UW Physics REU 2009 Project List

Projects are offered from the following physics subfields:

- Cosmology and astrophysics
- Elementary particle physics
- Nuclear physics and astrophysics
- Atomic physics
- Physics education
- Condensed matter and nanostructure physics
- Numerical modeling and simulations

If you have a special interest not represented in the list below, feel free to contact either Warren Buck or Wick Haxton for help. They may be able to design new projects that align with your interests.

Experimental Projects

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, and the results of that effort were published 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. Currently, 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.

REU projects associated with these last two projects involve testing the magnetic properties of the pendulums and developing improved magnetic shields. 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.

Search for Dark Matter
Leslie Rosenberg

Our group is operating the Axion Dark Matter eXperiment (ADMX), a detector to search for the axion, a hypothetical particle that may form the dark matter in our galaxy. We recently commissioned a new data channel that looks for axions that have recently fallen into our galactic dark- matter halo. We welcome someone with computing skills who can join our group in analyzing these data.

Creating and Controlling Quantum Gases
Subhadeep Gupta

The orchestrated use of laser, electronic, and high-vacuum technologies, can cool atomic gases to near absolute zero temperature, when quantum effects dominate their behavior. Such quantum gases can be trapped and exquisitely manipulated using lasers and other electromagnetic fields. We work with an atom cooling apparatus for studies of various new phases of matter such as Bose-Einstein condensates, paired-fermion superfluids, and quantum degenerate molecules. The entire apparatus is “table top” and an REU student can expect to get involved with multiple aspects of the experiment. Last summer, an REU student designed and built electromagnets for trapping and manipulating cold atoms. Possible REU projects for next summer include (1) building and operating optical imaging systems to study the cold gases and (2) work on laser light generation for probing cold atoms.

Quantum Computing with Trapped Ions
Boris Blinov

In the trapped ion quantum computing lab at the University of Washington we experimentally investigate the techniques for building a conceptually new type of computational device. A quantum computer will be extremely fast at solving some important computational problems, such as the factoring and the database search. While days of practical quantum computing may be quite far in the future, we are developing the main building blocks of such a device – the quantum bits ("qubits"), the basic logic operations, the qubit readout... The physical implementation of the qubit in our lab is the hyperfine spin of a single, trapped barium ion. Students in this REU project will participate in experiments with laser-cooled, RF-trapped single ions, will help develop techniques for single- and multi-qubit manipulation via microwave-induced hyperfine transitions and ultrafast laser-driven excitations. They will gain valuable hands-on experience with lasers and optics, RF and digital electronics, and ultrahigh vacuum technology.

High-precision Tests of Fundamental Symmetries
Norval Fortson, Blayne Heckel, Tom Loftus

Our research is in atomic physics, with a special emphasis on 'table top' elementary particle physics. 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. In a typical past project, the technical aspects involved modulating 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 usually involve 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/

Neutrinos from the Earth
Nikolai Tolich

Our group studies neutrinos coming from uranium and thorium decays within the Earth, "geoneutrinos". Neutrinos are elusive particles that pass through matter almost completely unhindered, so neutrinos produced deep in the Earth can be detected near the Earth's surface. Uranium and thorium decays within the Earth are thought to be the main source of heat within the Earth, which drives mantle convection, earthquakes, and plate tectonics.

A future geoneutrino detector might be placed in the Homestake mine in South Dakota, the site recently chosen by the NSF as the Deep Underground Science and Engineering Laboratory.   We need to determine how a new measurement at Homestake could be combined with a measurement using SNO+, a detector that will be constructed in the Canadian laboratory at Sudbury, to gain further insight into the distribution of uranium and thorium in the crust of the Earth. An REU student could perform an analysis to determine the expected signal at Homestake. We are also studying new detector designs. An REU student could perform simulations to determine backgrounds from natural radioactivity in these new detector designs.

Experimental Neutrino Physics
Peter Doe, Hamish Robertson, Nikolai Tolich

Our group is focused on studying neutrino properties and the neutrino's role in the universe. Like photons, neutrinos pervade the entire universe and until recently it was also assumed that they were massless particles. But thanks to a number of recent experiments (SNO, Super Kamioka, KamLAND) we now know that neutrinos have tiny masses and can transform from one type of neutrino to another as they propagate through space. Presently there are only upper and lower limits for the neutrino mass but no measured value. To address this question, a new experiment called KATRIN is under construction to make a direct measurement of the neutrino mass from the beta decay of tritium. Our group is designing and building the KATRIN focal-plane detector and the data acquisition system. We are also involved in two experiments aimed at searching for neutrinoless double-beta decay. Such decays can only occur if the neutrino and antineutrino are identical (Majorana particles) and require the violation of lepton number. These experiments can also provide information on the neutrino mass. One experiment, MAJORANA, plans to utilize an array of ultrapure, isotopically enriched ^{76}Ge crystal detectors. The other, SNO+ experiment, plans on adding ^{150}Nd, to liquid scintillator. This experiment may offer a path to a large-scale search in a short time, and also makes possible measurements of neutrinos coming from uranium and thorium decays in the Earth. These "geoneutrinos" allow us to directly measure the Earth's poorly understood uranium and thorium content, which is thought to provide the heat necessary to power mantle convection, plate tectonics, and earthquakes. Our group of 4 faculty, 2 postdocs and 7 graduate students, has a number of interesting potential projects available related to KATRIN, MAJORANA, and SNO+. For further information, please see http://ewiserver.npl.washington.edu/

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

WALTA (Washington Large Area Time Coincidence Array) is a project to investigate the highest energy cosmic rays with the participation of middle and high school students and teachers throughout the Seattle area. Particle detectors and front-end electronics are sited at high schools and linked to UW via the schools' internet connections. The school network forms an extensive air shower (EAS) array suitable for detection of extremely high energy cosmic ray showers. Twenty schools are already participating, and during Summer, 2009, we will hold a workshop to train teachers from another set of ~10 schools. REU students will assist with detector development and installation, preparation of materials for the summer workshop, developing and documenting tools and materials for classroom use, and maintaining contact with teachers and students.

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.

Electronic Phenomena in Nanowires
David Cobden

Some very interesting types of crystalline nanowires and other nanostructures are now available. The aim of this project is to investigate fundamental physical phenomena in devices made from these nanowires by fabricating electrical leads to them and performing transport and optical measurements. Some particular nanowires that we have available are the following: (a) Ultrathin gold wires, down to 3 nm in diameter, which provide the opportunity to investigate the limits of electrical conduction and plasmonic guidance in a nearly ideal metal. (b) Vanadium oxide nanobeams, which undergo dramatic metal-insulator transitions, offering the potential to study phase transitions in one dimension. (c) Organic nanowires such as hexathiapentacene which are semiconducting and have unusual light guiding properties. The student will begin by working with a senior graduate student in an ongoing project before choosing another novel kind of nanowire to focus on.

Semiconductor Nanostructures
Marjorie Olmstead

We are investigating growth and properties of novel electronic materials compatible with silicon. The materials we are currently investigating are chalcogenides and oxides, which are of interest for as high-dielectric constant insulators, non-volatile phase change memory, and/or spin electronics (spintronics) 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.

Likelihood, Resolution, and Lifetime in X-ray Spectroscopies
Jerry Seidler

X-ray spectroscopies, such as x-ray absorption fine structure and resonant and nonresonant inelastic x-ray scattering, play an important and diverse role in condensed matter physics, physical chemistry, and geophysical and environmental sciences. However, it commonly arises that the experimentally spectra are seriously degraded by broadened from lifetime effects or the limitations of experimental energy resolution. We have recently found that an information-theoretic-optimal removal of such affects is afforded by maximum-likelihood algorithms similar to those used to improve the optical performance of the Hubble telescope. After reviewing basic issues in information theory, maximum-likelihood algorithms, and the quantum mechanics of the path-integral full-multiple-scattering approach to x-ray spectroscopies, the interested student would take the lead in developing and exploring the efficacy of a second, similar algorithm for removal of lifetime effects. Time permitting, the student would also package both approaches in C or Fortran for distribution to x-ray spectroscopy teams located at synchrotron sources, such as the Advanced Photon Source or the National Synchrotron Light Source.

Atoms, Plasmas, Instrumentation and Economics
Jerry Seidler

The Linac Coherent Light Source (LCLS), presently under construction at SLAC, will be the world's first hard x-ray laser. It will allow measurements with unprecedented power and time resolution across multiple disciplines of science. Specific endstations are under construction to focus on: nonlinear x-ray optics in atomic physics, correlated electron physics in solid state and nanophase materials, pump-probe studies of biological and synthetic photochemistry, and plasma physics relevant for astrophysical nebula and planetary and stellar interiors. Science at the LCLS will, however, be constrained by a fundamental limit: it costs approximately $100,000 per hour to operate the light source, and therefore beamtime is a scarce resource and high-efficiency experimental methods become precious. Our group has recently developed a new type of x-ray optic which promises to greatly decrease the measurement time for x-ray emission spectroscopy at the LCLS. Several summer projects are possible, including taking lead responsibility for modeling and designing an x-ray spectrometer for one of several applications at the LCLS. A successful project may enable new and important science while also saving the science community millions of dollars. Students involved in this project will get an in-depth experience in experimental instrument design, including both a broad introduction to modern x-ray techniques and also complete training in computer-aided design software.

Theory/Numerical Modeling 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.

Light Front Quantum Mechanics
Jerry Miller

In 1947 Dirac introduced a new form of relativistic quantum mechanics in which the variable ct +z acts as a "time" coordinate and ct-z acts as a "space" coordinate. This so-called light front formalism was largely forgotten until the 1970's, when it turned out to be useful in analyzing a variety of high energy experiments. Despite the phenomenological success of this formalism, it has enjoyed only limited use in computing wave functions of particles and atomic nuclei. The present project is devoted to using the light front formalism to solve quantum mechanics problems involving bound and scattering states. A mathematically strong REU student would learn about relativistic quantum mechanics through the process of solving the relevant relativistic equations. This project would involve working on interesting and timely topics and could provide great preparation for graduate school quantum mechanics, field theory or even string theory.

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 or email trq@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 outsome analysis and visualization. For more information, visit www-hpcc.astro.washington.edu or email trq@astro.washington.edu

Computational Condensed Matter Theory and Response Functions:
Real-time Time-Dependent Density Functional Theory
John J. Rehr

Real-time, time-dependent density functional theory (RT-TDDFT) is a powerful numerical method for computing linear and non-linear response functions in condensed matter physics. This work goes beyond ground-state calculations to calculate excited-state properties, for example as measured in electron and photon spectroscopies. Interest in theoretical or mathematical physics, scientific programming, and high-performance computing is desirable.

Theory project on diffusive and localized electron states
David Thouless

In 1958 P. W. Anderson wrote a paper on "Absence of diffusion in certain random lattices", for which he was subsequently awarded the Nobel Prize. Physicists had been taught to expect electrons to propagate as waves in uniform lattice, and that the motion would become diffusive in the presence of disorder. We found Anderson's argument for the localizing effect of strong disorder counterintuitive. However, a rigorous proof of Anderson localization was obtained in 1985, but there is no comparable proof that weak disorder produces diffusive motion in three dimensions. It is known that any disorder in one dimension localizes all states, and there are reasons to think the same may be true in two dimensions.

I am starting to explore a new approach to this problem. The work involves numerical simulation of a single electron started at one point in a weakly disordered lattice, and following its subsequent motion, by mapping the lattice onto a one-dimensional lattice. The results of this simulation can guide the probabilistic arguments that are needed to get deeper understanding of the diffusive motion that we all believe in. The summer project would involve both aspects of this work.

* Tentative