UW Physics REU 2005 Project List

Our projects this year span a wide range of contemporary topics in physics:

- Cosmology
- Several aspects of astrophysics
- Nuclear reactions
- Atomic physics
- Physics education
- Condensed matter and biological physics
- Nanophysics

The projects are listed below, split only between experiment and theory—please read all of the project descriptions to get some idea of the breadth of opportunities available to you, to be sure that you don't miss an interesting possibility. If you think you might want to do a theory project, please be sure to carefully explain your theoretical, mathematical, and especially computational background in your application essay. Students with particular interests not on this list should feel free to ask Jerry Seidler or Alejandro Garcia whether a special project can be designed: this has been done successfully in past years.

Experimental Projects

Anesthetics, Phase Transitions, and Cell Membranes
Sarah Keller

Our lab studies biological physics. Specifically, we investigate domain formation in simple membrane systems that model cell membranes. Cells are surrounded by an outer wall or "plasma membrane" of proteins and lipids arranged in opposing leaflets of a bilayer. There is growing evidence that this membrane is not uniform, but instead laterally organizes into regions called "rafts" in which particular lipids and proteins are concentrated. In this particular REU project, we will use fluorescence microscopy of giant unilamellar vesicles to determine whether molecules that act as anesthetics change the miscibility phase behavior of the lipid membrane. In other words, does the presence of anesthetics make membrane domains appear at a higher or lower temperature? Is this correlated with the depth of penetration of the anesthetic into the membrane? If successful, this project could easily result in a publication. No prior biological experience is necessary. For general information on our laboratory, see http://faculty.washington.edu/slkeller/

Nano-pore DNA Sequencing
Jens Gundlach

This is an interdisciplinary research project combining biology and physics. We study a process wherein an individual single-strand DNA molecule is electrically driven through a 1.5nm diameter biological pore. While the DNA moves through the pore it modulates an ionic current that is also passing through the pore. This ionic current is used to learn about the structure and dynamics of the DNA and it contains information about the DNA's sequence. Ultimately this process could be developed into a direct and very fast DNA sequencing technique. We are presently studying the dynamics of this process by using targeted DNA molecules. We are also working to improve the quality of our measurements by developing new electronics, by exploring a variety of biochemical parameters and by attempting to physically control the motion of the DNA while it is in the pore. Our project involves techniques from several areas of modern science. This table-top experiment is small enough that an REU student will have the opportunity to get involved in areas as diverse as molecular biology, statistical modeling, electronics, and data analysis.

Measuring ultra-small forces for the LISA gravity wave detector
Jens Gundlach, Blayne Heckel, Eric Adelberger

NASA is preparing a giant gravity wave observatory that will be placed in space. The Laser Interferometer Space Antenna (LISA) consists of three spacecraft forming a equilateral triangle with 5 million km armlength. Changes in the armlength of 20pm will be detected. The ends of each interferometer arm are formed by freely floating masses that must be kept inertial (i.e. free of non-gravitational forces) at an unprecedented level. The spacecraft that shield the proof masses are servoed to exactly follow the proof masses. Small stray forces that could act between the spacecraft and the proof mass must be understood at an extremely delicate level. From our fundamental physics research we have gained the necessary expertise to build ultra-sensitive torsion balances to study these forces. Students working on this project will learn a broad spectrum of the experimental techniques necessary to measure forces that compete with gravitational waves, but they will also be introduced to the overarching physics.

Experimental tests of Universal Gravitation
Eric Adelberger, Blayne Heckel, Jens Gundlach

The Eot-Wash group is testing an exciting prediction that Newton's inverse-square could break down at length scales less than 1 millimeter. If verified experimentally, this prediction would provide strong evidence for more than 3+1 dimensions; i.e., that some of the "extra dimensions" of modern theories have observable consequences. Our experiments employ novel torsion pendulums and rotating attractors. Three REU students from 2000 and 2001 worked on the first version of this experiment, which recently appeared in Physical Review Letters.

In 2002, an REU student worked on a second-generation experiment that probed down to length scales below 100 micrometers. In 2003 a student designed and constructed a prototype electromagnetic "fiber twister" that can be used to damp the torsion oscillator. More recently, in addition to projects associated with testing the inverse-square law, we have several new projects involving "gravitational" experiments with electron spin. We are currently making torsion balance measurements with a spin-polarized pendulum to test CPT symmetry. New development projects involving polarized electrons include an axion search and tests for a recently proposed Lorentz-violating component of gravity.

Other instrumentation or computer projects will doubtless arise as time progresses. Our lab is well-equipped with instrumentation, machine and electronic shops so that plenty of resources are available for attacking these problems. You can learn more about our group by clicking on the Eot-Wash Gravity Group on the University of Washington Physics Department homepage.

Studies of the performance of planned gamma ray telescope
Toby Burnett

We at the UW have the lead in performing simulations of the response of GLAST, a satellite "telescope" to detect gamma rays from space. It is scheduled to be launched into low-earth orbit in early 2007. We are involved in planning and executing such simulations, modeling a variety of sources of incoming particles, some representing noise and some the sort of signals we hope to study (like gamma ray bursts). There are several projects to which an REU student could contribute. Some experience with C++ is preferred.

WALTA
R.J. Wilkes, T.H. Burnett, R. Gran

For WALTA (Washington Large Area Time Coincidence Array), we are investigating the highest energy cosmic rays by building particle detectors and placing them on the tops of high schools in the Seattle area. The data from this distributed network of sensors is uploaded to the university so that it can be searched for possible ultra-high energy cosmic ray air showers. We have several good REU projects for this summer. We have the materials to install and operate a second detector on campus. There are also several projects to evaluate and improve detector performance. Both these first two involve a lot of work with the detector equipment itself. Students with good programming skills may also be interested in some advanced analysis of data we have collected this past year and/or air shower simulation projects. Finally, if you are interested in science education there is a project in which you can work with a couple local teachers to develop materials for use in the high school classroom.

Experiments on Electroweak Interactions
Peter Doe, Joe Formaggio, Haemish Robertson

The research program of the Electroweak Interactions group (EWI) is focused primarily on studying neutrino mass and its role in the evolution of the universe. Neutrinos, like photons, pervade the entire universe. Until recently, it was assumed that the neutrino, like the photon, was massless. Thanks to a number of current experiments (SNO, Super Kamioka, KamLAND) studying neutrinos from the Sun, from cosmic rays and nuclear reactors, we now know that this is no longer true. The discovery of neutrino mass is one of the mast exciting developments in physics in the last decade. It has forced us to readdress the highly successful Standard Model of particle physics and is advancing our understanding of how the universe evolved. Now that we know the neutrino has mass, the next logical question is “how much mass?”. This is the thrust of the next generation of neutrino experiments, two of which (KATRIN and Majorana) the EWI group is a major participant. An REU student with the EWI group can expect to be exposed to diverse facets of experimental nuclear physics, ranging from data analysis, computer simulations of nuclear particle interactions, advanced data acquisition systems and a wide range of nuclear particle detectors. Our group consists of 4 faculty members, 3 postdoctoral Research Associates, 7 doctoral students and a number of undergraduate Research Assistants. We are based both in the Physics Building and at the Center for Experimental Nuclear Physics and Astrophysics (CENPA), where the students are exposed to a wide range of exciting experimental programs. For more information on our work, please see: http://ewiserver.npl.washington.edu/

Beta asymmetry from Neutron beta decay using UCNs
Tom Bowles, Alejandro Garcia

This project deals with measuring the angular distribution of electrons emitted from polarized Ultra Cold Neutrons (UCNs). UCNs are neutrons that have velocities of approx 5 m/s. At these velocities neutrons can be contained in guides and trapped. Because their energy is less than about 0.1 micro-eV they can be polarized by simply making them go through a large (approx. 7 Tesla) magnetic field. Part of the work involves participation in an on-going experiment at Los Alamos, part will involve developing Monte Carlo calculations to understand potential problems with the experiment, designing and building parts of the experiment that will need to be upgraded after the first round of data taking. The student will work on all these aspects, getting experience on all fronts -from theory through design to measurement.

Solar fusion of 3-He and 4-He
Kurt Snover and Derek Storm

We are making a laboratory measurement of the fusion rate for 3-He and 4-He to form 7-Be. This reaction takes place in our Sun as part of the solar p-p chain in which hydrogen is burned and converted to helium, and is very important for determining the rate at which our Sun produces neutrinos. It is also important in models of the Big Bang (BB), since essentially all of the 7-Li produced in the BB came from the decay of 7-Be formed in this reaction. The interested student would join our group and be involved in diagnostic tests and fusion measurements using the local accelerator.

Research-based Instructional Strategies for Teaching Physics
Lillian C. McDermott, Paula Heron, Peter Shaffer

The Physics Education Group conducts research on student understanding of physics and uses the results to guide the design of instructional materials, which are intended for national distribution. The effectiveness of these curricula is assessed at the University of Washington and at many other institutions. REU students will have the opportunity to participate in programs shaped by the group's research, such as the summer program for K-12 teachers and the tutorials for the introductory physics course. In addition to taking part in classroom activities, previous REU participants assisted in investigations of the effect of different instructional strategies on student understanding of important fundamental concepts.

High-precision Tests of Fundamental Symmetries
Norval Fortson

Our research is in lasers and atomic physics, with a special emphasis on 'table top' elementary particle physics. We measure atomic parity violation as a test of fundamental electroweak theory, we are searching for a permanent electric dipole moment as a test of time reversal symmetry, and we are developing optical atomic clocks with the goal of detecting a possible time change in the fine structure constant. We have many specific projects suitable for an REU participant, and have had great experiences with REU students for many years. The technical aspects of a typical (past) project was to modulate a laser beam at a rate of several GHz to create sidebands needed for exciting many optical transitions at once in a single trapped Ba ion. Our projects typcially involves lasers, optics and RF technology, and ought to be fun. For more information on our research group, see:
http://www.phys.washington.edu/users/fortson/

Penning Trap Mass Spectrometry
Bob VanDyke

By observing the motion of single ions using sophisticated electronics, we conduct measurements of atomic mass ratios to 11-digit precision, which can be combined with other precision experiments to determine important fundamental constants. Currently we are preparing for a measurement of the H-3 (tritium) to He-3 mass difference, which is related to neutrino rest-mass research. Undergraduates in our group help construct electronic apparatus, and carry out many other tasks associated with this table-top type of experiment. This summer, an REU student with some good electronics experience (such as a thoroughly-enjoyed lab-class), could help us with final assembly and testing of our computer-controlled ion-loading system, which will allow ions from our external source to travel down a beam tube and be captured between trapping electrodes in ultra-high vacuum at a temperature of 4K. The student could also work on the design of pulsing-sequences needed to transfer a single ion from one trap to another, although there may not be sufficient time to demonstrate this technique. More information on our research can be found at:
http://depts.washington.edu/uwptms/

Precision Measurements on Single Trapped, Laser-Cooled Ions
Warren Nagourney

Our experimental work involves trapping single atomic ions in an ultra-high vacuum and bringing them essentially to rest using the radiation pressure from laser beams ("laser cooling"). Our motivation is to observe simple atomic systems in nearly complete isolation, which will ultimately enable us to make a single-ion atomic clock which is accurate to about one second in the lifetime of the universe. Interested REU students can help our efforts by constructing simple electronic or mechanical devices which will be used in the experiments.

High Precision Calorimetry and Optical Measurements Near Double- and Triple-Critical Points
Jerry Seidler

The term ‘critical phenomenon’ refers to the universally-observed properties of systems at 2^{nd} order phase transitions. These properties are intimately related to the occurrence of a diverging length scale for correlations associated with the order parameter of the system as the phase transition is approached. These fluctuations can be measured by scattering processes or by thermodynamic measurements. We are in the midst of designing and constructing two instruments to be used in studies of critical fluctuations in confined geometries – essentially a thermodynamic analog for quantum electrodynamic effects such as the Casimir effect and related 'cavity QED'. The first instrument is a high-resolution calorimeter for measurement of the contribution of the critical fluctuations to the heat capacity. The second is an optical transmission apparatus for measurement of light scattering by the critical fluctuations. The interested student would take the lead on the (final) construction and computer interfacing on at least one of these instruments and would perform measurements on liquid mixtures near double and (potential) triple critical points. These special phase transitions exhibit critical fluctuations with remarkable length scales easily observed to be many tens of microns, and are possibly the only systems in which such large length-scale critical fluctuations can be easily observed without a microgravity environment.

Electrolytic gating and fluid drag of nanotube transistors
David Cobden

It has recently been shown that an individual carbon nanotube immersed in an aqueous electrolyte can be gated electrolytically, by applying a suitable voltage to a counter-electrode. This means that the charge density on the nanotube is controlled by the electrode voltage. When the nanotube ahs electrical leads attached, the resulting 'wet-gate' transistor, which is a kind of field-effect transistor, can have a remarkably high transconductance, limited by quantum effects. Additionally, if the electrolyte is made to flow past the nanotube, 'drag' effects may occur between the fluid and the electrons in the nanotube, giving rise to a nonoscale hydroelectric current. IN the Nanodevice group we grow and manipulate single-wall nanotubes 1 mn in diameter, and build them into electronic devices. In this project, we will modify a probestation so that it can be used to carry out electrical measurements on devices combined with microfluidics, so that, in turn, we can pursue investigations of these issues.

Semiconductor Nanostructures
Marjorie Olmstead

We are investigating formation of silicon-based nanostructures. The materials we are currently investigating are of interest as high-dielectric constant insulators and/or spintronic materials that will add functionality to silicon technologies. We study the interplay between nanoscale kinetics and thermodynamics while forming an interface between two dissimilar materials, and the impact of the growth process on the structural, optical, magnetic, and electronic properties of the resultant nanostructure. Our primary experimental tools are in situ scanning probe microscopy, photoelectron spectroscopy and diffraction and ion scattering spectroscopy. This interdisciplinary research involves collaborators from physics, chemistry, and materials science.

Computed Tomography and the Physics of Disordered Materials
Jerry Seidler

For several years our group has used micron-scale computer tomography to obtain fully three-dimensional images of disordered materials such as sandpiles, foams, and bone. We are in the process of designing and building apparatus that will let us move these experiments from the x-ray synchrotron to the laboratory. Projects may include: assistance with instrument design, construction, and testing, and significant software tasks such as cone-beam inversion code and Bayesian reconstruction algorithms to make use of prior information about structures.

Theory Projects

Neutrino Mass and Dark Energy
Ann Nelson

Two of the most dramatic developments of the past five years have been the discovery that neutrinos oscillate, or quantum-mechanically change from one type to another due to a non-zero mass, and that 70% of the energy density of the universe exists in the form a mysterious, smooth, negative pressure fluid which has been dubbed "dark energy." Recently, a group of UW theorists have linked these two developments, by introducing theories in which neutrino masses depend significantly on the matter and neutrino densities in the local environment, as a result of new neutrino interactions. Such theories of mass varying neutrinos (MaVaNs) can explain the origin of the cosmological dark energy density and why its magnitude is apparently coincidental with that of neutrino mass splittings. An undergraduate with good familiarity with upper division quantum mechanics and some computer skills would be able to assist with studies of how the matter density dependence of neutrino masses affects the interpretation of neutrino oscillation experiments.

The Standard Model, Nonstandard Physics, and Colliders
Matt Strassler and Steve Ellis

The Tevatron collider is collecting data, and the Large Hadron Collider (LHC) is being built. These colliders will dominate high-energy physics for at least the next fifteen years, and any potential particle physicist should learn about them. Professors Steve Ellis (an experienced collider theorist) and Matt Strassler (a string theorist and an expert in supersymmetry) are developing new methods for discovering new physics using these colliders. Most of the work involves hard thought, analytic (i.e. pencil-and-paper) or Mathematica-algebraic calculation, and (when available) a dose of cleverness. A student working with our group will learn about the Standard Model of particle physics, and about the many suggested models that try to solve its various problems. The student will also learn profound ways of thinking that all physicists should develop, through the tools of dimensional reasoning, perturbative and nonperturbative estimation, and symmetries. The student will also learn, concretely, how the experiments are carried out. At the very least, the student can make some of the estimates necessary to test out one or two of the ideas that we are working on. (The most likely ideas to explore are the effect of new physics on (1) violations of certain symmetries , or (2) violations of scale invariance.) At very best, the student might invent a new estimation technique, or even a new discovery method.

Studying supernovae with neutrinos
Cecilia Lunardini

The neutrinos are elementary particles of very special nature. Indeed, they are the only particle known that is insensitive to the electromagnetic force. Furthermore, they are much lighter (smaller mass) than all the other particles we know, a fact still unexplained. Precisely because of their peculiar properties, neutrinos have a unique role in astrophysics. In particular, they are emitted by stars and galaxies just like light is, but, in contrast with light - which is absorbed and modified by the intergalactic medium - neutrinos can travel across their source and across the whole universe with practically no modification. Using dedicated ``neutrino telescopes'' we can infer astrophysical information which is different and complementary to that given by astronomy. An important example of this is the study of supernovae with neutrinos. While collapsing into a supernova, just before the final, dramatic explosion, a star emits a large flux of neutrinos. These neutrinos can tell us a lot on how the collapse happens and on the properties of the star itself. A possible project for an undergraduate student would be to formulate a prediction of the diffuse flux of neutrinos from all the supernovae in the sky. This flux is likely to be measured by future neutrino detectors: the comparison between measured and predicted flux will allow to extract information on the population of supernovae in the universe. The work would involve a mix of analytical work and simple numerical calculations (for instance: evaluation of an integral). One or the other may have more emphasis depending on how the project develops.

Physics of high-energy cosmic rays and their propagation
Cecilia Lunardini

Cosmic rays are a wind of particles (protons, nuclei, photons) that reach us from the cosmo. Their distribution in energy is very wide, and extends up to the highest energies ever observed in a atomic and subatomic physics. The highest energy cosmic rays represent a mystery in many respects. First, their chemical composition is not well know yet, nor is the mechanism that produces them. Furthermore, it is not even clear how such energetic particles can reach us! Indeed, while appearing cold and empty to the human eye, the universe is filled with a thin gas of microwave photons that should absorb the cosmic rays beyond a certain energy. The question of how cosmic rays are modified on their way to Earth is complex, and requires taking into account many different process, from simple energy degradation to change of ``identity'' (from one nucleus to another) due to loss of nucleons. A possible project for an undergraduate student would be to calculate the evolution of a flux of cosmic rays of given initial spectrum and composition as they propagate to the Earth. This would be important for comparison with existing data on cosmic rays and in the perspective of future, more precise, observations. The problem has an analytical setup and would require some numerical calculations, typically the solution of differential equations. The level of complexity can vary depending on how the project develops.

Planetesimal Dynamics
Tom Quinn

From planet formation to planetary rings, from fragile comets and asteroids to sandpiles, there is a large diversity of problems related to planetary science that can be addressed with numerical simulations. For example, the surprising configurations of planetary systems recently discovered around nearby stars imply that planets can undergo large-scale radial motions during their formation. It is known that planetesimal scattering can cause a planet's orbit to shrink and circularize, but numerical simulations are needed to quantify this process for various disk parameters. As a different example, the spectacular breakup of Comet Shoemaker-Levy 9 and measurements of remarkably low bulk densities in some asteroids imply that small bodies in our Solar System may not be solid monoliths as we once thought. Numerical simulations reveal how these fragile bodies evolve but there are many parameters to explore. At even smaller scales, there are interesting topics in granular dynamics to investigate, such as self-organized criticality in sandpiles. The chosen project would provide experience performing simulations with sophisticated numerical code on a cluster of workstations and carrying out some analysis and visualization. For more information, visit:
www-hpcc.astro.washington.edu.

Cosmic Structure Formation
Tom Quinn

Results from recent Cosmic Microwave Background experiments have confirmed our standard model of cosmology. In this model, the structures we see in the radiation from the early Universe eventually turn into the objects we see in the local Universe such as galaxies and clusters of galaxies. Therefore we can use the properties of these bodies to further constrain the cosmological models. However, following the process of structure formation in order to make these comparisons requires large numerical simulations in order to model the gravity and the gas dynamical physics. The chosen project would provide experience performing simulations with sophisticated numerical code on a cluster of workstations and carrying out some analysis and visualization. For more information, visit www-hpcc.astro.washington.edu.

Parallel Calculations of Electronic Structure and Response Functions
John J. Rehr, Alexi Ankudinov

This project deals with high performance computer calculations of electronic response functions, such as the absorption and emission of x-rays, based on parallel computational algorithms. Our codes are based on a real space Green's function (RSGF) formalism which is applicable to complex, nano-scale systems of order 1000 atoms. This project is appropriate for students with an interest in theoretical condensed matter physics or computational physics more broadly. The project may also involve comparisons of theoretical calculations with high precision experiment, such as from synchrotron radiation x-ray sources.

Integral Geometry and Real Materials
Jerry Seidler

As physicists, we often say that "partial differential equations are the language of physics." However, there are some problems where purely integral methods, including those of integral geometry, serve to give an alternate and sometimes superior description of a problem. Recent developments suggest that the following hypothesis may be reasonable: “The electrical conductance of a disordered material is entirely determined by four scalar invariants defined in integral geometry: the volume fraction, surface area, integral mean curvature, and genus”. Some students in my group are testing the breadth of applicability of this hypothesis by combining materials simulations, finite-element simulations, and computational integral geometry. The interested student would take a major role in this team, learning our existing software, and then leading a project to investigate the use of Markov chain Monte Carlo techniques in Bayesian statistics to determine the breadth of structures which can be specified purely by the Minkowski functions. A strong background in programming is necessary for this project.