphere (solar-terrestrial physics), and project management. A specific example would be a ground-based GPS receiver that also monitors the effects of the ionosphere on your location. Currently NASA data streams from the ACE satellite provide monitoring of the solar wind. Additionally, the SDO EVE instrument provides real time monitoring of the solar irradiance that creates the dayside ionosphere. These data streams are used in our models. A recent expansion of the USU Sun-Atmosphere interaction research has moved towards stellar-exoplanet systems. Our expertise in this particular area is the response of the atmosphere to solar impact, flares, CME, solar and cosmic rays, etc.

I am also the faculty mentor of the USU Get Away Special Program—an interdisciplinary undergraduate organization that designs, fabricates, tests, and flies experiments in space. Currently, MRT students are working on a 1 kg "cubesat" to demonstrate how a UV curable resin can become a space based fabrication technology. The team has flown in zero gravity on three separate NASA zero-g flight competitions and placed an experiment on the International Space Station. During the summer and fall of 2016 the GAS team flew experiments in Cache Valley on High Altitude Balloons. Their experiments tested the UV curable resin concept, radio communications and real time experiment operations.

Mentor: **Mike Taylor** ***Upper Atmospheric Imaging Studies***

My research group utilizes an array of sensitive digital and video imaging systems for studying a range of upper atmospheric optical phenomena. These include acoustic-gravity waves, polar mesospheric clouds, equatorial ionospheric instabilities, thunderstorm-induced transients called "sprites" and "elves", infrared meteor emissions, and satellite re-entry tracking and disintegration. We operate cameras at a number of sites around the world for long-term measurements of the atmosphere. Our remotely operated cameras in Utah, Chile, South Pole, Antarctica (and soon in northern Norway) are used to study the global variability of atmospheric gravity waves and their dissipation signatures, while other studies such a sprite imaging are usually performed on a campaign basis, most recently from southern Brazil. We are also Co-Investigators on the NASA Aeronomy of Ice in the Mesosphere (AIM) mission to study the dynamics of polar mesospheric clouds (NASA Group Achievement Award 2008), which are the highest clouds on Earth at an altitude of 82 km (50 miles). Graduate and undergraduate students are involved in all aspects of these programs, including field measurements, data analysis and presentations at scientific meetings. In particular, undergraduate students participate in regular group meetings where we discuss ongoing research results and they also have the opportunity to participate in the annual CEDAR conference at Boulder, Colorado in June (sponsored by the National Science Foundation). At CEDAR the students participate in seminars, workshops and present posters of their research work to leading scientists in this field and to fellow undergraduate and graduate students.

Mentor: **Vincent Wickwar** ***LIDAR (Light Detection And Ranging) Used to Explore the Middle Atmosphere (15 km to 115 km)***

The original lidar in the Atmospheric Lidar Observatory (ALO), located here in the SER building, was a powerful Rayleigh-scatter lidar. A big Nd:YAG laser emitted pulses of green light that were scattered off atmospheric molecules. Good returns were obtained with a 44-cm diameter mirror from the mesosphere between 45 and 90 km.

Eleven years of good data were acquired with this system. They have been analyzed for relative densities and temperatures; noctilucent clouds; occurrences of gravity waves, tides, and planetary waves; wave potential energy; occurrences of convective instabilities; and trends. Nonetheless, much good scientific analysis remains to be done with this unique data set. The software used is IDL, which is very common in the atmospheric, space, and environmental areas.

The original lidar has been very significantly upgraded. With the equivalent of a 2.5-m diameter mirror and 42 W of laser power in the green, it is the most sensitive Rayleigh-Mie-Raman lidar. First data were obtained, between 70 and 105 km, in June 2012. We are making periodic observational campaigns to examine specific scientific questions, while we are continuing the upgrade to cover the full altitude range between 15 km in the stratosphere and 115 km in the lower thermosphere, and to scan much of the sky.

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

My research current projects are focusing on optical remote sensing of the upper atmosphere. Measurements are made with a Faraday filter based ultra-narrow band Sodium spectrometer for Na nightglow measurement and an advanced Na lidar. 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 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.

Plasma Physics Group

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

Possible projects:

(1) Explore relativistic corrections in plasma kinetic theory and computation.
(2) Study particle, momentum and heat transport in magnetized fusion plasmas.
(3) Develop novel numerical treatments of the Coulomb collision operator for ionized plasmas.

Skills: E&M, Newtonian Mechanics, Thermal Physics, Lagrangian/Hamiltonian Dynamics, Fluid Mechanics, Fortran programming experience and Unix skills (or a willingness to learn).

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

Possible projects:

(1) Develop a plasma fluid model including runaway electrons
(2) Study heat confinement with the integral (non-local) heat flow

Skills: Mathematical Physics and Programming

Mentor: **Farrell Edwards** ***The Electron***

Perhaps the most fundamental of all particles is the electron. Yet it remains a mystery in many ways. Study of the electron requires knowledge of electromagnetism and quantum mechanics. We will study what has been accomplished from experiments and what different experiments reveal as to the electron's size and magnetic moment. It is interesting that different experiments seem to indicate various sizes, differing by factors as large as 10^5. Will our study reconcile these differences? Probably not, however the possibility does exist.

Complex Materials and Dynamics

Mentor: **Boyd Edwards** ***Microfluidics***

I model the dynamics of charged and neutral particles in solution in response to applied electric fields. Applications include forensic and disease detection in microfluidic lab-on-a-chip devices. These devices are like computer chips but with electronic pathways replaced by fluid pathways.

Skills: Strong interest in theoretical electromagnetism and Newtonian mechanics, and programming experience.

Mentor: **David Peak** ***Complex systems***
(http://www.physics.usu.edu/peak/personal/Computation_in_natural.htm)

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 and is partly computational, partly theoretical, and partly experimental. Students interested in working with me/us should have (a) some programming skills (C++, Python, or some dialect of Basic or Fortran) or some familiarity with Mathematica, Maple, Mathcad, or Matlab, (b) good familiarity with calculus and algebra, and/or (c) the ability to make delicate measurements without destroying stuff.

Some facts about undergraduate research in Physics at USU

- Except for the Physics and Composite Physical Science teaching majors, all degree programs in Physics require at least 2 credits of Physics 4900 – Research in Physics. This requirement is designed to give the student a taste of what real science is like (as opposed to doing canned labs or solving end-of-chapter homework problems) before they graduate.

- Though Physics 4900 is usually taken in the senior year, most Physics majors get involved in research earlier—some as early as first term freshmen. Getting started early in some kind of scientific work outside of the classroom is strongly encouraged by the faculty. With extended experience, students often can be employed as research assistants on faculty grants.

- Many physics majors continue to gradate study after leaving USU and ultimately establish research careers. Those who enter the technical workforce immediately after receiving their BS degrees invariably attribute their employment success to their undergraduate research experience.

- Faculty listed above have substantial experience mentoring undergraduates. Their students have received prestigious awards, including Rhodes, Fulbright, and Goldwater Scholarships and honorable mentions, national SPS Outstanding Undergraduate Researcher awards, and College of Science Undergraduate Researchers of the Year. Dennison, Taylor, and Peak have also been named College of Science Outstanding Undergraduate Research Mentors.