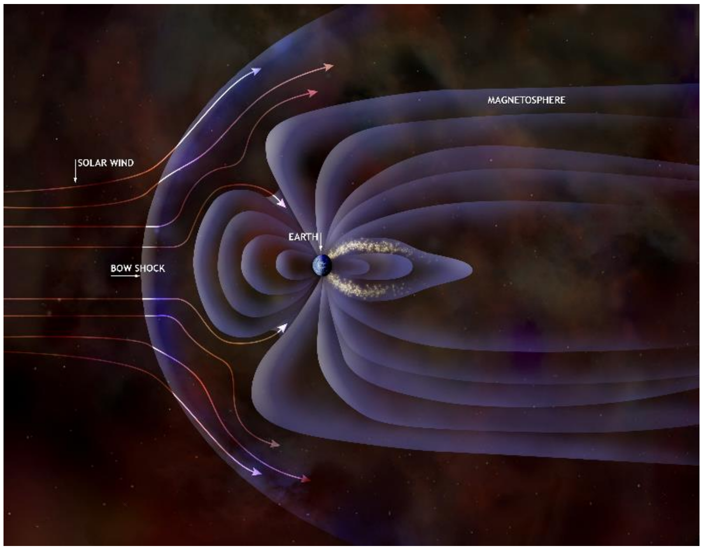
Seeing the Invisible

Mentors: Profs. Yu Lin, Kaijun Liu, and Joe Perez

Overview: The solar wind containing both protons and electrons along with magnetic fields impinges on the Earth creating what is called the magnetosphere. An artist's conception is shown in the figure to the right. Scientists and students both graduate and undergraduate in Auburn University's Physics Department work together and with scientists from around the world to explore this region around the Earth. The fastest computers in the world are used to simulate the important physics determining the spatial and temporal evolution of the plasma and electric and magnetic fields in the magnetosphere. We work with NASA missions such as TWINS, THEMIS, Van Allen Probes, and MMS to make observations that provide incredible detail as to the happenings in this very important region around the Earth. Even though it is not visible to the naked eye, it is responsible for the Aurora Borealis, one of nature's most grand sights. It is also the place where the satellites fly that provide so much entertainment and information for the people of the Earth. We invite you to come and spend 10 weeks during the summer working with us to see and understand the invisible.



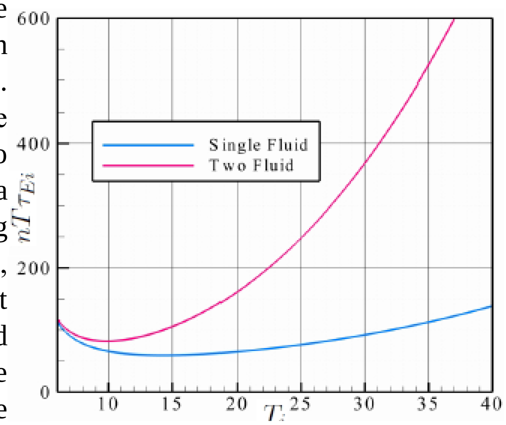
Model of the solar wind interactions with the magnetosphere

Student Project: You will work with us in performing and interpreting the results of our simulations. You will examine and process data from the satellites in orbit around the Earth. You will explore the wonders of the state of matter called plasma, which makes up the vast majority of the material in the universe. Students will use computer software to plot and analyze the information from the simulations and the data from the satellites. Each student will have their own project that is an important component of the space plasma research done at Auburn. The results are regularly published in the peer reviewed journals, and the students are co-authors. In addition, there are opportunities to present scientific papers at meetings hosted by professional societies like the American Geophysical Union and the American Physical Society. Specifics of the project will depend on the status of our research in this fast moving and exciting field.

Improving the Lawson Criterion for Nuclear Fusion Ignition

Mentor: Prof. Luca Guazzotto

Overview: Nuclear fusion is the process that powers the stars. For many decades strong research efforts have been devoted to obtain controlled nuclear fusion on Earth. Experiments using magnetic fields to confine the "fuel" for the fusion reactions (plasma, i.e. hot, fully ionized gas) aim to produce a net power output by maintaining the plasma at a sufficiently high temperature and density for a sufficiently long time. It was quickly realized that the "ignition" condition, defined as the condition in which the plasma produces net thermal power with no external heating applied, can be obtained if a simple criterion is satisfied. Namely, the product of average density, temperature and energy confinement time must be larger than a critical value. This is known as the Lawson criterion.



Lawson criterion for single- and two-fluid plasma

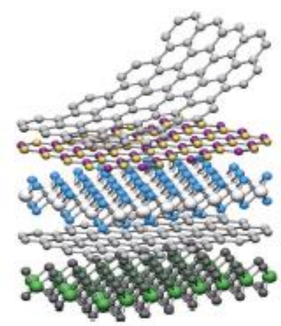
Student Project: Recent work has been devoted to the improvement of the Lawson criterion, by including more realistic space-dependent profiles for ion and electron temperatures and density, see http://www.auburn.edu/cosam/faculty/physics/guazzotto/research/TF_Lawson_main.html. Many additional improvements are possible and planned. The student project will be to determine (1) the importance of any difference in the spatial profiles of ion vs. electron temperatures and (2) the importance of self-consistent charge balance. The research work will be performed using sophisticated numerical models implemented in the Mathematica language. Results from this work will be published in a peer reviewed journal as well as presented at a professional meeting, with the student participating as a co-author.

Computational Materials Physics

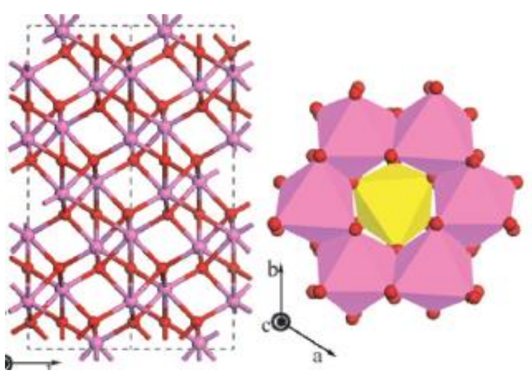
Mentors: Profs. JJ Dong and Marcelo A. Kuroda

Overview: Over the last quarter century, a key development in solid state physics is our fast-growing capability to predict properties of materials from first-principles: by applying laws of quantum mechanics and statistical physics to describe the behaviors of electrons and phonons at the microscopic level. In recent years, the Computational Materials Physics Group at Auburn University has been adopting and further developing state-of-the-art first-principles computational tools to (1) design novel materials that can be used for the next-generation electronic devices and renewable energy technologies, and (2) model thermal and thermal transport properties of complex Earth minerals at extreme pressure-temperature conditions.

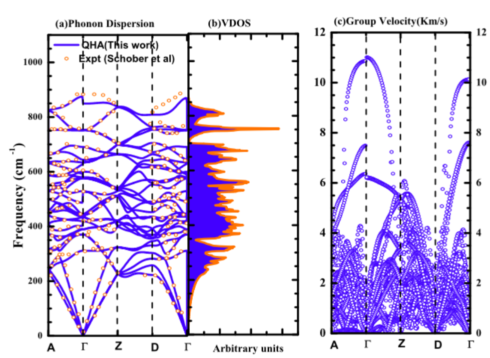
Student Projects: First, students will be trained to write computer codes in Python to generate and analyze various structural models of 2- and 3-dimensional crystals, and to submit computing jobs at the Auburn University High-Performance Computing (HPC) parallel computer cluster. They then will gain hands-on experiences in using first-principles computer packages (VASP/Quantum ESPRESSO) to optimize crystal structures, and calculate electron and phonon band-structures. The emphasis is primarily on conceptual understanding of "What and How", not on quantitative physics theories. Finally, the students will participate in writing reports to summarize their calculation results and to compare their theoretical findings with available experimental measurements. Results from this work might be published in a peer-reviewed journal as well as presented at a physics conference, with the student as a co-author.



Heterostructure based on 2D materials crystals



Crystal structure of corundum Al_2O_3

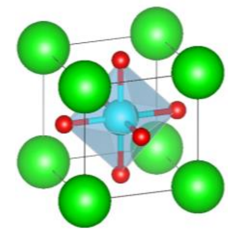


Phonon band structures of corundum Al_2O_3

Engineering the Surface Electronic Properties of Oxide Substrates

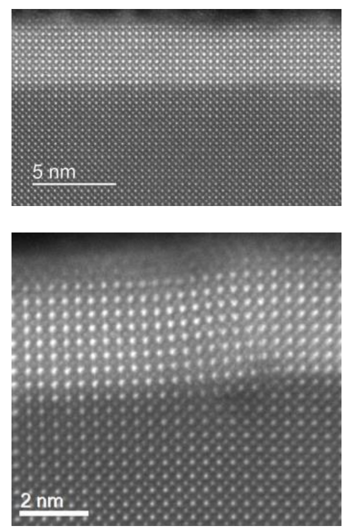
Mentors: Profs. Ryan Comes and Sarit Dhar

Overview: Nobel Prize winning physicist Herb Kroemer famously said in that when it comes to electronic devices “the interface is the device.” This is true for everything from Si transistors to solar cells to next-generation technologies like graphene. One of the biggest challenges in making a good interface is controlling defects in the materials so that the device will perform as intended. To do this, one must carefully examine how a material is prepared and correlate that with the resulting electronic behavior through characterization. For one class of materials—complex oxides like $SrTiO_3$—this means preparing a single crystal substrate to have a specific surface structure before depositing a thin film on top of the substrate. The goal is to achieve an atomically smooth surface with minimal defects and terminated on a particular atomic plane, such as a TiO_2 layer in $SrTiO_3$. Recipes exist to accomplish this, but results are often inconsistent and small concentrations of defects can have big effects on the resulting samples. However, a wide range of unusual behaviors can be found at interfaces between oxides, such as superconductivity, ferromagnetism, and photoconductivity. This makes understanding the interface vital to creating new technologies out of these materials.



$SrTiO_3$ crystal, Sr-green, Ti-blue, O-red

Student Project: Nb-doped $SrTiO_3$ (Nb:STO) is commonly used as a substrate in the oxide community due to its cubic crystal structure and because the Nb dopants make the material conductive. However, the recipes to prepare pure STO are not effective for the preparation of Nb:STO, resulting in rough surfaces and more defects. In addition, the effect of high temperature annealing (necessary to prepare these substrates) on the Nb dopants and the electronic behavior near the surface is not well understood. This can have a profound effect on materials grown on the doped substrate, changing the functional properties of the structure. In this project, the student will investigate the effect of wet etching and heat treatments on the surface structure and the electronic properties of Nb:STO substrates . Using atomic force microscopy (AFM), x-ray photoelectron spectroscopy (XPS), and reflection high-energy electron diffraction (RHEED) the student will determine the surface structure of the substrates. Then they will perform current-voltage and capacitance-voltage based electrical measurements to understand the conductivity of the surface and measure doping concentrations. Following this, deep-level transient spectroscopy (DLTS) will be used to measure electronic defect concentrations near the surface of the samples. This will improve our understanding of how to prepare substrates for novel complex oxide thin films that rely on interfacial phenomena to achieve new behavior. The student will get hands on experimental research experience in solid state physics and electronic materials characterization. Results from this work will be published in a peer reviewed journal, with the student participating as a co-author.



Atomic-resolution electron microscopy images of ideal interface (top) and defective interface (bottom) between a Nb:STO substrate (dark region) and $LaFeO_3$ film (bright region)

Wave-particle Interactions in Space Plasmas

Mentor: Prof. Kaijun Liu

Overview: The Universe is comprised mainly of plasma, which is the fourth state of matter after solid, liquid, and gas. Plasma is essentially an ionized gas with a portion of its atoms/ molecules ionized so its dynamics is dominated by electromagnetic forces. Because of the coupling between charged particles and electric and magnetic fields, many electric and magnetic field fluctuations, called plasma waves, can occur in a plasma. The interactions between charged particles and plasma waves are complex and remain to be better understood. Wave-particle interactions play an important role in the dynamics of plasmas in space, including the plasma in the magnetosphere around the Earth and the solar wind plasma in the heliosphere.

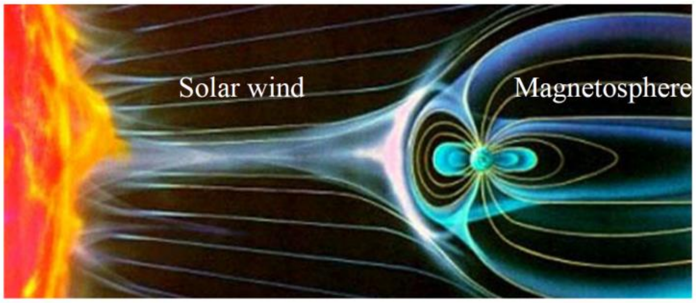


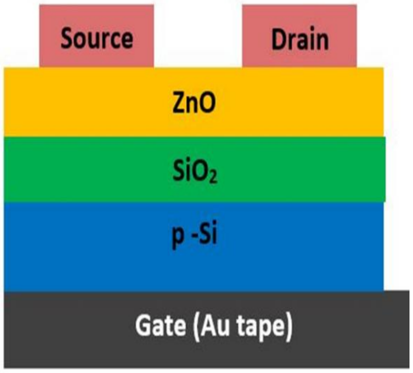
Illustration of the space plasma environment around the Earth

Student Project: Using a computer simulation model, prospective students will explore how certain plasma waves are excited and how they interact with charged particles (electrons and ions) in various space plasmas. The study is relevant to the excitation of plasma waves in the terrestrial magnetosphere as well as the pickup ion dynamics in the heliosphere. Students will be trained to run the simulation model on large scale parallel computers and help to analyze the simulation results. So they will gain valuable experience with parallel computing and develop important analysis skills along the way. Moreover, the investigation will make significant scientific contributions to the fundamental understanding of wave-particle interactions in space plasmas. The results will also be beneficial to a broad range of plasma studies in laboratory and fusion plasmas.

Radiation-Hard ZnO Thin Film Transistors

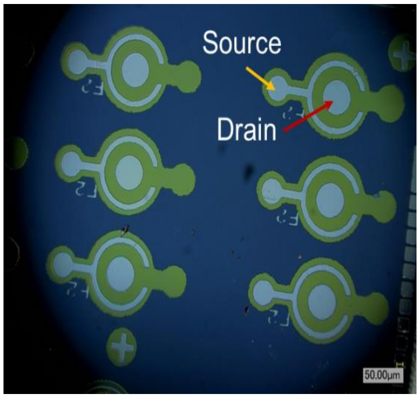
Mentor: Profs. Minseo Park and Michael Hamilton (ECE)

Overview: With the continued increase in our society's dependence on technology, electronics have become integral to nearly all aspects of human activity. One of the great technical challenges we currently face is the development of electronics that can function well in a harsh environment, whether inside a nuclear power plant or in outer space, where ionizing radiation can cause failure in basic electronic devices. One approach to solve this problem is the development of radiation-hard electronics, systems that resist interruption due to interactions with debilitating radiation. This is particularly critical for space applications, since radiation shielding adds additional weight (and therefore expense) for missions to space. Therefore, it is crucial that we pursue new electronic devices that can operate effectively in radiation-harsh environments.



Schematic of a ZnO TFT device

Student Project: Zinc oxide (ZnO) is a novel metal-oxide semiconductor that is a strong candidate for radiation-hard electronic applications. The student will create their own ZnO thin films on oxidized silicon wafers using state-of-the-art deposition techniques. They will then analyze these deposited films with multiple diagnostics including: X-ray diffraction, scanning electron microscopy, micro-Raman spectroscopy, and photoluminescence. The students will then perform ohmic contact (source/drain) metallization to form circular thin film transistors which will be characterized through current-voltage and capacitance-voltage measurements. Finally, the student's newly fabricated devices will be tested after irradiation using the unique radiation environments available at Auburn University: the ultra-intense cobalt-60 gamma-ray source and energetic protons from the Auburn University Particle Accelerator. Results from this work will be published in a peer reviewed journal as well as presented at a professional meeting, with the student participating as a co-author.



Optical micrograph of fabricated devices