

# UW Physics REU 2011 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 Subhadeep Gupta or Alejandro Garcia for help. They may be able to design new projects that align with your interests.

## Experimental Projects

### **Bilayer Graphene Optoelectronics**

Xiaodong Xu

Bilayer graphene has extraordinary physical properties: an electrically tunable bandgap (0-250 meV) and large photon absorption (~5%). It holds great potential for dynamically tunable optoelectronics at room temperature. However, little is known about the optoelectronic properties of bilayer graphene. There is also lack of a growth method to synthesis large scale bilayer graphene. In this project, REU students will be involved in the development of chemical vapor deposition growth of bilayer graphene, and measure the optoelectronic properties of tunable-bandgap bilayer graphene devices using scanning photocurrent microscopy.

### **Study the Universe with Gamma-rays**

Toby Burnett

Our group is heavily involved in studying data from the orbiting Fermi gamma-ray telescope. A student could help with tasks involved with submitting and analyzing jobs to reduce the data to useful images and properties of sources that we see. Some experience with the python language would be useful, but not required.

### **Ultracold Atoms and Molecules**

Subhadeep Gupta

Through the orchestrated use of lasers and electronics, neutral atomic gases can be cooled and trapped at microKelvin temperatures in a high-vacuum environment, where their properties are dominated by quantum mechanics. In our laboratory, we prepare and study such ultracold gases with a focus on their quantum collisional properties, including studies of ultracold molecule formation through collisional resonances. REU students can engage in multiple aspects of the experiment - past REU students have made

significant contributions by building electromagnetic atom trapping coils and diode laser assemblies. Please see our website <http://www.phys.washington.edu/users/deepg/> for further details.

### **Laser trapping of $^6\text{He}$**

Alejandro Garcia

This project aims at determining the angular correlation between the electron and the neutrino in the decay of  $^6\text{He}$ . We plan to use a Magneto-Optical laser trap to hold the  $^6\text{He}$  atoms so that the decay particles can be observed with minimal interference. The student will participate in setting up the laser equipment and in the first tries to trap  $^6\text{He}$ .

### **Development of new tests of Einstein's Equivalence Principle**

Eric Adelberger, Frank Fleischer

The Eot-Wash group has made the best tests of the universality of free fall, the most precisely tested (2 parts in  $10^{13}$ ) consequence of Einstein's Equivalence Principle. We are currently pursuing 2 paths aimed at improving this precision by a factor of 10--the first by increasing the power of our tests by making the test-body pair more sensitive to Equivalence Principle violation, the second by reducing the noise in our differential acceleration measurements. Both of these have REU projects. Specifically, the first REU project involves design and testing work on a prototype torsion pendulum that contains both neutron-rich (Be) and proton-rich ( $\text{CH}_2$ ) test bodies. The other project deals with a new cryogenic torsion balance designed to study the ultimate limits of the classical technique. Both projects require hands-on hardware work, computer modeling, and data analysis.

### **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. Also, we're in the process of rebuilding the detector for its next and more sensitive phase. We welcome someone with computing and mechanical skills who can join our group and who has an interest in experimental cosmology.

### **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.

### **Next generation neutrino detectors**

Nikolai Tolich

Our group is involved in a number of experiments to detect neutrinos. Neutrinos are elusive particles that pass through matter almost completely unhindered, which makes them excellent probes of the physics occurring deep inside objects such as the earth and the sun, but also makes them extremely difficult to detect. We are currently working on ideas for two different neutrino detectors, which both use liquid scintillator as the detection medium. One detector, around 1 kton in mass, could be used to measure neutrinos coming from the earth. This would allow us to measure the main source of heat within the Earth, which is thought to power mantle convection, earthquakes, and plate tectonics. The other detector, around 50 to 100 kton in mass, could measure neutrino oscillations from a man-made neutrino source. This would allow us to understand the nature of neutrinos. An REU student could help us simulate new detector designs, or could help us make measurements of the optical properties of the liquid scintillator to see if such detectors would be possible. For more information on our research group, see: <http://www.phys.washington.edu/users/ntolich/>

### **Neutrinos and Dark Matter**

Michael Miller

We have an opening for an REU student in our neutrino/ dark-matter group at CENPA. I am one of four professors in the group and am working primarily on the MAJORANA project (\*), although my interests are increasingly towards using the same technology to also search for Dark Matter interactions in the lab (\*\*). This summer we have multiple projects that are well suited for a 10-week program. I include a few below:

1) Hardware: we have a large, fully constructed detector that holds 1 ton of liquid Argon. The goal is to use liquid Ar as an active "shield" for neutrino/Dark Matter detectors. When charged particles traverse the Ar light is produced and collected in photo multiplier tubes. The goal for the summer would be to play the lead role in operating and calibrating this device. It is a rare chance to play a leading role in an expensive (~\$1M) device.

2) Software: we have multiple project choices involving simulations of neutrino detectors. These include learning how to write custom, high performance c++ code, as well as using standard tools of particle physics: the GEANT4 and ROOT c++ libraries.

3) Analysis: We have a rich set of data currently being collected at the Soudan deep underground laboratory that is probing terra incognita in the search for direct detection of Dark Matter. Data analysis would include in situ measurement of various background sources that are critical to fully utilizing the discovery potential of the Majorana prototype dark matter detector.

(\*) Majorana home:

<http://majorana.npl.washington.edu/>

(\*\*) Big picture description:

We are developing and building novel detector technologies to probe some of the most compelling questions of physics beyond the standard model: (i) the absolute neutrino

mass scale, (ii) the Dirac/Majorana character of neutrinos, (iii) lepton-number conservation and its implications for the matter/anti-matter asymmetry, and (iv) general searches for dark matter interactions. The prospective student would join an active group based at University of Washington and be expected to contribute to both hardware and software tasks.

### **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

A huge variety of nanowires and nanotubes of many materials can now be synthesized. They allow us to explore numerous physical phenomena that are either new or significantly different from those seen in the bulk. These include phase transitions in reduced effective dimensionality and coupling of electronic and nanomechanical properties. One possible summer project in our lab is to study the coupling of the metal-insulator phase transition in vanadium oxide nanowires to their mechanical distortion, induced either by micromanipulation or by electric field. Another project is to try to detect the predicted but never seen chiral photomotive force, by studying chiral nanowires of selenium and tellurium in a circularly polarized laser beam.

### **Semiconductor Nanostructures** (tentative)

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.

## **X-ray Optics, Nonlinear Spectral Signatures, and Economics**

Jerry Seidler

The Linac Coherent Light Source (LCLS), recently completed and commissioned at SLAC, is the world's first hard x-ray laser. It will allow measurements with unprecedented spatial 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 beam time 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 scientific 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 multiple aspects of instrument design. These students will also participate in one of my group's trips to a synchrotron light source for characterization of, and experimental measurements with, the instruments that we design and build.

## **Theory/Numerical Modeling Projects**

### **Computing Dark Matter Cross Sections with Gaming Cards**

Huey-Wen Lin, Saul Cohen

From a variety of astrophysical observations, beginning with galactic velocity curves and including the precise modern measurements of the CMB provided by WMAP, we now know that dark matter constitutes 80% of the matter in the universe, while ordinary matter makes up only 20%. Recent evidence suggests the dark matter must be cold with non-relativistic velocities that give it a Compton wavelength above the width of a proton. One promising candidate for dark matter is a class of supersymmetric particle called neutralinos. If dark matter is neutralinos, they will interact with nuclei at low-energy with couplings that depend on the nonperturbative properties of quantum chromodynamics (QCD), particularly strange-quark contributions to the scalar and axial nucleon matrix elements that are poorly known from experiment.

We will use lattice gauge theory to perform a direct numerical calculation of these quantities from the first principles of QCD. In order to harness enough processing power to invert the  $O(108)$ -rank fermion matrices that appear in this problem, we will apply graphics processing units (GPUs), which have shown great potential to supplement conventional CPUs in high-performance computing. Students will have a chance to learn programming techniques for GPUs and have first-hand experience with numerical evaluation of Standard Model path integrals.

## **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. A full year of quantum mechanics is a necessary prerequisite.

## **Planetesimal Dynamics**

Tom Quinn

Comets provide unique constraints on the formation of the Solar System, however their evolution from "planetesimals" in the proto-planetary nebula involves a combination of orbital, collisional and even galactic dynamics. This project will perform simulations of these processes using clusters of workstations, and analysis of the results to compare with the observed comet distribution in our Solar System and the observation of disks around other stars.

## **Cosmology**

Tom Quinn

Groups and clusters of galaxies are the largest bound objects in the Universe, containing more than a third of the hot diffuse gas and a significant fraction of the galaxies in the Universe. Therefore, understanding the physical processes that occur in group and cluster environments, including the interactions between the dark matter, hot diffuse gas, galaxies, and the Active Galactic Nuclei, is key to gaining insights into the evolution of baryons and galaxies across the age of the Universe. This project will analyze large N-body simulations of galaxy clusters formation in order to understand the role these interactions play in establishing the observed cluster properties across cosmic time.

## **Computational Condensed Matter Theory and Response Functions: Real-time and Real-space Methods**

John J. Rehr

This project deals with high performance computer calculations of electronic response functions, such as the absorption and emission of x-rays, modern real-space and real-time computational algorithms. Our real-space codes are based on a Green's function (RSGF) formalism as implemented in the FEFF codes. Our real-time codes are based

on time-dependent density functional theory using an extension of SIESTA. These codes are applicable to complex, nano-scale systems. This project is appropriate for students with an interest in theoretical condensed matter physics and computational physics.