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: **Shane L. Larson** (http://www.physics.usu.edu/shane/)
Gravitational Astrophysics

(1) Astrophysics, Gravitational wave astronomy, General Relativity: My research interests involve the astrophysics of gravity and the emerging science of gravitational wave astronomy – learning about the Cosmos by detecting the faint ripples imprinted in the structure of spacetime by colliding neutron stars, by relativistic compact degenerate stellar systems, and by supermassive black holes eating other stars in galactic cores. There are many opportunities for students to model astrophysical sources or simulate gravitational wave detection and analysis. Good Skills to Have: Students should be capable of programming in C, Fortran, or some other high level language, or working with mathematical analysis software (Mathematica, Maple, Matlab, IDL, etc). A working knowledge of calculus and Newtonian mechanics (2200 level physics) is essential in all cases. Experience with differential equations and Fourier analysis will be necessary for advanced projects.

(2) Observational Astronomy: The physics department maintains an observatory with a well-equipped 20" telescope, located on the roof of the SER building. We have a variety of ongoing observational research projects that can be carried out by any student willing to learn observatory procedures, and spend some dark time at the telescope. These include deep sky imaging, astrophotography, photometry and light curve monitoring, and many other endeavors. A working knowledge of astronomy is useful (PHYS 1040 level), but not necessary.

(3) High Altitude Ballooning (HARBOR): I also work with a high altitude ballooning program known as HARBOR, which allows students to fly small experiments to the edge of near space (typical altitudes of ~35 km). There are ample opportunities for students to construct experiments, engineer new balloon hardware, or do science analysis. Balloon flights generally run over the summer months, with ~5-10 flights per year to altitudes around 100,000 feet – this is the edge of space!

(4) Science and the Public: I also have a strong interest in bringing science to the public through public lectures, educational efforts and direct engagement activities. Students interested in public level science and science outreach should be skilled in public speaking, outreach or mentoring to schools; computer visualization (or many other skills) will be valuable.

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: **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

(1) Core-Level Photoemission. This project is aimed at understanding the formation and growth of layered metallic systems. We are currently analyzing photoemission data from a variety of metals layers grown on tungsten surfaces. (2) Vibrational Dynamics at Surfaces. We seek to understand vibrations at surfaces and how those vibrations differ from inside the material (bulk vibrations). (3) Temperature Dependence of Semiconductor Energy Gaps. We are currently exploring a new method of analyzing energy-gap temperature dependence.
(4) Ultrafast Spectroscopy of Semiconductors. This research explores the femtosecond excitation and subsequent decay of carriers in semiconductors. GaAs and related materials are currently under study.

Skills: Experience in experimentation and/or computer modeling is useful, but the necessary skills can be acquired during the course of the project.
More Details: http://www.physics.usu.edu/riffe/bio/index.htm

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 the parameter space of growth conditions, including hydrocarbon precursors, catalytic nanoparticles, diffusion barrier layers, and growth temperatures to achieve CNT growth on copper. Scanning electron microscopy is used to characterize the CNT growth.

(2) Surface adhesion: Insects and spiders are able to walk on vertical and underside surfaces thanks to the micro-nano structures on their feet. The forces involved are van der Waals force and capillary force. The goal of this research is to understand the nature of these forces as a function of the contact geometry and materials by measuring them directly by an atomic force microscope.

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: **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

I am specifically interested in: instruments to monitor the upper atmosphere, both from 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 of an interest would be a ground-based GPS receiver that also monitors the effects of the ionosphere on your location. Other instruments used in my research are ionosondes, magnetometers, and VLF receivers, examples of which are operating at the USU Bear Lake Observatory in Northern Utah.

I am also the faculty mentor of the USU microgravity research team (MRT)—successor of the NASA 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 celebrate the 1957/58 anniversary of Sputnik 1, the first man-made satellite to orbit Earth.

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 Mesosphere

The major lidar in the Atmospheric Lidar Observatory (ALO), located in the SER building, is a powerful Rayleigh-scatter lidar. A big Nd:YAG laser emits pulses of green light that are scattered off atmospheric molecules. From the return, the relative density and absolute temperature are derived from the mesosphere between 45 and 90 km.

Eleven years of good data have been acquired. They have been analyzed for relative densities and temperatures; noctilucent clouds; occurrence of gravity waves, tides, and planetary waves; wave potential energy; occurrence of convective instabilities; and trends. These provide background for a number of future new analyses. The software used is IDL, which is very common in the atmospheric, space, and environmental areas.

We are also upgrading hardware and optics from the present lidar configuration to one that is a much more sensitive system. This involves changing from a 44-cm diameter telescope to one that is the equivalent of 2.5 meters. This includes setting up the full detector chain—optical fibers, lenses, choppers, interference filters and photomultiplier tubes—and the mechanical pointing controls.

Plasma Physics Group

Mentor: **Eric Held**

Theoretical plasma physics—how charged particles generate and interact with electromagnetic fields

Possible projects:
(1) Study motion of charged particles in presence of spatially varying magnetic fields.
(2) Study confinement of electron heat by the tangled magnetic field structures of galaxy clusters.
(3) Apply hybrid fluid/kinetic models to problems in magnetic fusion and astrophysical plasmas.

Skills: E and M, Newtonian Mechanics, Thermal Physics, Lagrangian and/or Hamiltonian Dynamics, Fluid Mechanics, Maple and/or programming experience.

Mentor: **Ajay Singh** (Contact: Ph: 797 4363, email: ajay.singh@usu.edu.)

Experimental Plasma Physics

Research in experimental, plasma physics at Utah State University (USU) is advancing our ability to confine thermonuclear, fusion plasmas in the laboratory. We are pursuing cutting edge research in the development of a hybrid electrostatic/magnetic scheme for confining dense, high-temperature plasmas, contributing to ongoing international efforts to make magnetic fusion an abundant, environmentally friendly energy source. We have a Tokamak operational at our Research Park. Opportunities exist for undergraduates for hands on experience on this machine. Students who feel excited about electricity and magnetism can come and try their hands on following possible experiments:

1. Plasma density, potential and temperature measurements using electrostatic probes.
2. Measurement of magnetic perturbation structures using magnetic pick up coils.
3. Optical spectroscopy of hot plasma.

Complex Materials and Dynamics Group

Mentor: **Tim Doyle**
Complex materials

My research involves the computer modeling and experimental measurement of ultrasonic waves, electromagnetic waves, mechanical fields, and nuclear radiation in complex heterogeneous materials. Applications of this research include:

- Ultrasonic characterization of tissues for medical diagnostics. My current program focuses on the development of computational and experimental ultrasonic methods to detect microscopic breast cancer in tissues during surgery.
- Nondestructive evaluation of aerospace composites.
- Remote sensing of moisture content and microstructure of soils.
- Monitoring of cavitation and crystallization in liquids for advanced food processing applications.
- Modeling the micro-biomechanics of breast cancer, biological tissues, and biocomposites.
- Application of tomography and other imaging methods to upper atmospheric research and the detection of nuclear materials.

Projects associated with this research would be to have students run the computer programs to simulate wave propagation in "virtual" tissues or particle packings for a range of structures, properties, and wave parameters; to analyze the data; and to compare the computer predictions with published and experimental results. Students may also participate in the building of experimental systems and assist in collecting experimental data. Skills needed: the ability to understand and work with Excel and Mathcad files for evaluating the data. Knowledge of basic wave principles (sophomore-level physics), Matlab, or FORTRAN would also be helpful.

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

I am also interested in science education at pre-college levels and am involved in a project to create and test modules that integrate learning science and mathematics with hands-on activities focusing on art and music.

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 are able to 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 (2), Fulbright (1), and Goldwater (12) Scholarships and honorable mentions, a national SPS Outstanding Undergraduate Researcher award (and an honorable mention), and three College of Science Undergraduate Researchers of the Year. Dennison and Peak have also been named College of Science Outstanding Undergraduate Research Mentors.