Experimental Nuclear Physics

Title: Investigating the Discovery of Isotopes (available for 2 students)
Supervisor: Prof. Michael Thoennessen

Abstract: There are many combinations of neutrons and protons that can make up a nucleus (isotope) of a given mass. Only 300 isotopes are stable and a few thousand more radioactive isotopes are known. However, there are still thousands of nuclei that have not been discovered. The limit of existence is only known for the lightest elements. Major new accelerator facilities are being built and designed around the world that will be able to produce many new very exotic nuclei. Unfortunately no comprehensive compilation of the discovery of isotopes exists. We started a major project to find the discoveries of all isotopes (http://www.nscl.msu.edu/~thoennes/2009/discovery.htm) where the first publications are listed.

The goal of the student project is to investigate and verify the various claims of discovery of all isotopes for a given element. It is very likely that the work will result in a first-author publication for the student. This project will be performed at the National Superconducting Cyclotron Laboratory and the student will also have the opportunity to participate in an experiment with the Modular Neutron Array MoNA (http://www.cord.edu/dept/physics/mona/).

Title: MoNA-LISA: The New Modular Neutron Detector Array (available for 2 students)
Supervisors: Thomas Baumann, Artemis Spyrou and Michael Thoennessen

Abstract: The Modular Neutron Detector Array (MoNA) is a large area, high efficiency neutron detector designed for neutrons stemming from breakup reactions of fast rare isotope beams. MoNA was built by a collaboration of predominantly undergraduates schools which continue to collaborate on the experiments. Currently the collaboration is upgrading the array to add LISA, the Large-area multi-Institutional Scintillation Array. During this summer we will perform an experiment at the NSCL to measure the neutron emission in the production of rare isotope beams. The REU students will have the unique opportunity to participate in a cutting-edge nuclear physics experiment. The project will involve the preparation and participation in the experiment as well as data analysis and physical interpretation of the collected data.

Title: Get Trapped: Ion traps for precise mass measurements
Supervisors: Prof. Georg Bollen and Dr. Ryan Ringle

Abstract: The Low-Energy Beam and Ion Trap facility at the NSCL is dedicated to perform high precision mass measurements of unstable “rare” isotopes. Such measurements are important since they provide direct information on the binding energy of a nucleus, which is one of its most fundamental properties. A Penning trap mass spectrometer is used for these studies. In a Penning trap a single ion can be trapped in space. By probing the ion's motion in a very strong magnetic field mass measurements can be performed with a relative precision of better than about 1 part in 100 million. The LEBIT facility has recently been relocated within NSCL and is being commissioned. It provides excellent opportunities for REU activities.
Examples of possible REU projects within the LEBIT project are development and test of electronic components, computer simulations of the motion of ions in electromagnetic fields, or the further development of data evaluation and computer control for LEBIT. REU students in the past have made significant contributions in these areas. Possible projects this year include differential FT-ICR detection in the trap (electronics work, measurements, simulations), building and testing a ultrastable power supply for a miniature ion trap under development, systematic measurements of "Stark shifts" or the study of phase dependencies in the trapped ion motion. Enjoy your training!

**Title: The Low Energy Neutron Detector Array (LENSDA)**
**Supervisors:** Prof. Remco Zegers and Dr. XXX Sasano

*Abstract:* A Low Energy Neutron Detector Array (LENSDA) has been developed by the charge-exchange group at NSCL. It is the most advanced detector for studying spin-isospin responses in unstable nuclei via the charge-exchange (p,n) reaction in inverse kinematics. LENSDA was successfully used in a (p,n)-reaction experiment on an unstable nucleus at NSCL in October 2010. From this study, important parameters in nuclear structures related with spin and isospin are being deduced. The obtained information is of interest for applications in other fields of physics, e.g., neutrino-nuclei processes in supernovae and neutron star cooling. This first experiment, however, manifests many improvements needed for extending our experimental study to other unstable nuclei which will show a variety of exotic phenomena. Therefore, there are many projects available for a student to work on during the REU, for example, the optimization of efficiency and resolution, the upgrade of circuit system using a new type of electronic modules such as digital data acquisition, or the simulation of upcoming experiments. The project is an excellent opportunity for a student who is interested to learn more about detection systems, data acquisition/analysis, and Monte Carlo simulations.

**Title: SuN -- A 4 Pi gamma-ray detector for nuclear reactions of astrophysical interest**
**Supervisor:** Prof. Artemis Spyrou

*Abstract:* The astrophysical processes responsible for the synthesis of chemical elements inside stars are fueled by nuclear reactions. We can study these reactions in the lab by choosing the proper experimental conditions to match the stellar environment. At NSCL we will have a unique opportunity for such studies at the new facility for low energy radioactive beams (ReA3), which is currently under construction. We are developing a new detection system to be used for this purpose, which is a 4π gamma-ray detector called SuN. The REU student will have the opportunity to participate in hands-on work with SuN, compare the results to simulations and investigate the effect of nuclear reactions in astrophysical calculations.
**Nuclear Astrophysics**

**Title: Weak Rates for Nuclear Astrophysics**  
Supervisors: Richard H. Cyburt and Prof. Hendrik Schatz  

*Abstract:* In the field of nuclear astrophysics, we study the origin and evolution of the chemical elements. In doing so, we use experimental input in our models and make predictions to compare with astronomical observations. One key input are the weak decay rates of unstable elements (and their isotopes). A difficulty arises when astrophysical models need experimental weak decay data, where none currently exists. We therefore rely on theoretical estimates to guess the decay rates to use in our models. We would like to write a computer script (fortran or c- programming languages) that calculates theoretical rates for use in astrophysical model calculations.

**Title: Simulations of proton transfer reactions for Nuclear Astrophysics**  
Supervisor: Prof. George Perdikakis  

*Abstract:* Nuclear reactions in stars produce the chemical elements our world is made of. The exact way in which these reactions participate in the birth of nuclei is not completely known yet. Studying relevant nuclear reactions can shed light into such questions. In this project, we will study a particular type of nuclear reaction called proton transfer. These reactions can help us understand the process of proton-captures in stars. The goal is to investigate theoretically such reactions through Monte Carlo simulations and determine what is needed in order to observe them in experiments with the LENDA neutron array of NSCL. The project involves working with special nuclear physics simulation software. It offers experience in basic nuclear reaction principles as well as on the practical considerations related to the design of nuclear physics experiments. It requires interest in computer programming although knowledge of a programming language is not a prerequisite.

**Astronomy**

**Title: Observing Pulsating Stars**  
Supervisor: Prof. Horace Smith  

*Abstract:* Pulsating stars have been keys to the Galactic and extragalactic distance scale and have served as probes of stellar and galactic evolution. RR Lyrae stars, among the oldest of the types of pulsating star, are evolved stars in the core helium burning stage of their existence. Photometric observations of RR Lyrae stars through different filters can provide information on their physical properties. We will observe RR Lyrae stars and related variables at the campus observatory, and use the resultant photometry to determine the heavy element abundances, surface temperatures, and luminosities of the stars.
Title: Ultrafast Meets Ultrasmall (available for 2 students)
Supervisor: Prof. Chong-Yu Ruan

Abstract: Nanoscience is the buzzword for studying things that are small but unique in their property because of their small size. These objects are too small for human eyes or typical optical microscope to see, and to investigate their function one faces challenges from huge dispersion of sample sizes and the complexity of their interaction with their environments and within. We have recently successfully imaged the dynamical transformation of very small gold and silver nanoparticles (size-selected from 1 to 20 nm in diameter) using femtosecond diffraction camera. Because of our shutter speed is ultrafast, the atomic motion within the nanoparticles is thus frozen in time. By capturing these acts at the critical steps of transformations, we highlight the effects that are unique to their size and composition. For example, these noble metals become very reactive when their size is close to 1 nm, and they change into a semiconductor around 5 nm. We are now expanding these efforts to include studying their electronic and compositional transformation that cannot be seen from optical spectroscopic method (meaning by observing the electronic transition in these materials using light). Many of these “dark” transformations are key to understand the hidden mechanism for energy conversion, a potential field nanotechnology can help to solve the energy crisis. We are also exploring using nanolens made by nanoparticles to defeat diffraction limit, so we can produce nanoscale features to trap liquids and gases to study chemistry and biology. We would like to invite interested students to help us to explore these areas, where light and atom, ultrafast and ultrasmall meets. The students will help conduct experiments and simulations related to nanostructures and energy transformations, design instruments that couple to ultrashort pulses, and detect the electronic, structural and compositional changes.

Title: Nanoscale Morphology and Charge Transport in Hybrid Solar Cells
Supervisors: Prof. Pengpeng Zhang and Dr. Jiebing Sun

Abstract: Measurements of the dependence of photoactive response on nanoscale morphology provide essential insights to further improve processing and achieve morphologies with enhanced device performance. To study the correlation between local morphology and photoactive response, we fabricate hybrid polymer/zinc oxide nanostructures and characterize their electrical properties at nanoscale resolution with conducting probe atomic force microscopy (c-AFM). For this REU project, the student will learn the basics of AFM techniques, assist in the fabrication of ZnO nanostructures, and then focus on the finite element simulation of the current density and electric field distribution in the AFM tip-sample geometry. We are looking forward to working with a REU student in the summer.

Title: Ultrafast vibrational dynamics at water interfaces
Supervisor: Prof. John McGuire

Abstract: We are at the initial stages of research to extend our earlier studies of ultrafast vibrational dynamics of H₂O and its isotopic variants at liquid water interfaces. H₂O has many anomalous properties compared to other similarly light molecules. These properties are due to its
hydrogen-bond (HB) network, which is highly dynamic. The O-H stretch mode frequency is strongly correlated with the strength of the hydrogen bonds in which a water molecule participates. We thus use the O-H stretch modes as a probe of the HB network. At surfaces, the termination of the HB network and the generally different local environment than in the bulk results in properties different than the bulk (e.g., surface melting of ice occurring at a markedly lower temperature than melting of bulk ice). The challenge in probing fast dynamics at surfaces is finding a probe that produces a surface-specific signal. One such probe is the coherent process of sum-frequency generation (SFG) in which one infrared photon and one visible photon mix to generate a photon at an energy corresponding to the sum of the infrared and visible photon energies.

Using SFG, we were able to show that while vibrations of hydrogen-bonded O-H stretch modes relax on a ~200 fs (1 fs = 10^{-15} s) timescale, the dangling O-H stretch mode at hydrophobic water interfaces decays about one order of magnitude more slowly. We are preparing experiments to understand the relaxation pathways of the dangling O-H stretch mode, which may reveal the timescale of hydrogen bond breaking and reformation at the water interface. A capable, motivated REU student will collaborate with a senior undergraduate and Professor McGuire on setting up time-resolved SFG experiments to measure the relaxation time of excited OD stretch modes. This will entail learning about ultrafast and nonlinear optics, basic sample surface preparation, helping to build and characterize an optical parametric amplifier (OPA) for generating 100 fs pulses of tunable infrared radiation, learning photon-counting techniques, and participating in experimental measurements of vibrational dynamics.

Title: Ultrafast dynamics in graphene quantum dots

Supervisor: Prof. John McGuire

Abstract: We are currently studying ultrafast (10^{-13} s) and nonlinear optical processes in chemically synthesized graphene quantum dots. These systems can be viewed as large polycyclic aromatic hydrocarbons built of up many benzene rings or as a quantum confined flake of single-layer graphene. Excitation of an electron out of the valence band of a semiconductor into the conduction band can give rise to a bound electron-hole pair called an exciton (the hole simply refers to the now unoccupied state in the valence band). When a semiconductor crystal is smaller than the dimensions of an exciton in the bulk parent material, the exciton experiences a confinement-induced change in energy. This results in size-tunable electronic structure that is the basis of many of the applications, both potential and realized, of nanocrystal quantum dots (QDs). Although nanocrystal QDs can be understood in simple terms as quasi-zero dimensional systems insofar as carriers are quantum confined in all three directions, the underlying Coulomb interactions between carriers are still screened in all three dimensions. In contrast, graphene QDs consist of a single layer of sp²-hybridized carbon atoms. These structures allow us to explore quantum confinement in a two-dimensional system in which Coulomb screening is much weaker than in three-dimensional nanocrystals (the field lines extending out of the plane of the QD are not screened effectively compared to the field lines in the plane of the carbon lattice).

Our initial studies indicate that the interaction between pairs of excitons is even stronger than in carbon nanotubes, another nanoscale system of sp²-hybridized carbon atoms, and we are currently exploring the consequences of these strong interactions and other questions about the electronic structure and interactions within these QDs. A capable, motivated REU student will work on time-resolved spectroscopy of graphene QD with 100 fs (10^{-13} s) resolution. The student
will learn ultrafast optical spectroscopy and characterization techniques and the physics of nanoscale quantum-confined structures and graphene while collaborating on measurements of dynamic processes in graphene QDs.

**Title: Probing a surface with an ultra-sharp tip**
Supervisor: Prof. Stuart Tessmer

*Abstract:* Seeing is believing. In our group, we develop and apply scanning probe techniques to study the behavior of charges in nanoscale systems. Current projects include probing electrons in atomic-scale semiconductor structures and probing electrons in surprising spin-sensitive quantum states in conducting surfaces. An example of one of our tools is the Scanning Tunneling Microscope (STM); it actually allows you to map out the position and to manipulate individual atoms and molecules. All of these methods require a very sharp tip which interacts with the sample's surface. For this REU project, the student will first learn the basics of STM and similar techniques and then assist in an effort to develop new ultra-sharp tips.

**Acoustics**

**Title: Sound Localization by Human Listeners (available for 2 students)**
Supervisor: Prof. William Hartmann

*Abstract:* There are two REU projects in acoustics for the summer of 2011. Both study the human ability to localize sounds in space. The first project tests models of midbrain cross-correlator cells by detailed measurements of interaural time difference thresholds as a function of frequency. The second exploits virtual reality technology in an anechoic room to present surreal sounds, thereby testing the human response to sound localization cues in extreme contexts.