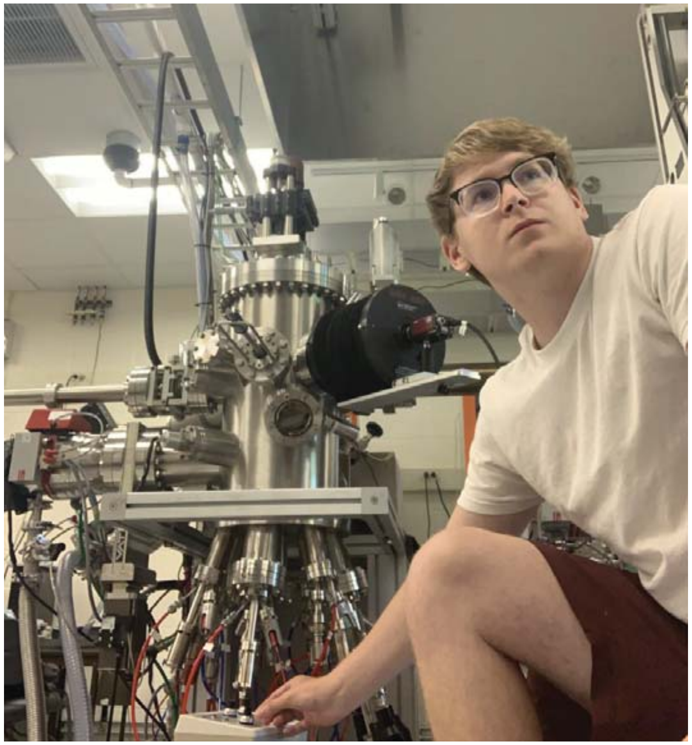
NSF-REU Site Funded Student and Teacher Highlight Slides

Superconductivity at the Interface of $MnBi_2Te_4$ and FeTe

Dustin Hassenmayer, Department of Physics, Lock Haven University
CuiZu Chang, Wei Yuan, Zijie Yan, and Zihao Wang, Department of Physics, Penn State University

Interface superconductivity can occur at the junction of two materials which can enhance the high temperature superconductivity and reveal exotic quantum phenomena. $MnBi_2Te_4$ is a topological insulator (TI) that has intrinsic ferromagnetism which may overcome the disadvantages of magnetically doped TIs. Quantized anomalous Hall resistivity in $MnBi_2Te_4$ was recently discovered and gives reason for further study of its quantum properties. In this work, we report on $MnBi_2Te_4$/FeTe heterostructure thin films grown by Molecular Beam Epitaxy (MBE). A study of their surface topology and interfacial magnetotransport measurements are used to determine the best growth conditions.

This summer I was able to learn about superconductivity and topological insulators which has become an important and popular field. During research, I was able to contribute ideas on how to grow the next heterostructure better because we change growth parameters for every heterostructures based on the previous samples, and able to analyze the transport measurements as I was also tasked with learning about the Quantum Anomalous Hall Effect which Dr. Chang discovered in 2013. The project goal of obtaining superconductivity in MnBi2Te4 was achieved, and the new goals are to obtain antiferromagnetic properties and an image of the septuple-layer cross section using TEM. The REU program gave me the opportunity to learn how research is conducted and showed me research is a fun and rewarding job that creates an impact on our technology and knowledge as a society.



Multiple Winding of Chiral Edge States in 1D Photonic Crystals via Dimensional Extension

Megan Goh, Department of Physics, Amherst College
Sachin Vaidya, Christina Joerg, Mikael C. Rechtsman, Department of Physics, Penn State University

A Thouless pump is a one-dimensional lattice model that exhibits quantized transport of charge as a function of an adiabatic parameter. This phenomenon can be understood as a Chern insulator in two dimensions, where the adiabatic parameter is considered as a second momentum coordinate. The consequence of a non-zero Chern number is the presence of robust chiral edge states that reside on the boundaries of the system. This project demonstrated the presence of such chiral edge states in the transmission spectrum of spatially modulated one-dimensional photonic crystals (PhC). Recently it has been proposed that topological edge states of Chern insulators could be used to generate broadband slow light by coupling the edge states to dispersionless resonances. This project sought to experimentally demonstrate this method of generating broadband slow light by coupling the edge states in our system to a Fabry-Perot cavity that is monolithically integrated into the PhCs.

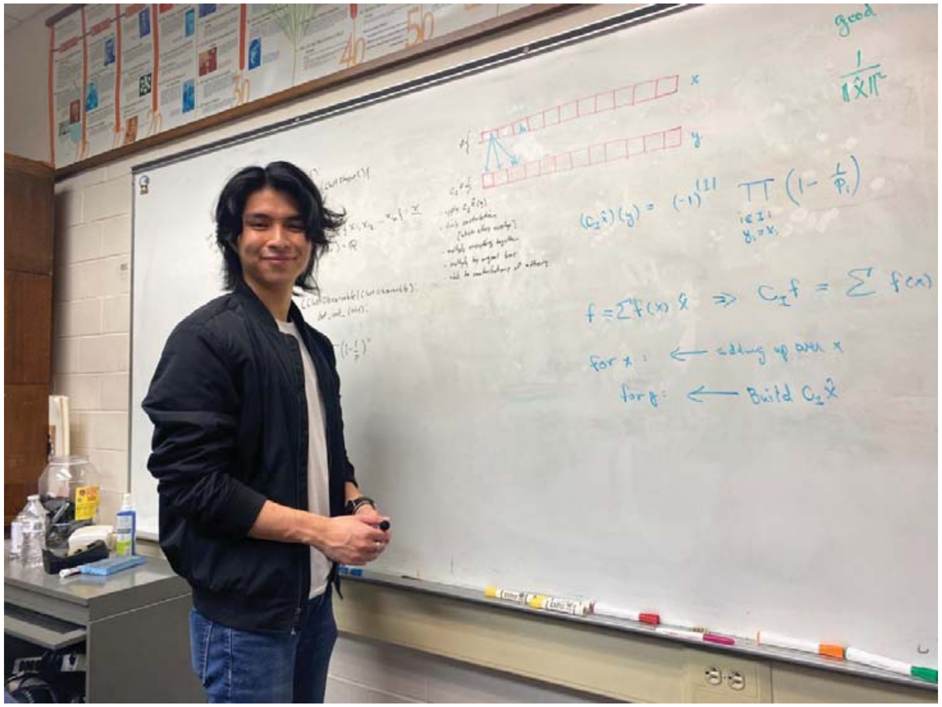
In this project, I fabricated PhCs consisting of alternating layers of silicon and silicon dioxide using plasma enhanced chemical vapor deposition (PECVD) and characterized them using a supercontinuum laser. I also used the transfer matrix method of determining the transmission through a PhC using the Fresnel equations to simulate the results of our experiments. Through this project, I have learned a lot of skills in both simulation and experiment that will help me in future research. This summer also helped me decide that I want to go to graduate school, as I loved the problem solving process I was able to do in the lab and would love to pursue that as a career.

GCEP: A Revised Cluster Expansion Method Formulation based on Hilbert Space Geometry

Miguel O. Mercado, Department of Physics & Astronomy, Department of Mathematics, University of Southern California
Paul E. Lammert, Department of Physics, Penn State University

The Cluster Expansion (CE) method is a widely successful theoretical development used in the calculation of thermodynamic properties and ordering phenomena within multicomponent systems, such as order-disorder phase transitions. Using CE, one can accurately model the configurational dependence of scalar properties (like energy) within a given material through evaluating the sums of contributions of partitioned groups of sites (termed clusters), with limited density functional theory data as input. Consequently, CE provides the necessary extension for computing the underlying phase diagrams and thermodynamic information for structurally complex systems.

My advisor and I developed a revised geometrical formulation of CE, and a corresponding numerical, object-oriented implementation in Python: Geometrical Cluster Expansion Package (GCEP). Our proposed foundation of CE improves upon the conventional methodology through solving the underdetermination problem inherent in fitting the model, and reinstates it with an axiomatic, computationally effective approach grounded in Hilbert Space geometry. Built from scratch this summer, GCEP interprets cluster components as Möbius inversion of conditional expectation in functions of a structure's configuration. This project was an amazing opportunity to develop both my mathematical knowledge (group theory, finite-dimensional Hilbert Spaces), and programming abilities in Python. This summer helped me become closer to my goal of becoming a mathematical physicist—I hope that my package is continued to be developed and finds some use within theoretical physics and materials science.

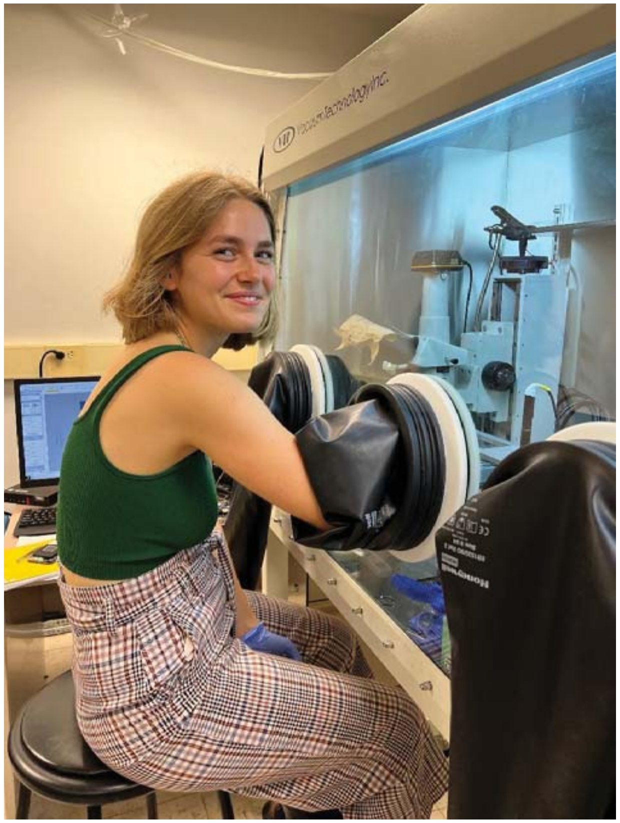


Building a Tunnel Junction to Explore the Magnetic Phases of $CrGa_2Te_7$

Emma Lickey, Department of Physics, Harvey Mudd College
Carlton Drew, Yangyang Chen, Dr. Jun Zhu, Department of Physics, Penn State University

$CrGa_2Te_7$ belongs to a family of materials called magnetic van der Waals crystals whose magnetic properties, along with their ability to be exfoliated down to few layers, make them useful for studying magnetism in 2D systems. Since a tunnel junction can be used to investigate the magnetic state of its barrier, our goal in this project was to fabricate a tunnel junction using $CrGa_2Te_7$ as the barrier.

I was successful in building the tunnel junction we designed, which can now be used to map the magnetic phases of $CrGa_2Te_7$ under changing temperature and magnetic field. I learned how to use an AFM, solder, operate a glovebox, exfoliate 2D materials, and build 2D heterostructures. I also learned a lot of exciting solid-state physics!



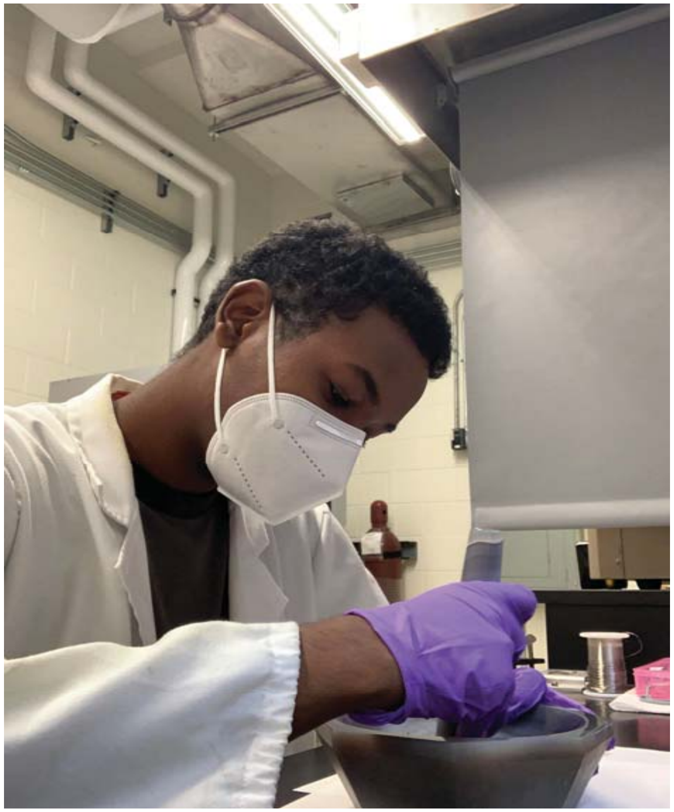
Crystal Growth and Characterization of High-Entropy Spinel Oxide

Ahmed Abdelhameid[1], **Chandan De[2,3,],Yu Wang[2,3],Lujin Min[2,3] and Dr. Zhiqiang Mao[2,3]**

[1]Department of Materials Science and Engineering, Carnegie Mellon University; [2] Department of Physics, Penn State University; [3] Center for Nanoscale Science, Penn State University

High-entropy oxides (HEOs) are complex oxide compounds that possess equimolar amounts of 5 (or more) metal cations in a single-phase solid solution. HEOs have attracted much interest over time as a result of their unique structural and functional properties, specifically with applications in energy production and storage. Growing single-crystals of HEOs allows for isotropic testing of material properties and is integral for the exploration of the material properties of this class of materials. This project focused on the fabrication of a single-crystal of a high-entropy spinel oxide to explore the magnetic properties associated with lattice distortions due to high entropy.

My work focused on preparing and carrying out the solid-state reactions to achieve the desired powder phase of material before then pressing a rod and using an optical furnace to grow the crystal using the floating-zone method. This project was an amazing opportunity to get a better understanding and some practice with the floating-zone method used for single-crystal growth and allowed me to grow my skills as a researcher.

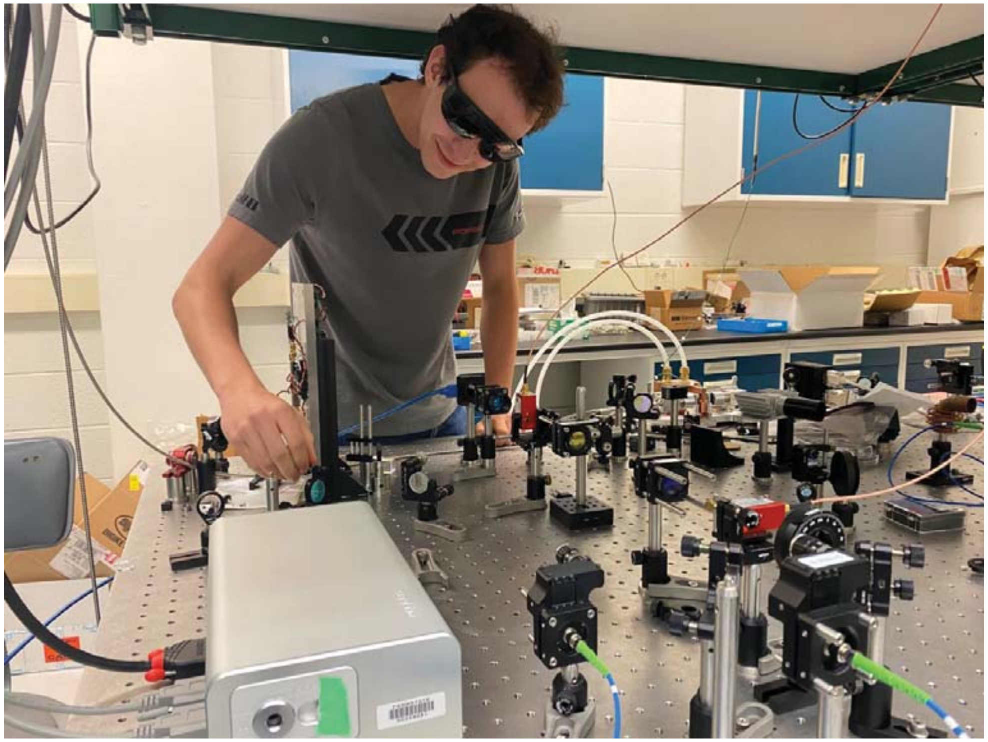


Creating a Laser Grid For Parallel Addressing In a Quantum Computer

Brayant Garcia, Department of Physics , Harvard University
Peng Du, David S. Weiss, Department of Physics, Penn State University

In our group's quantum computer, neutral Cesium atoms are optically trapped in a lattice, serving as quantum bits (qubits). To address single qubits, the group shines two lasers onto a target qubit. In order to increase computational power, it is desirable to address several quantum bits in parallel.

My work was to generate a laser beam array that would be used to address the qubits. In order to do this, we used two acousto-optic deflectors (AODs), which use an acoustic wave driven by a sum of several RF frequencies to generate multiple output beams. By having the AODs in a cross position, the grid was created. With this project, I've been able to gain more experience working with optics and quantum information and am interested to possibly explore these subjects more in graduate school.

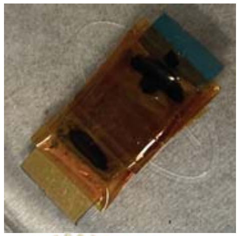


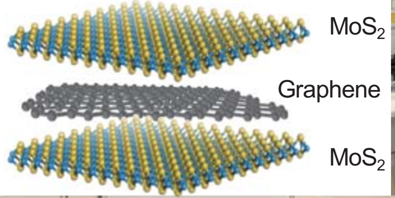
Solution processed graphene/MoS_2 heterostructure based supercapacitor electrodes

<u>Ámbar E. Escobar</u>[1], Dr. George Bepete[2,3], Andrés Fest[5], Conghang Qu[5], Dr. Mauricio Terrones[2,3,4]

[1]Department of Chemistry, University of Puerto Rico at Cayey; [2]Department of Physics & Center for 2D and Layered Materials, Penn State University; [3]Department of Chemistry & Center for 2D and Layered Materials, Penn State University; [4]Department of Materials Science and Engineering & Center for 2D and Layered Materials, Penn State University; [5]Department of Materials Science and Engineering, Penn State University

Previous investigations have shown that the restacked chemically exfoliated metallic 1T MoS_2 nanosheets can electrochemically intercalate ions such as K^+ and H^+ with extraordinary efficiency and achieve very high capacitance values. While these restacked 2D material-based supercapacitor electrodes have interesting properties of their own, more complex systems can be engineered through the integration of disparate 2D material layers to form so called 2D heterostructures with unprecedented properties. We used solution processing and the vacuum filtration to prepare graphene, MoS_2, and Graphene/MoS_2 supercapacitor electrodes. Using electrochemical measurements we show that the graphene/MoS_2 heterostructure based electrode, has a significantly higher capacitance compared to the capacitance of the MoS_2 nanosheet based electrode.





I made graphene and MoS_2 solutions through intercalation and exfoliation process. With these solutions I then used vacuum filtration to prepare graphene, MoS_2 and graphene/MoS_2 heterostructure films. After this I was able to prepare some capacitor devices.

This experience has helped realize how much I enjoy doing research. While it also helped me decide that I want to do a PhD after I graduate. It was also a great opportunity to meet grad students and listen about their experiences. I was able challenge myself professionally and intellectually while being able to have fun and enjoy every step of the process. Also, I grew as a future researcher and scientist. This project helped me improve my analytical skills while learning new synthesis and characterization techniques. Finally, got to expand my knowledge and networking skills as much as I could. Furthermore, discovered my interests to be able to decide what my future professional plans will be.

Estimating Quantum Tunneling Times in a Symmetric Double-Well Potential Using Quasiclassical Models

Javier Cano Rodriguez, Department of Mathematics, University of California, Berkeley
Nicole H. Drew, Dr. Venkatraman Gopalan, Department of Physics, Penn State University

Quantum tunneling is a spontaneous phenomenon where a particle can travel through a classically forbidden region and land in a classically allowed region. Applications that serve as a motivation for this project are instances of proton tunneling in hydrogen bonded chemical processes in low temperatures. Hydrogen transfer in a benzoic acid dimer molecule is modeled by an asymmetric double-well potential [1]. The parameters of the potential describe the benzoic acid dimer. Our objective is to see how the parameters of a symmetric double-well potential affect tunneling times in a quasiclassical model.

Approximating wave functions is not always an easy task. Therefore, we can take advantage of a quasiclassical approach and calculate the system's ”moments” that represent quantum expectation values and quantum fluctuations. This project required me to learn how to use Wolfram Mathematica. A software that is currently being used heavily in research. I also learned how to read and search for academic journals. Professional development was a significant part of the experience. I consistently talked to graduate students and professors. This experience has made me interested in new areas of physics and narrowed down topics.

Synthesis and characterization of molybdenum carbonitride nanoplates

Samantha J. Stapf[1], David E. Sanchez[2], Alexander J. Sredenschek[3], and Dr. Mauricio Terrones[2,3,4]

[1]Department of Physics and Engineering, Slippery Rock University; [2] Department of Material Science and Engineering, The Pennsylvania State University; [3]Department of Physics, The Pennsylvania State University; [4]Department of Chemistry, The Pennsylvania State University

Molybdenum carbide (MoC/Mo_2C) in bulk is chemically stable, corrosion resistant, metallic, and superconducting. Due to the advance in the nanotechnology field and synthesis procedures, single crystal Mo_2C in a nanoplate morphology has been fabricated and retains the properties of bulk down to a few nanometers in thickness. Further tuning the electronic properties of this nanomaterial could potentially be achieved by alloying with nitrogen through ammonolysis. Ammonolysis temperature and time were varied to study the conversion process.

In this project, I synthesized the Mo_2C through chemical vapor deposition, transferred the Mo_2C nanoplates to a silicon/silicon oxide (Si/SiO_2) substrate, and converted the nanoplates to molybdenum carbonitride (MoCN) through ammonolysis. I characterized the morphology using scanning electron microscopy (SEM) and optical microscopy. The crystallinity of the nanoplates was analyzed using selected area diffraction (SAED) and transmission electron microscopy (TEM). Energy dispersive X-ray spectroscopy was used to obtain the elemental composition of the nanoplates.

This summer, I was introduced to material science and worked alongside many well-versed graduate students who taught me everything they know about the field. Along with that, I learned how to conduct research and the many struggles that come with it. I also had the chance to operate characterization equipment and developed many technical skills that I will use throughout my career.

Memory of a Cyclic Multiphase Flow in a Porous Medium

Jennifer M. Lee, Department of Physics, Penn State University
Ashbell Abraham, Nathan C. Keim, Department of Physics, Penn State University

The phenomenon of memory in soft condensed matter is widely applicable. For example, shape-memory materials are used in the automotive, aerospace, and biomedical fields today. However, memory formation in contact lines, the triple phase boundaries of liquids, has received little attention. In this project, we aimed to observe and document memory of cyclic motion in the contact line of a porous medium partially filled with liquid, and we were successful. This study may possibly inform and improve the efficiency of processes that involve multiphase flows in porous media, such as geological carbon sequestration or enhanced oil recovery.

Over the duration of this REU, I designed, continually redesigned, and ran this experiment. Using a syringe pump and code, I injected and withdrew a constant volume of deionized water from a porous medium of glass beads in order to train the contact line to a steady state shape (encode memory). Then, I recovered the steady state shape (performed readouts of memory) through a separate cyclical injection and withdrawal process, fulfilling our project goals.

This project has been very beneficial to me as a researcher as it provided me with a wide array of communication and technical laboratory skills as well as a position in Dr. Keim's lab for the following school year. I am also grateful for this opportunity as it generally opened my eyes to the nature of research and helped me to make informed decisions regarding graduate school.

Distinct Aqueous Phases without Membranes:

A Study of Complex Coacervation Under pH and Salt

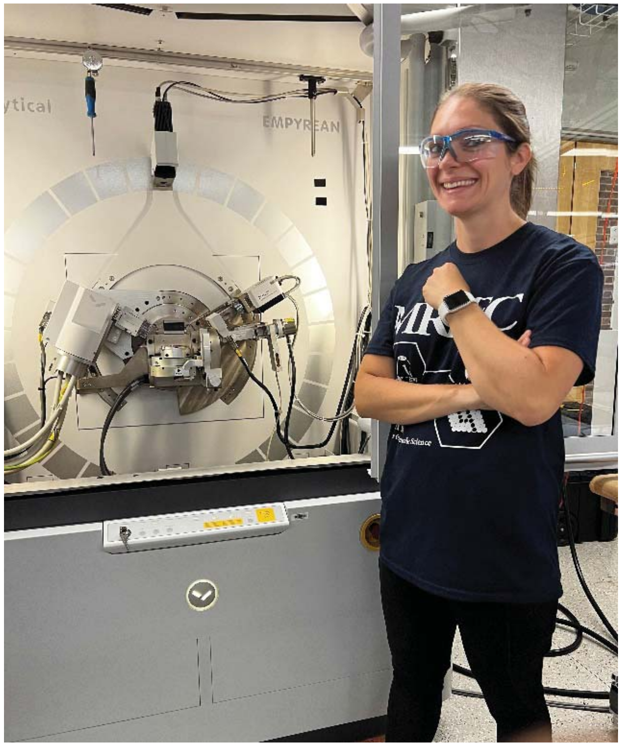
Steve Schulz, Manheim Township High School
Jessica Lee, Jacob Shaffer, Dr. Christine Keating, Department of Chemistry, Penn State University

This project explores aqueous phases that do not mix because of intermolecular forces between polymers, water, salt, acids, and bases. It is important because 1. cells compartmentalize their cytoplasm using coacervates of biomolecules to separate components of aqueous solutions and 2. this separation method can be used in industry as a green alternative to organic solvents.

I adapted a known system of poly(diallyldimethylammonium chloride) and poly(acrylic acid) to classroom use and substituted the polycation with a biopolymer, protamine, to show its coacervates T dependence. This projected opened new developments in chemistry for me and my students.

Creating an X-Ray Lens Model for Dark-Field X-Ray Microscopy

Samantha Knepp, Altoona Area High School
Kenneth Peterson, Dr. Darren Pagan, Department of Materials Science and Engineering, Penn State University



X-rays are currently one of the leading methods used to examine crystalline structure of materials. Even so, the current resolution for such imaging techniques is only 1 µm. To improve the resolution, one can use microscopy techniques in order to reach resolutions one or two orders of magnitude smaller. My work on this project will give a basis for future computational analysis of these types of techniques.

My project this summer was to build a refraction simulation for x-ray microscopy. I was able to construct a 3d lens model simulation that allows the user to input an incident x-ray vector given certain parameters, put the vector through a change in medium, and yield an output x-ray vector. After working on this project, I have found that I am much more comfortable working with computational methods, specifically those coded in Python. Additionally, I no longer feel overwhelmed when tasked with working on computer programming.

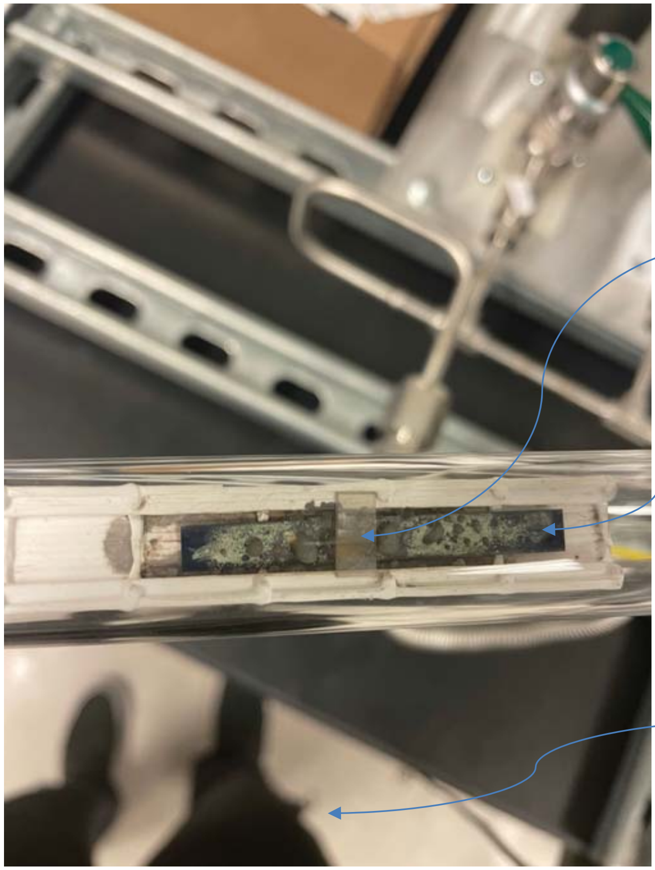
Other NSF Funded Students Participating in REU Professional Development

Effective intercalation of 2D-Bi on an epitaxial graphene and silicon carbide interface

Isabela Galoustian, Department of Physics, Emory University
Alexander Vera, Dr. Joshua Robinson, Department of Materials Science and Engineering, Penn State University

Previous research has demonstrated the energy saving potential of quantum spin Hall materials due to dissipationless spin current characteristics. While efforts to stabilize such materials as 2D-Bi have been achieved through intercalation of epitaxial graphene on silicon carbide, growth is limited to nanoscale regions not effective for energy saving devices. This project aimed to establish a process property relationship for larger scale, uniformly intercalated 2D-Bi through confinement heteroepitaxy applicable to device function. This process was optimized through adjustment of temperature, gas flow ratios, and growth time, and results were analyzed through Raman spectroscopy, scanning electron microscopy (SEM), and x-ray photoelectron spectroscopy (XPS). This information will add to a wider understanding of effective conditions for metal intercalation and contribute towards the goal of creating more energy efficient devices.

Over the course of the summer I was responsible for creating and and defending a project plan based on an introduction to the lab and its goals, preparing the samples under the conditions I had planned, and analyzing them through the techniques I was trained on. These results suggest trends in the effectiveness of Bi intercalation under varying conditions of time, temperature, and ratios of Ar to H_2 gas flows that will be useful for later projects. The amount of control I was given in terms of project planning and being involved in every step of the process from sample preparation to analysis was extremely informative- this is the first time I've had the opportunity to participate further than shadowing or completing small parts of someone else's project, and it was extremely fun and engaging to know that I could design an experiment based on answers I wanted to know and then receive those answers. It's further pushed me towards applying to graduate school and a career involving research if not directly out of college then definitely at some point in the future.



Finished sample of graphene, intercalated 2D-Bi, and SiC

Bi powder (balled up after high heat/pressure in furnace) on Tungsten sheet

My feet!

Crystal Structure and X-ray diffraction Analysis Of ABX_2

Jennifer Rittenhouse, Department of Physics, Millersville University
Jingyang He , Dr. Venkatraman Gopalan , Department of Materials Science and Engineering, Penn State University

I helped weigh and measure out samples for synthesizing Crystal ABX_2 *, a chalcopyrite semiconductor. The powder samples are currently being repurposed to make large single crystals. These single crystals will be measured for their feasibility of being a nonlinear optical crystal. Only few commercially available nonlinear optical crystals extend their range into the mid infrared region.*

By analyzing XRD data, my mentor and I were better able to adapt the polycrystalline for its usefulness in being made into a single crystal. It will soon be tested in the laser lab for its second harmonic generation. This summer research has boosted my confidence in learning new skills in the lab such as precision weighing, crystal growth and using a glovebox. I also learned a lot about calibrating a high-powered laser system for research.

Atomic Layer Deposition of Gallium Oxide

Yeseul Choi, Materials Engineering, Brown University
Bangzhi Liu, Fan He, Dr. Susan Trolier-McKinstry, Department of Materials Science and Engineering, Penn State University

Gallium oxide Ga_2O_3 has gained traction for its large bandgap and predicted ferroelectric properties in its epsilon phase. While various approaches of growth have been reported for the alpha, beta and epsilon phases, its ferroelectric properties have not been proven experimentally. If ferroelectric, ε-Ga_2O_3 could be used in various applications, such as a substitute for lead zirconate titanate in non-volatile ferroelectric memories. Low temperature growth would allow for the memory to be deposited directly on top of the computer process and lower access times markedly.

I particularly focused on the growth of ε-Ga_2O_3 using plasma enhanced ALD (Atomic Layer Deposition). I grew samples on lithium tantalate, lithium niobate, 111 silicon, c-plane sapphire and platinum coated silicon and platinum coated sapphire. Various ALD growth parameters were explored, including temperatures from 375-450°C, thicknesses of 30-100nm, and pressures of 75-100 sccm O_2.Furthermore, I tested various cleaning methods for each substrate and analyzed the crystallinity of each of the samples using x-ray diffractions. I also tested post annealing with varying times and temperatures, and eventually was able to create mixed phase beta and epsilon samples with a bottom platinum electrode that could be lithographed to have electrical tests performed on them. We will soon be able to determine whether there is a possibility that the epsilon phase is ferroelectric as calculated, and if so, the ALD parameters can continue to be modified to allow for its usage in non-volatile memory.

Fabricating a Novel Organic Polariton Laser

Julian Stewart[1], Robert Cawthorn[2] and Dr. Noel C. Giebink[2]
[1]Department of Materials Science and Engineering, University of Maryland, College Park
[2]Department of Electrical Engineering, Penn State University

The purpose of this project was to develop an indirectly pumped polariton laser that utilizes organic thin films in a Fabry-Perot microcavity. Polariton lasers are known for their characteristic low lasing threshold and have applications in biosensing and research. This project could broaden the amount of materials used in current organic polariton lasers and may eventually lead to room temperature organic infrared lasing. In order to realize this goal, I used thermal evaporation, PECVD, and a custom layer-by-layer deposition procedure to fabricate the laser microcavity. For characterization, I used photoluminescence, UV-Vis spectroscopy, and ellipsometry.

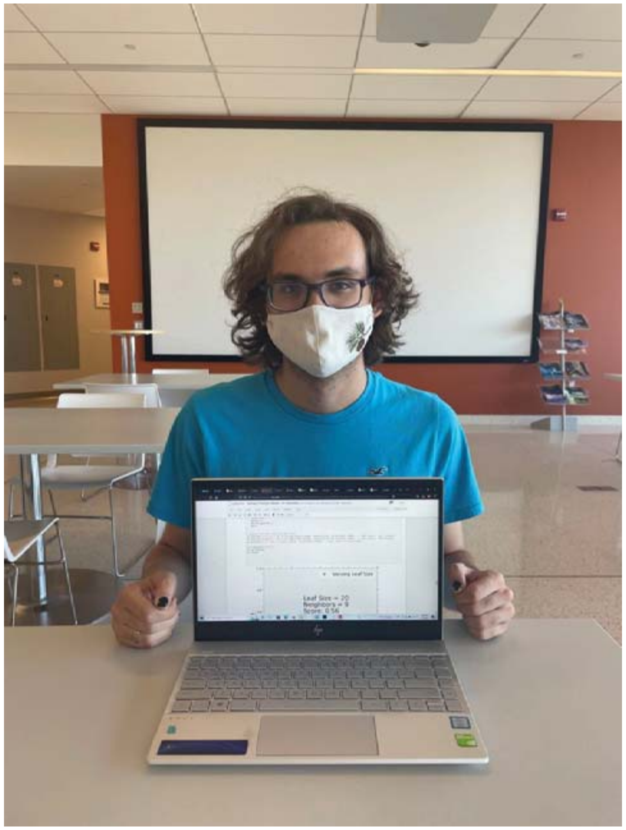
This summer I was in charge of testing our organic materials and their interactions. I also fabricated laser cavities and tested for their polaritonic character and capacity to lase. I was able to start this project from scratch, and I came close to successfully making a polariton laser. I have never worked in a laser lab before, so I was able to develop many technical skills in an exciting field. I joined this REU with intentions to apply to graduate school and pursue research in materials science, but I now have a clear sense of direction and a newfound interest in optoelectronics and device physics.

Constructing Free Energy Functions of Ferroelectric Thin Films Using Thermodynamics and Machine Learning

Sebastian Olsen, Departments of Physics and Computer science, Beloit College
Jacob Zorn, Dr. Long-Qing Chen, Department of Materials Science and Engineering, The Pennsylvania State University

Ferroelectric materials conform to their elastic and electrostatic constraints to lower their free energy by forming domains. These domain orientations are formed by material properties or external fields. For researchers, it is often easier to determine the domain wall orientations of a material than it is to determine the material properties.

To aid in this task, we have created a machine learning program that predicts material properties of a ferroelectric material based on the known ferroelectric domain structure. We have determined the Polydomain Phase Diagram of a specific Ferroelectric System, Barium Titanate ($BaTiO_3$) using high-throughput calculations. From our machine learning model, a researcher will be able to input a specific ferroelectric domain structure, whether experimental or experimentally captured, to learn the material properties of that system, such as elastic or electrostrictive properties.



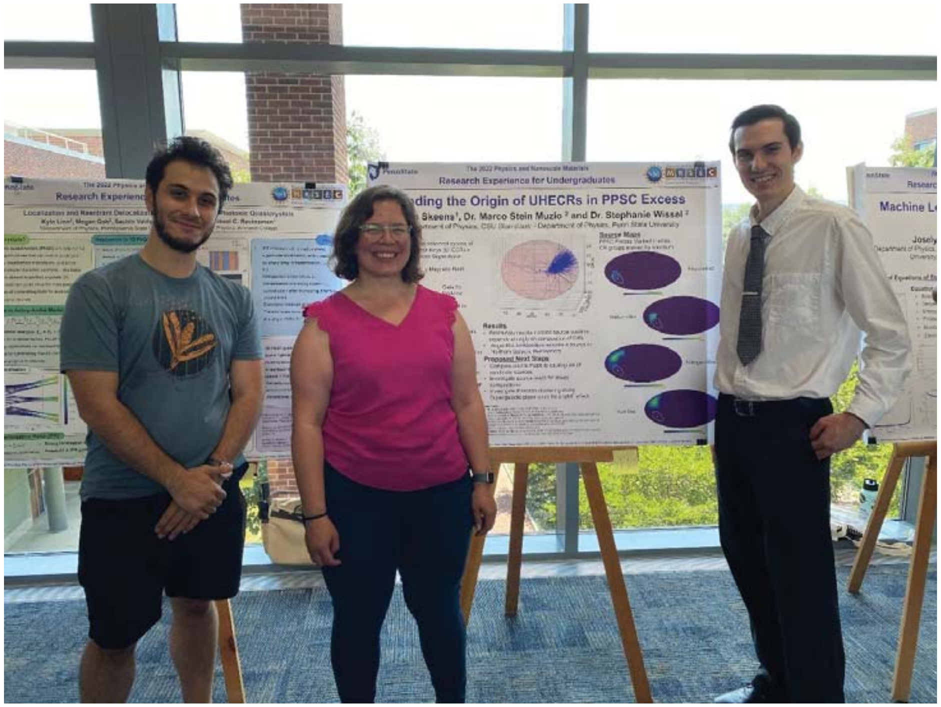
Physics Department Undergraduate Research"hosts"
participating in REU-Site hosted
professional development programs

Finding the Origin of UHECRs in the PPSC Excess

Ethan Skeens, Department of Physics, CSU Stanislaus
Dr. Marco Stein Muzio, Dr. Stephanie Wissel, Department of Physics, Penn State University

This project focuses on back-propagating the excess of Ultra-High Energy Cosmic Rays (UHECRs) detected by the Telescope Array (TA) in the direction of the Perseus-Pisces Supercluster (PPSC). These UHECRs are deflected by the Galactic Magnetic Field (GMF), and are extragalactic in origin. TA detected these CRs at three energy bins, but could not considering rigidity given TA's size, and as such they were assumed to be purely protonic in makeup. Thus, they would have pointed directly back to their source. However, data from the Pierre-Auger observatory (PA) suggests they could be made up of particles of intermediate mass with potentially a nitrogen-like makeup, but this is unknown. There is not a lot of data on what type of particles make up CRs, so through locating the sources of these UHECRs, we hope to gain an understanding of what types of environments are capable of accelerating CRs at the energies they were detected, and by extension what particles could make up CRs. My contributions to this project will hopefully lead to further conclusions about what particles make up the CRs that have been detected as the extragalactic environments in these source directions are investigated.

This summer, my work has been purely computational. I have coded and run all of the back-propagation tests using Python, as well as putting together all of the source maps from our results. The back-propagation was done using CRPropa, a program designed for back-propagation, and the plotting was done using Healpy, a program for creating healpix maps. 17 rigidities were back-propagated through the JF12 GMF model, and each energy was weighted by its spectral flux. Assuming pure makeup of four CR groups, the appropriate rigidities were plotted, with the weightings applied. Through this work, I have gained more of an understanding of what is expected when performing research at a professional level, and it has given me a desire to continue it, as I find it a very gratifying form of work.



From left to right: Dr. Marco Stein Muzio, Dr. Stephanie Wissel, Ethan Skeens

Ultrahigh Energy Neutrino Detection with BEACON and PUEO

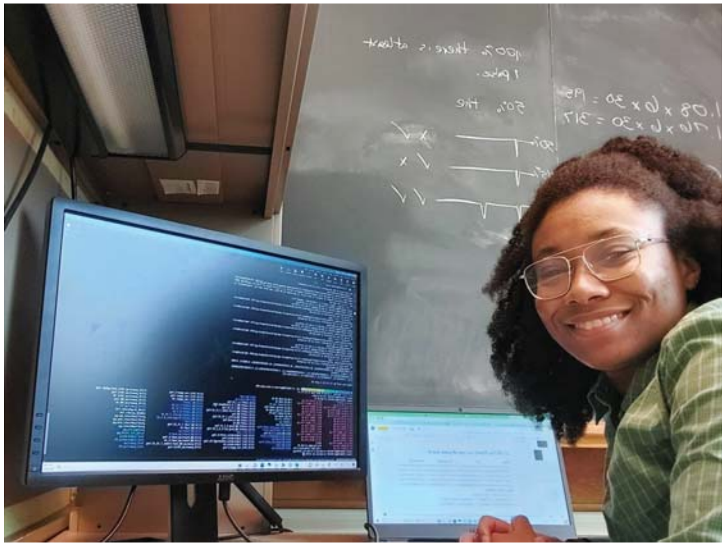
Grant Sommer, Dr. Stephanie Wissel, Dr. Valentin Decoene, Yuchieh Ku, Andrew Zeolla
Department of Physics, Penn State University

Over the summer, our research group studied ultrahigh energy neutrinos and the radio waves emitted during air showers. Both PUEO and BEACON aim to further our understanding of these neutrinos by observing low frequency radio waves.

I worked on reconstructing cosmic ray air showers for BEACON to determine if these techniques could be applied to neutrino detection. For PUEO, I worked on the ¼ model we built in our lab to test the deployment and created an electronics enclosure.

Observations of TeV gamma-ray pulsars with the High Altitude Water Cherenkov (HAWC) Observatory

Kenya Mitchell, Math and CS Department, Penn State Harrisburg
Dr. Miguel Mostafa and Dr. Hugo Ayala Solares, Department of Physics, Penn State University



The Project

This summer I studied very-high-energy gamma-ray emissions with Dr. Miguel Mostafa and Dr. Hugo Ayala Solares. My project was to conduct a detailed analysis of gamma-ray sources seen by the HAWC observatory. Early on in the summer, it was discovered that three of these sources very closely overlap with pulsars seen by the Fermi Large Area Telescope (Fermi-LAT). This was of interest to us because of the insight it could give into what is causing the acceleration of the gamma-rays.

My Contribution

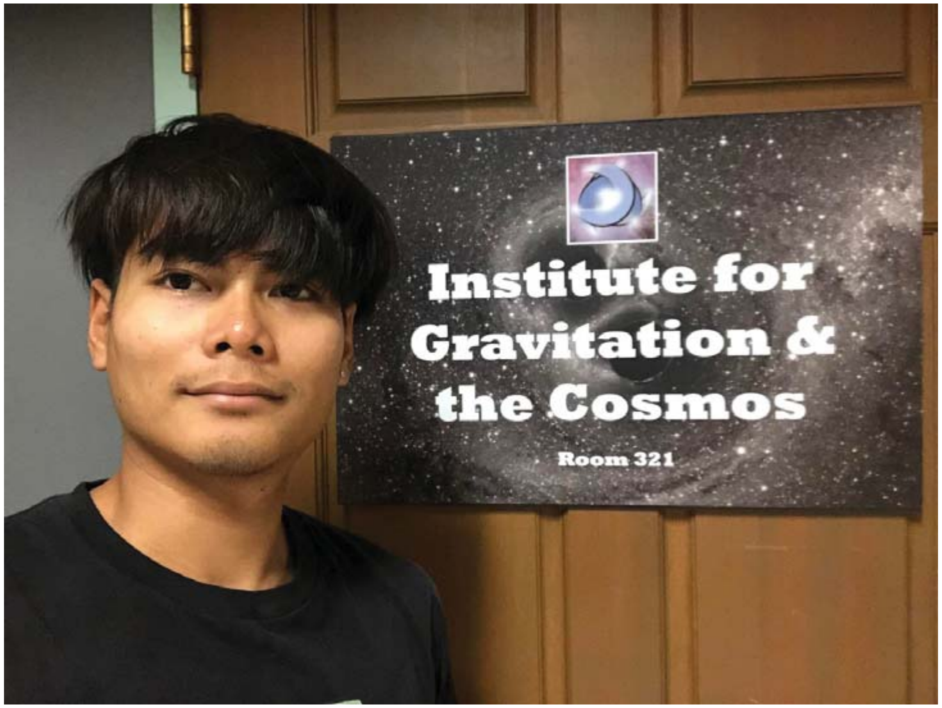
In order to conduct this analysis, I used several common core programming packages designed for astrophysical research. The bulk of my work involved creating the energy spectrum of each source and recording my findings. With these results, we are further able to describe these pulsars at high energies. Future work will include extending the source spectrums into lower energy ranges to better achieve these goals.

Deep Learning Model for the Equation of State and Beta Equilibrium of Neutron Stars

Vorrapard Kumthongdee, Department of Physics, The Pennsylvania State University
David Radice, Department of Physics, The Pennsylvania State University

Equation of State (EOS) table, which some physicists are using to study Neuron Stars, normally relies on an interpolation between the existing quantities. This process consumes lots of time and resources in a large-scale computing. By creating a deep learning model to sample an EOS table, any calculations from the EOS model is a lot faster. The model could also predict the data outside of the range of the existing quantities. We also used the model to find a neuron star's beta equilibrium at different density.

In this project, I created and tested the neuron network model from scratch, with some help from my advisor. We compared the predicted data from the model with the actual EOS table, and the error was tiny. This project has challenged me to think and act more like a researcher. Every time I got stuck at a problem was a step back to ask questions and think about what to do next. It also helped me improving my teamworking skill and learn to communicate among colleagues.



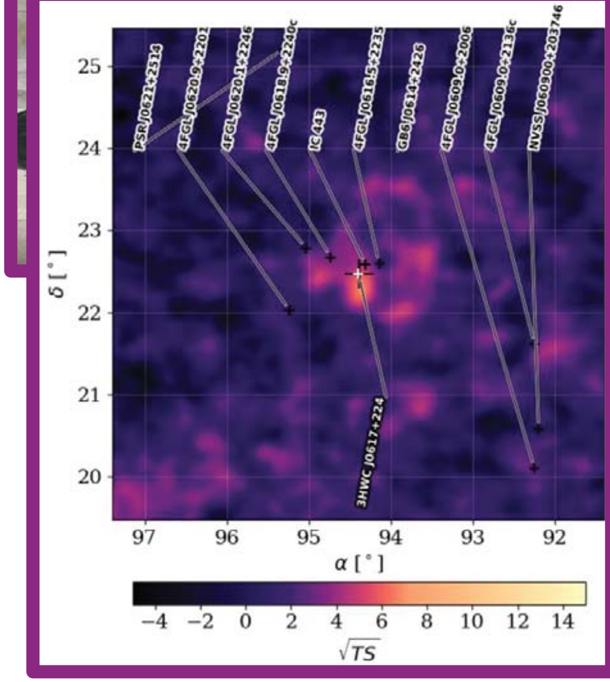
Gamma-Ray Emission from the Super Nova Remnant IC-443

Edjivede Firmelia Yamonche[1], Dr. Hugo Solares [2], and Dr. Miguel Mostafa [2]
[1]Department of Aerospace Engineering, Penn State University ; [2] Department of Physics, Penn State University

Gamma-ray emission can be observed in the region around supernova remnants, the aftermath of the death of massive stars. The environment surrounding the supernova and the acceleration mechanisms of cosmic-rays (which are produced during the supernova event) can be understood through the observation of high-energy gamma rays. We use the High-Altitude Water Cherenkov (HAWC) Observatory to measure the gamma-ray flux from supernova regions.

This summer I focused on analyzing the flux from the supernova remnant IC-443. I ran tests to quantify how statistically significant the HAWC detections are using different data analysis techniques. I also ran various gamma-ray models against the HAWC detections to learn more about IC443.

This REU has helped in diversifying my research and thinking approaches. As an engineering student, I am used to an iterative, product focused thinking process. But working on an astrophysics project has helped me learn about a hypothesis and study focused thinking process. I have also improved in my programing skills and can write and manipulate programs in Bash to support my research. I'm excited to continue my work with supernova remnants and overall diversifying my research skills with this lab in the fall!



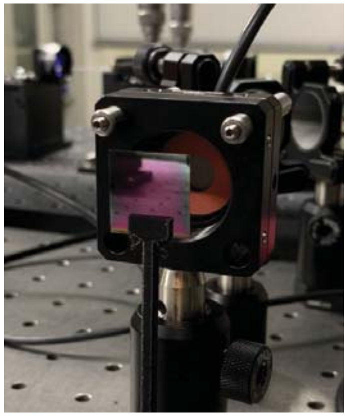
IC443 Significance Map

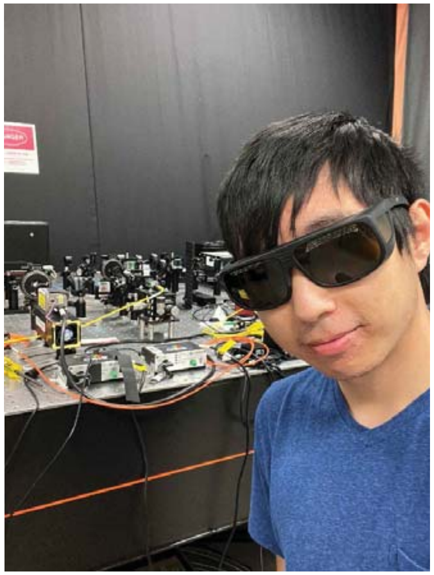
Localization and Reentrant Transitions in 1D Photonic Quasicrystals

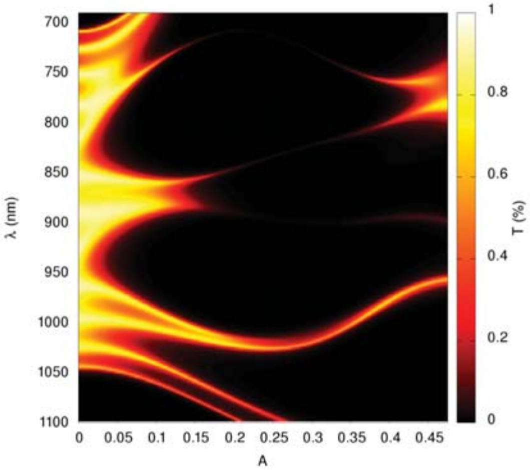
Kyle Linn, Department of Physics, Penn State University
Sachin Vaidya, Christina Jörg, Mikael C. Rechtsman, Department of Physics, Penn State University

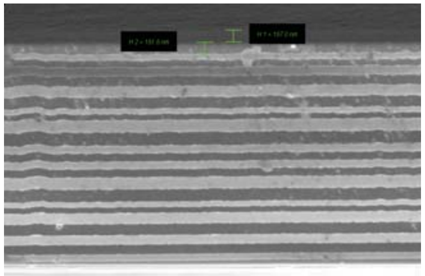
I was tasked with observing localization and novel delocalization/reentrant transitions within a 1D photonic crystal platform. The localization phenomenon is tied together with the transmission of light in this system, such that we can control how light passes through these crystals as a function of disorder. It ultimately provides a robust and unique way of controlling and filtering light transmission for use in modern photonic devices or in common everyday lasers and telecommunications.

I fabricated photonic crystals through plasma enhanced chemical vapor deposition, depositing alternating layers of Si and SiO_2, and measured the transmission spectrum through the sample with a pulsed laser. I also created simulations to study such localization transitions within a similar platform. The project was a great success and has helped to put in perspective the amount of perseverance and patience needed for experimental work. It has also further piqued my interest in continuing research at a graduate school.





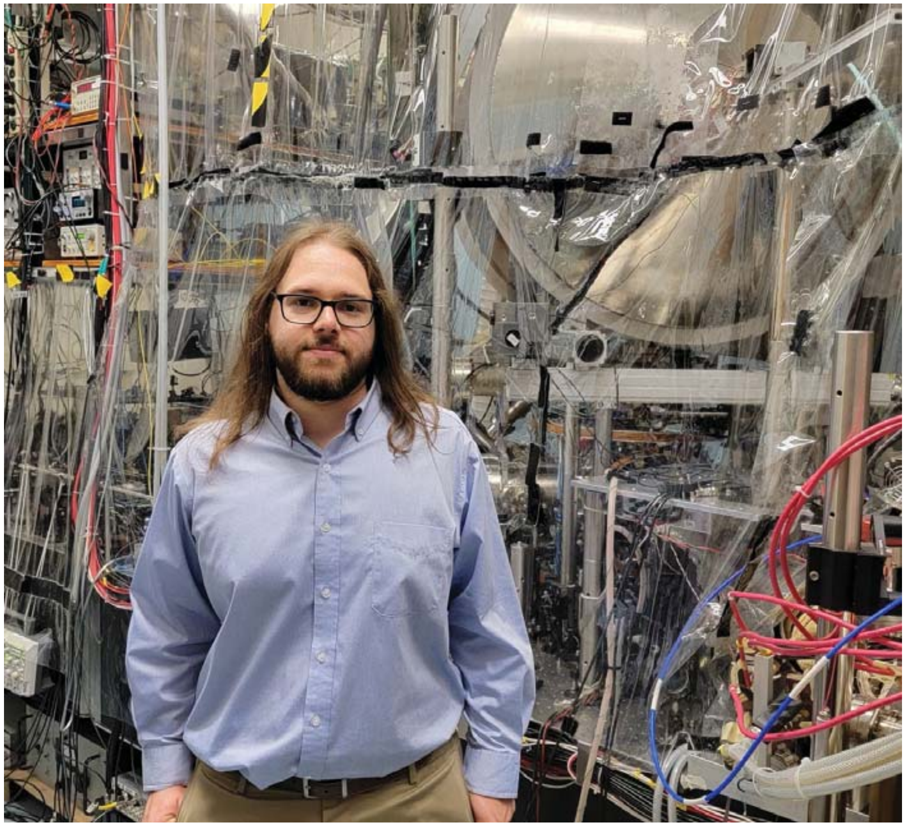




Active Magnetic Field Suppression for Cs GSTP Measurement

Drew McConnell, Zhenyu Wei, David S. Weiss,
Department of Physics, Penn State University

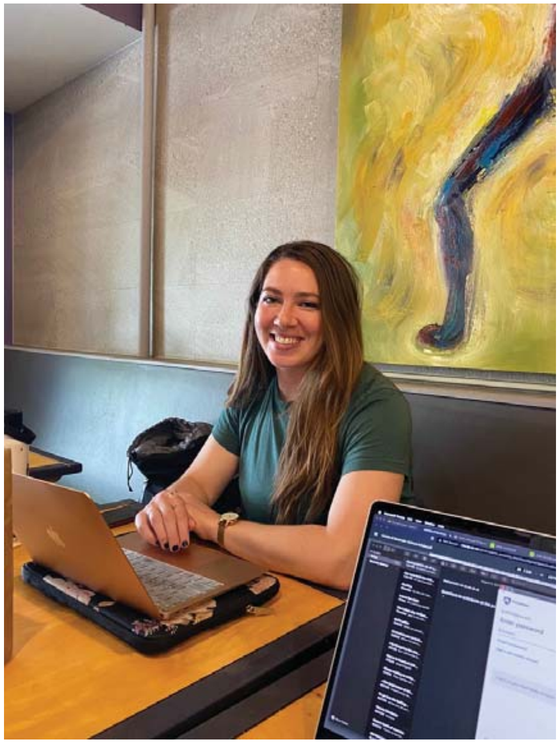
Trapped Cesium atoms provide the opportunity to measure the Cs Ground State Tensor Polarizability (GSTP) with greatly improved precision. An improved GSTP measurement will provide a test of the atomic theory that is central to extracting Weak force physics from atomic parity non-conservation measurements. The measurement of the GTSP is sensitive to background magnetic field changes. So, if a distant source changes the B-field at the experiment by a few mG the GSTP measurement can be skewed.



I created a magnetic field suppression system to reduce the amplitude of drifting background magnetic fields by a factor of ten. During the summer, I learned valuable technical skills like soldering while making a circuit box and programming with LabVIEW to control a magnetometer. I also solidified my interest with AMO physics, a topic I want to pursue further in graduate school.

Inference of dark matter in neutron star cores from gravitational wave observations

Haley Steuber, Physics & Astronomy, California State University, Sacramento
Divya Singh, B.S. Sathyaprakash, Department of Astrophysics, Penn State University



Even though dark matter was discovered in the 1930's, we still do not understand what it is. However, gravitational waves might hold the keys to the detection of dark matter. One parameter embedded in gravitational waves is the tidal deformability in a merging neutron star system. The presence of dark matter can alter the tidal deformability significantly in a binary neutron star leading to a unique imprint on the gravitational waves that occur. Knowing and understanding dark matter would answer many fundamental questions about the universe and physics beyond the standard model of particle physics.

I created a program that extracted three candidate equations of state of neutron stars that model dark matter accumulation with the guidance of my mentor. We then used this extracted data with parameter estimation techniques to create samples of the tidal deformability parameter affected by dark matter accumulation. Then, I learned how to use the samples collected to run through Bayesian inference software to run simulations on populations of binary neutron stars, with and without dark matter. I am able to run the simulations and check they are running as expected.

This project has taught me a lot about research, a small portion of astrophysics, and has kept my passion of research growing. I have thoroughly enjoyed learning and interacting with the professionals and students alike. I have been able to build communication skills, better ways of critical thinking, and more about the astrophysics community. I look forward to building the professional relationships I have made and am looking forward to graduate school.

Electrical characterization of topological semimetals

Xiaojiang Wu, Department of Physics, Penn State University
Saurav Islam, Wilson Yanez, Nitin Samarth, Department of Physics, Penn State University

Topological materials have attracted considerable attention over the last decade due to their unique properties, both from fundamental and applications point of view. These materials have interesting topological band structures and can be used as a platform for a new generation of post-silicon low-power electronic devices.

My works are to scratch the hall bar pattern on the prepared thin film of topological semimetals and measure their electrical properties of them. To scratch the hall bar, I can use the needle to mechanically scratch or use optical lithography. After scratching the hall bar, I use the four-probe measurement to get data. With this project, I have learned knowledge about a lot of material science and what research is like. And I get more interested to explore these subjects more in the graduate school.