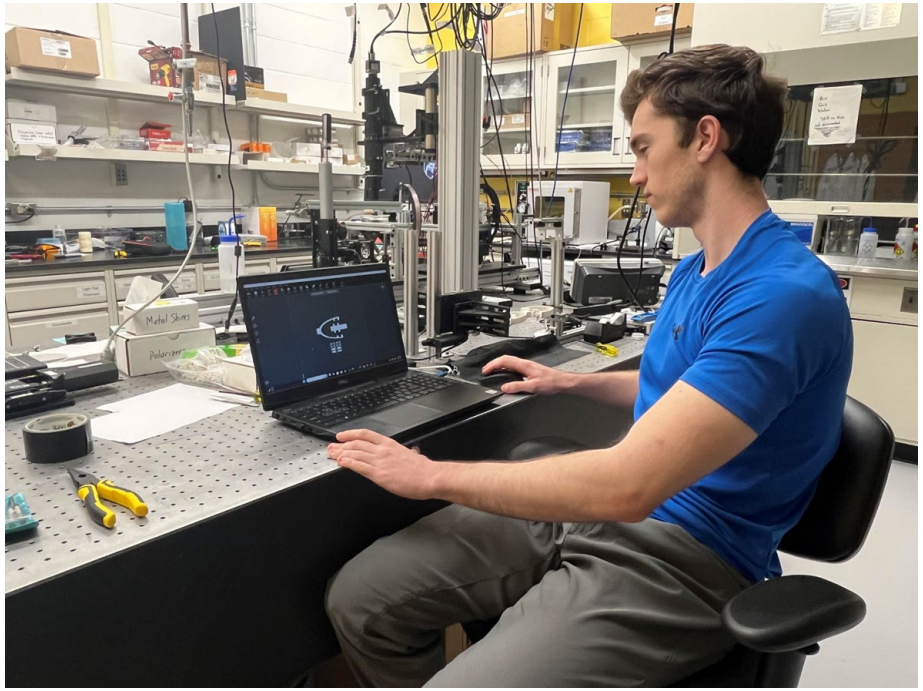
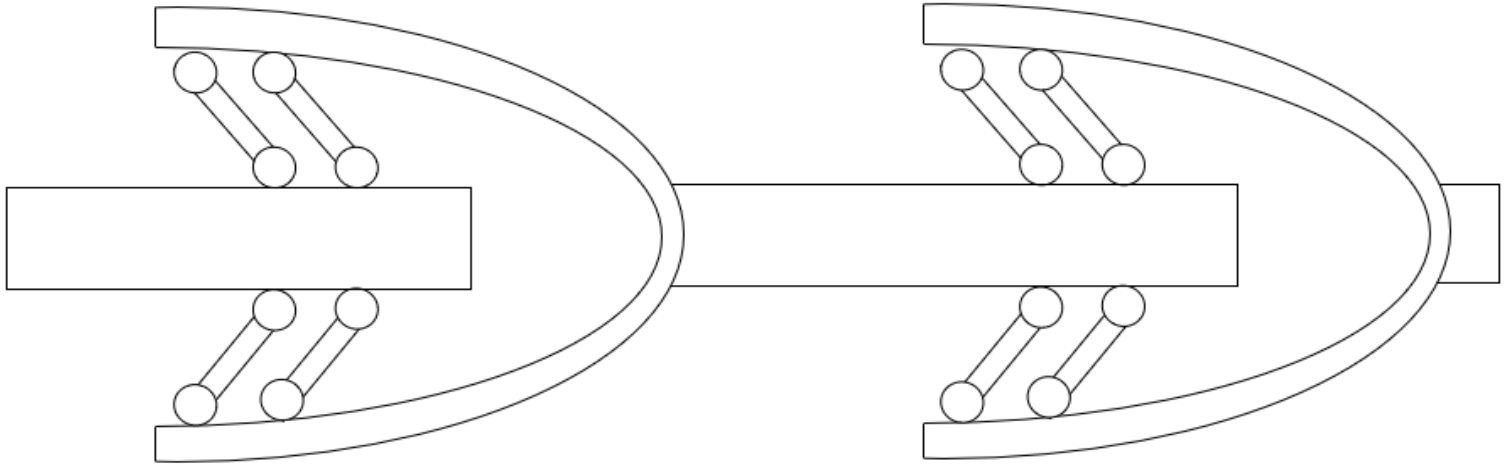
2023 Summer
Undergraduate
Researchers
Physics and MRSEC
REU program

Memory Structure of Bi-stable Buckling Elements

Tristan Rosenberry, Department of Physics, Lebanon Valley College
Zhicheng Wang, Nathan Keim, Department of Physics, Penn State University



This project's goal was to study the memory structure of mechanical systems. To accomplish this task, we studied the behavior of a series of bi-stable elements, such as in a bendy straw. This system was then artificially designed as modules that could be in the “0” or “1” state. Factors of total length and history of compression and extension effect what state each element in the series is in, indicating that state is a memory. Unveiling the behavior of this system may provide insight into how mechanical systems form and hold a memory. We where able to accomplish these goals and give explanation to the behavior of systems containing more elements.



I was instructed to determine, construct, and test a design based on the structure of the bendy straw using a 3d printer. Each element had to be easily modifiable through adjustments to the outward buckling frame, thus allowing for activation energy of each element to be changed. Selecting two elements with slightly different activation energies allowed for all four possible states to be achievable. Tracking the motion of these two elements became increasingly important, so FIJI and Tracker were used for image analysis. Following this, a plain of these distances was constructed with transition pathways identifiable. Depending on instances of compression or extension, memories were observed in the system that occurred in select circumstances of total length and compression/extension history. Through the means of this project, I learned valuable skills in presenting my research to my lab peers as well as developing skills regarding 3d design and imaging.

Discovery of a Potential Quantum Spin Liquid and Non-linear Optical Material

Caeli Benyacko, Department of Physics, University of Florida
Yu Wang, Yingdong Guan, Seng Huat Lee, Suguru Yoshida, Venkatraman Gopalan, Zhiqiang Mao, Department of Physics, MSE, Penn State University

Deep-ultraviolet non-linear optical materials are important for advancing laser technologies with applications in lithography and micromachining. Few materials have been identified that exhibit second harmonic generation with frequencies in the range of 200-280 nm, motivating the search to identify more of these materials. Quantum spin liquids are materials that do not magnetically order in the limit of 0 K and therefore have wide applications in quantum computations, also motivating the need to identify more materials that exhibit this exotic state of matter.

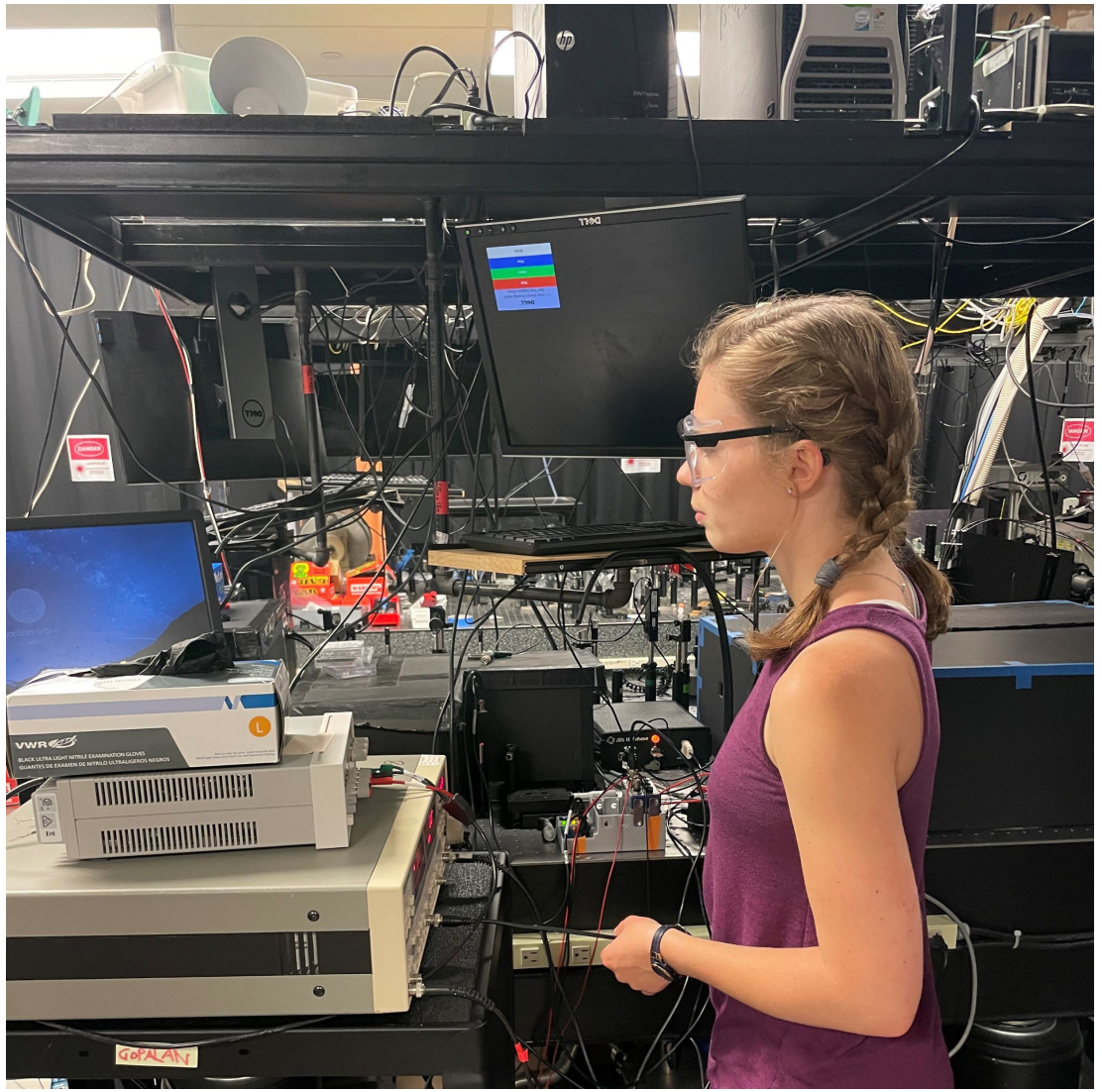
During my project, I helped to grow (Dy, Gd, Sm, Er, Yb, Nd, Tb)$Ba_3B_9O_{18}$ single crystals using a floating zone furnace and demonstrate that these were non-linear optical materials through second harmonic generation measurements, expanding off the work previously done by my group for $EuBa_3B_9O_{18}$, showing that the $REBa_3B_9O_{18}$ (RBBO) family exhibited non-linear optical properties. I also successfully made the first high entropy RBBO material (Dy, Sm, Er, Nd, Tb)$_{0.2}$BBO. Lastly, I helped carry out magnetic data analysis that showed promising indications that the RBBO family of materials may be quantum spin liquids. This summer research project helped me to gain a better understanding of working in a research laboratory and develop critical thinking skills on how to carry out experiments to address a research question.

Construction of an Optical Setup for the Measurement of Electro-Optic Coefficients

Brynn Graybill, Department of Physics, Grove City College
Albert Suceava, Dr. Venkatraman Gopalan, Department of Material Science and Engineering, Penn State University

My research project was to measure the electro-optic (EO) coefficients of $BaTiO_3$ thin films grown by hybrid MBE with varying amounts of TTIP precursor on a $SrTiO_3$ substrate. The field of integrated optics seeks to use optical circuits to improve the efficiency and speed of the transfer of information. The electro-optic effect is used to embed information on light. By measuring the EO coefficients of a material, we can determine if that material would be useful in optical circuits.

I built a Mach-Zehnder Interferometer, which I used to measure the phase shift of light caused by the electro-optical properties of the material. I successfully tested my setup on a $LiNbO_3$ crystal. I did not succeed in measuring the coefficients of the $BaTiO_3$ thin films. Because $SrTiO_3$ exhibits electro-optical behavior, and since it was much thicker than the thin film, I was just seeing a signal from the $SrTiO_3$. In the future, I could measure the EO coefficients of the thin film if it was deposited on a substrate that did not exhibit the EO effect. This summer has solidified my desire to go to grad school and get my PhD in physics after I graduate college. I have learned a lot about how to apply my theoretical knowledge in the lab and how to do experiments well.

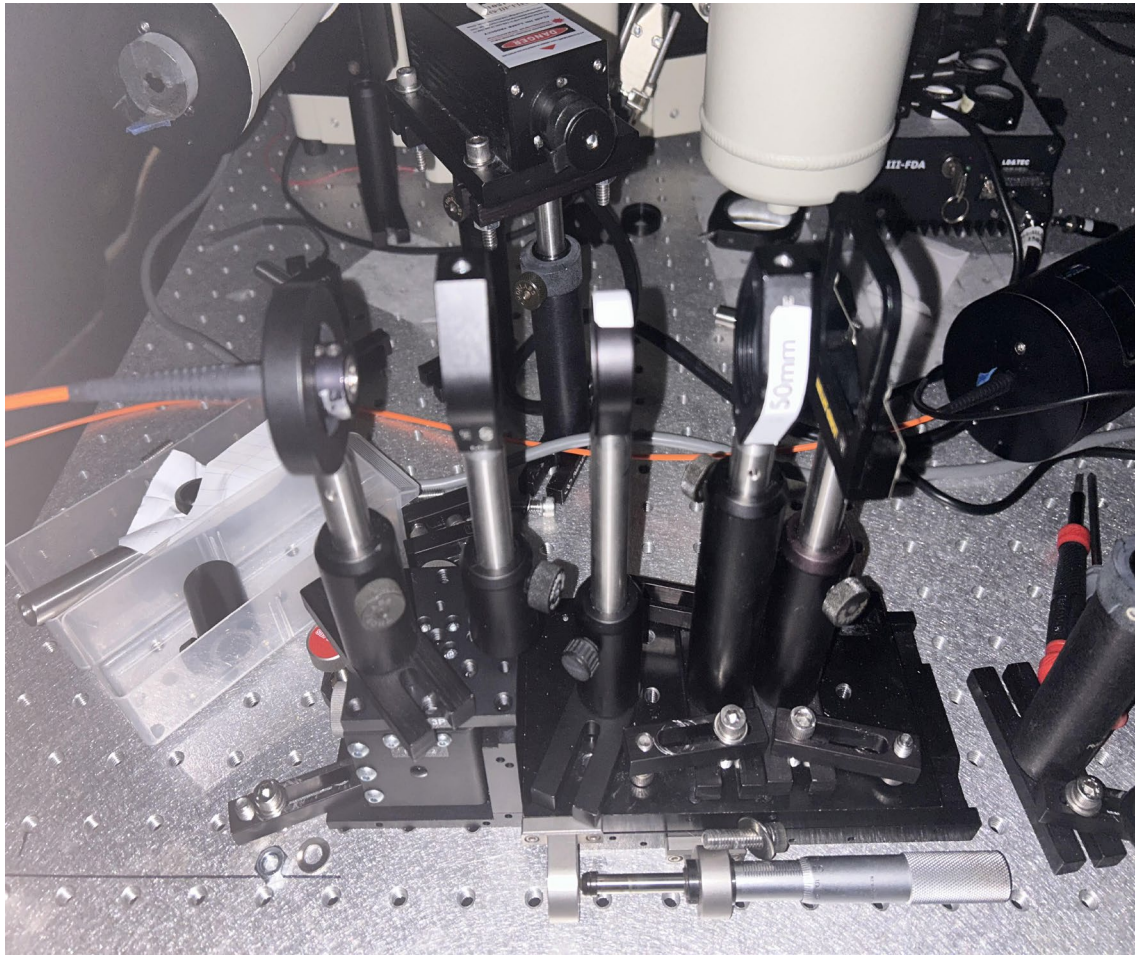


Fluorescence of Nitrogen Vacancy Centers in Diamond

Graham Hadesman, Swarthmore College, Department of Physics and Astronomy, Jake Morris, Penn State University, Department of Physics, Dr. Nitin Samarth, Penn State University, Department of Physics

Nitrogen Vacancy (NV) centers are a common defect in the carbon crystal lattice of a diamond. This occurs when a nitrogen atom replaces a carbon atom, as well as a vacant spot in one of the four adjacent bonds. When excited by a high enough energy laser, an electron will jump from its ground state to a higher energy level emitting a fluorescence via electron relaxation back to the ground state. This property of NV centers is very useful in quantum sensing as it can serve as a qubit. Brighter and dimmer fluorescence correspond to different NV center spin states, s=±1 being dimmer emissions, and s=0 being brighter emissions. We can collect this spectrum via a grating spectrometer which was the goal of my research this summer. Over the past couple months, I created an optical setup which would collect the fluorescence of these NV centers via 532nm monochromatic excitation and plot it by using a charged coupled device (CCD) which transfers photons to electrical signals via the photoelectric effect.

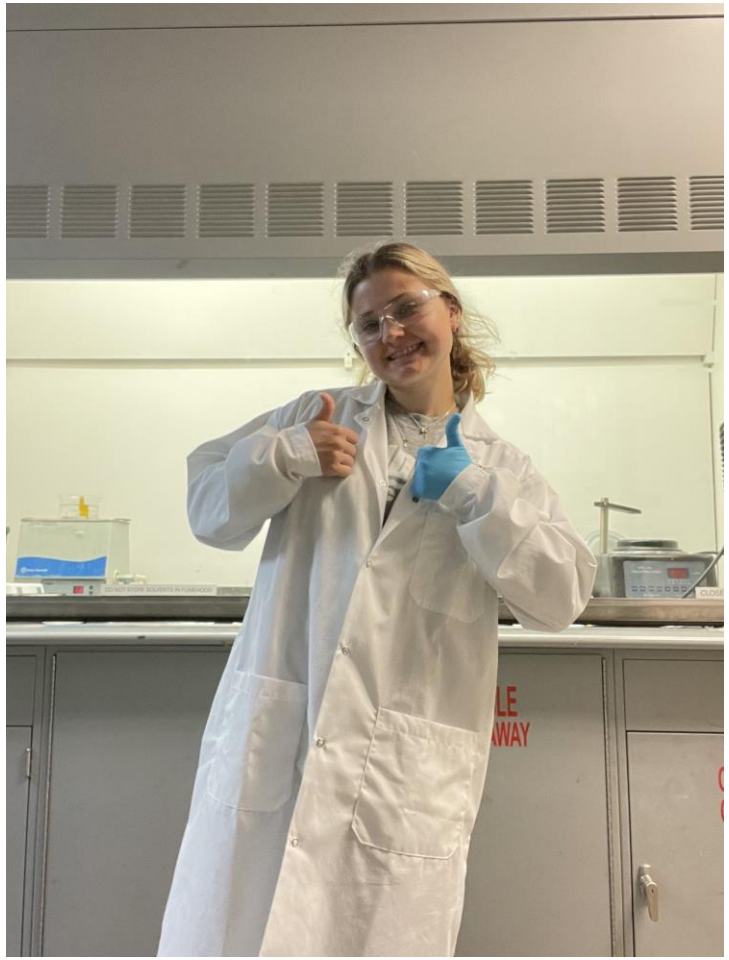
Over the last couple months I created an optical setup that could collect the fluorescence of NV centers within diamonds. This experience taught me a lot about what experimental physicists do in the lab and also gave me a good idea of what to expect when pursuing a PHD. It also opened a new door for me in terms of my research since I had no real interest in solid-state physics before this.



Characterization of WS_2 with Allotrope Sulfur Capping

Brianna Rapp[1], Jo Laura[2], Riccardo Torsi[3,4] and Joshua A. Robinson [3,4]

[1]Department of Biochemistry, Chemistry and Physics, University of Mount Union; [2]Department of Chemistry; [3]Department of Material Science and Engineering; [4]Center for Nanoscale Science, Penn State University `



2D Transition Metal Dichalcogenides (TMD) are semiconductors with the formula MX_2, where M is a transition metal and X is the chalcogenide 2D TMDs have been known to display unique optical and electronic properties due to their direct band gap in the monolayer. These ultrathin sheets have the potential to open the field of 2D electronic devices that can range from transistors to sensors. Some applications include quantum devices and field effect transistors.

During my project, tungsten disulfide (WS2) was synthesized via chemical vapor deposition onto sapphire substrates then transferred to another sapphire substrate. The purpose of the dry transfer process is to limit the substrate and material interactions that occur during growth. To limit imperfections, sulfur capping is used. Atomic Force Microscopy, Raman Spectroscopy, and Optical Microscope were used to verify optical and topographical properties. The results display sulfur capping displayed a combination of multiple allotrope sulfur, with sulfur-beta conveying non-conventional properties in its stability at room temperature. Also is a viable way to prevent imperfections, although there is still room to further optimize this process.

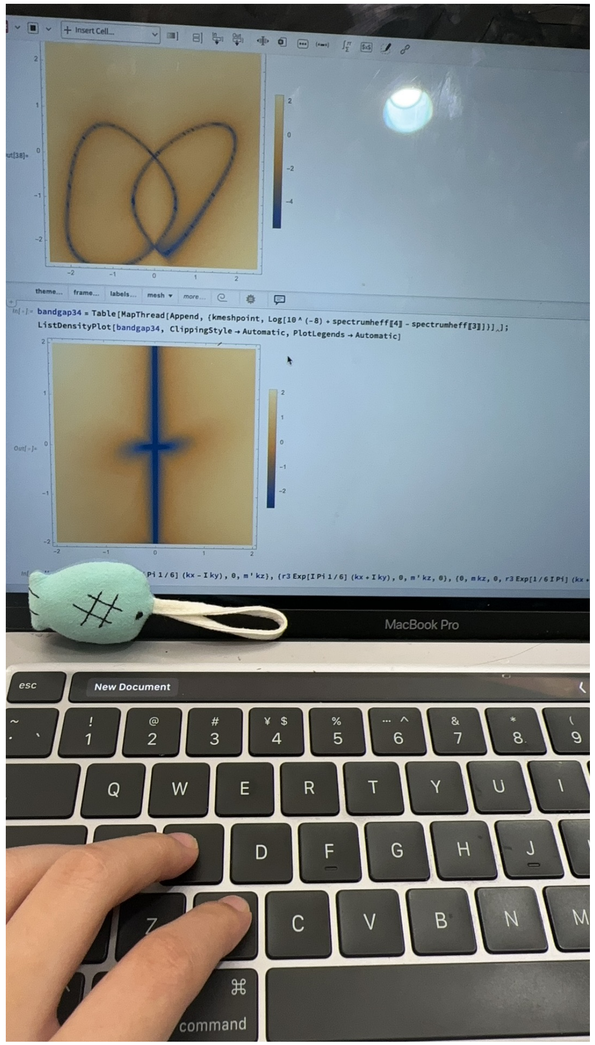
I learned a variety of skills ranging from dry transfers process to characterization methods and understanding the basics behind chemical vapor deposition.

Symmetry Enforced Nodal Line in Effective Hamiltonian

Xinrui Wang, Bryn Mawr College,Physics Department
Kaijie Yang,Chaoxing Liu, Penn State University, Center for Nanoscale Science

- This project will study the effective model Hamiltonians in a variety of crystals and search for approximated degeneracies in the electronic band structures of materials. It aims to explore the connection between crystal symmetry and approximated band degeneracies. The student will learn how to conduct both analytical and numerical calculations to understand electronic band structures from this project.

- In this summer, I have learned how to construct the tight binding model for solids, what is effective Hamiltonian and symmetry operators. I used different kinds of symmetry operators to construct first and second order effective Hamiltonians for space group 163, and draw out the band spectrums of them. Then, I analyzed the band gaps between them to find the nodal lines. Then, I figured out what protects the nodal lines and what enforced the nodal lines. I also summarized all materials that has a nodal point on the high symmetry line resulting from the intersection of the nodal line.



Terrace Engineering and Sulfur Capping in WS_2 CVD Synthesis

Michael Robison, University of Utah, Materials Science and Engineering
Li-Syuan Lu, Josh A Robinson, Penn State University, Materials Science and Engineering

The goal of this project is to understand the sapphire substrate reconstruction during WS2 growth and explore sulfur capping to prevent PMMA residue after the transfer process. The study aims to investigate the impact of growth temperature, duration, and precursors on sapphire reconstruction to achieve better controllability of coalesced WS2 monolayer growth with minimized step bunching or separated WS2 ribbons with higher step barriers.

This summer I capped TMD's with a layer of sulfur to help our research group investigate if this aids in the transfer process as well as grow and characterize samples for pristine TMD growth. I have learned valuable characterization skills that will allow me to further my career in materials science as well as practice using the scientific method in every day work. I've also gained some understanding of how a PhD could look in my future as I continue my educational pathway in science.

Synthesis and Analysis of SnS_2 using Chemical Vapor Deposition

Elizabeth Houser, Department of Physics, Kenyon College
Zhuohang Yu[1], Edgar Dimitrov[2], Dr. Mauricio Terrones[1,2], Department of Materials Science and Engineering[1], Department of Physics[2], Pennsylvania State University

Tin Disulfide (SnS_2) is an emerging material in the world of 2D materials due to its large bandgap (2.2 – 2.6 eV). By introducing defects into SnS_2, we can intentionally create states within the bandgap that will lead to color centers, which is when light is emitted at an energy that would not emit light in a pristine sample. These color centers could lead to single photon emitters, which have important applications in quantum communication. The goal of my project was to develop a method to synthesize thin SnS_2 for the future purpose of inducing defects into the material.

Over the course of the summer, I varied many parameters in an attempt to discover which ones would lead to the most optimized growth. My research gave me the opportunity to learn many new things about the world of materials science that I would not have been able to learn at my school and to become a self-sufficient researcher.

Exploring Solvent Dependent Relaxation Dynamics in $[Au_{11}(BINAP)_4X_2]^+$ clusters

Seth A. Nelson, Department of Chemistry, Mansfield University of Pennsylvania
Daniel J. Heintzelman, Kenneth L. Knappenberger, Jr. Department of Chemistry, The Pennsylvania State University

Ultrafast relaxation dynamics of $[Au_{11}(BINAP)_4X_2]^+$ (X=Cl,Br) clusters were studied in this project using femtosecond transient absorption (fsTA). Relaxation mechanisms and dynamics are important to understand as they lead into studies of spin dynamics and spin persistence which has practical applications to quantum computing and spin catalysis. For this project $[Au_{11}BINAP)_4X_2]^+$ (X=Cl,Br) were used as model systems and their relaxation dynamics were observed in different solvents of various dielectric constants and hydrogen bond ability. The samples were excited by a 575nm laser pulse and probed at the same wavelength at some time delay between the two pulses. Across many time delays the relaxation dynamics can be observed and plotted. One of my jobs was to plot this relaxation data and show the relationships between the different solvents in $[Au_{11}BINAP)_4Cl_2]^+$ clusters and then in $[Au_{11}BINAP)_4Br_2]^+$ clusters, then comparing the dynamics from both clusters to show their differences.

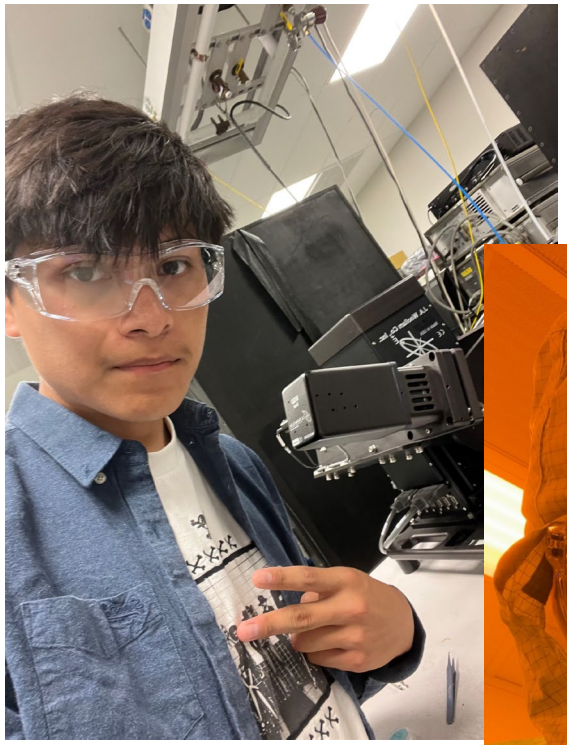
My contributions to this project included synthesis of the $[Au_{11}(BINAP)_4X_2]^+$ clusters as well as learning how to operate the laser and align the optics which was both fun and helpful for the project. Data collection and analysis of my own data was the most significant for my development as a researcher this summer. During this time I was able to learn how to setup experiments and take data while also learning about the ups and downs of doing research projects. The skills I was able to acquire throughout this project will be very beneficial for me in graduate school or any other future work I end up doing.

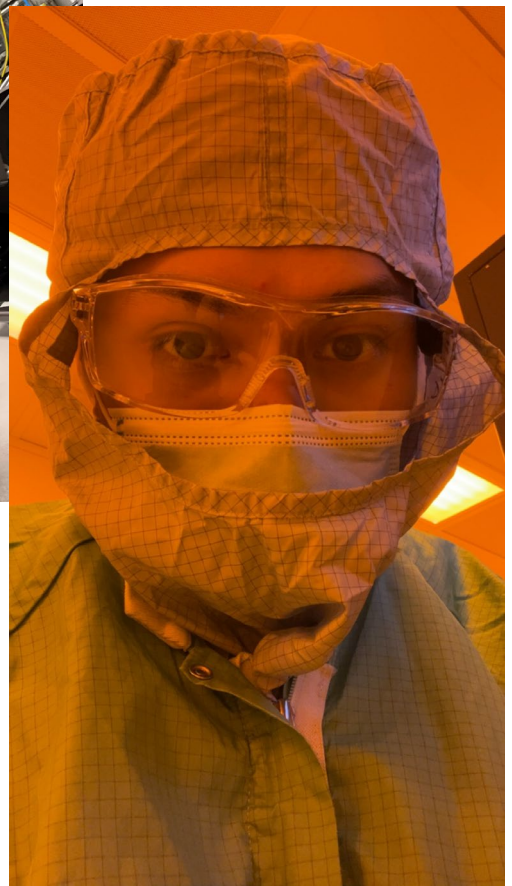
Development of a Dependent-Composition Model of the Refractive Index of “Lionglass”

Leonardo Ramos, Department of Physics, Lewis University
Albert Suceava, Nicholas Clark, Dr. John Mauro, Dr. Venkatraman

My research revolved around characterizing “Lionglass”. Lionglass is a new composition of glass developed by Dr. Mauro’s research group that reduces the amount of carbon emissions of typical soda-lime glass. It also reduces the amount of energy on furnaces which will increase lifetime helping factories out. The amount of carbon emissions of soda-lime glass contributes around 15-25% of annual emissions globally. By characterizing this composition, it is a step in order to combat climate change.

In order to characterize the glass, I decided to look at compositions of glass with varying iron content. When iron is added into glass it transitions from transparent to a darker color. This effect can help verify if it follows the same trend as soda-lime glass while also extracting the complex refractive index. This way we can look at these compositions to begin further studies such as replacing solar-panel glass or greenhouse glass which would be more efficient in combatting climate change.





Modeling Fast Energy Storage Reactions in RuO2 Pseudocapacitors under Realistic Conditions.

Maria Maalouf[1], Simon Gelin[2] and Dr. Ismaila Dabo[2]

[1]Department of Physics and Astronomy, Cal-State Univ. Long Beach; [2]Department of Material Science, Penn State University

My research this summer focused on simulations of RuO2 pseudocapacitors and improving their energy performance. Pseudocapacitors are energy devices that push the “electrochemical frontier” which signifies the limitations of batteries and supercapacitors. Pseudocapacitors have high energy storage like batteries and high power like supercapacitors. They are used in wind turbines, solar panels, and regenerative braking. All of which are great for environmental issues relating to clean energy.

In order to study RuO2 pseudocapacitors, I used Quantum-Espresso to produce a database of free energies for distinct configurations of adsorbed hydrogen atoms on the RuO2 surface. Then, I used Monte Carlo to identify the most likely configuration from which we can extract the total charge on the surface, thereby the charge storage and charging speed of the pseudocapacitor. This experience was valuable to me since it allowed me to learn to use python and quantum espresso in a professional setting. I also learned how to set up a Monte Carlo code, and to improve it in order to achieve a simulated result that is loyal to experimental results and is theoretically accurate. It was great to network with many collaborators and faculty working on other projects.

Summer research students
funded by NSF supplements

Detecting High Energy Neutrinos Utilizing the Radio Neutrino Observatory in Greenland (RNO-G)

Sergio Lopez, Dept. of Physics and Astronomy, San Francisco State University
Ethan Bletsch, Dept. of Physics, Penn State University
Bryan Hendricks, Dept. of Physics, Penn State University
Dr. Stephanie Wissel, Dept. of Physics, Penn State University

The Radio Neutrino Observatory in Greenland (RNO-G) is currently the largest in-ice Ultra High Energy neutrino detector. To prepare for mass production, the construction process specifically for the Horizontally Polarized (Hpol) antennas needed to be improved. This helps lay the foundation for future radio neutrino detection, such as with IceCube-Gen 2

This summer we reduced production time for antennas by 1/3, now taking 40 minutes per antenna vs 60 minutes during the 2021 season. We also constructed 75 Hpol centerfeeds for the 2024 season, enough for 10 additional stations. I learned a lot this summer, especially about what research is and how I can challenge myself to try new things. This experience has motivated me to pursue more research opportunities in the future.

Neutrino Production from Circumstellar Interacting Supernovae

Adrian B. Barajas[1], Dr. Kohta Murase[2] and Dr. Mainak Mukhopadhyay [2]

[1]Department of Physics and Astronomy, San Jose State University; [2] Department of Physics, Astronomy and Astrophysics, Pennsylvania State University

In this work, we focus on the phenomenology of high energy neutrino production in type II circumstellar (CS) interacting SNe. This allows us to pinpoint the origins of ultra-high energy cosmic rays (UHECRs) and neutrinos, which will also aid us in probing, a) Physics of cosmic ray acceleration, b) Mass loss mechanism of progenitor star, c) The dynamics of interacting SNe, along with region of emission. My work generated neutrino *light curves* with different varying physical parameters to then be put through likelihood-based methods to conclude if such SNe correlate with IceCube events.

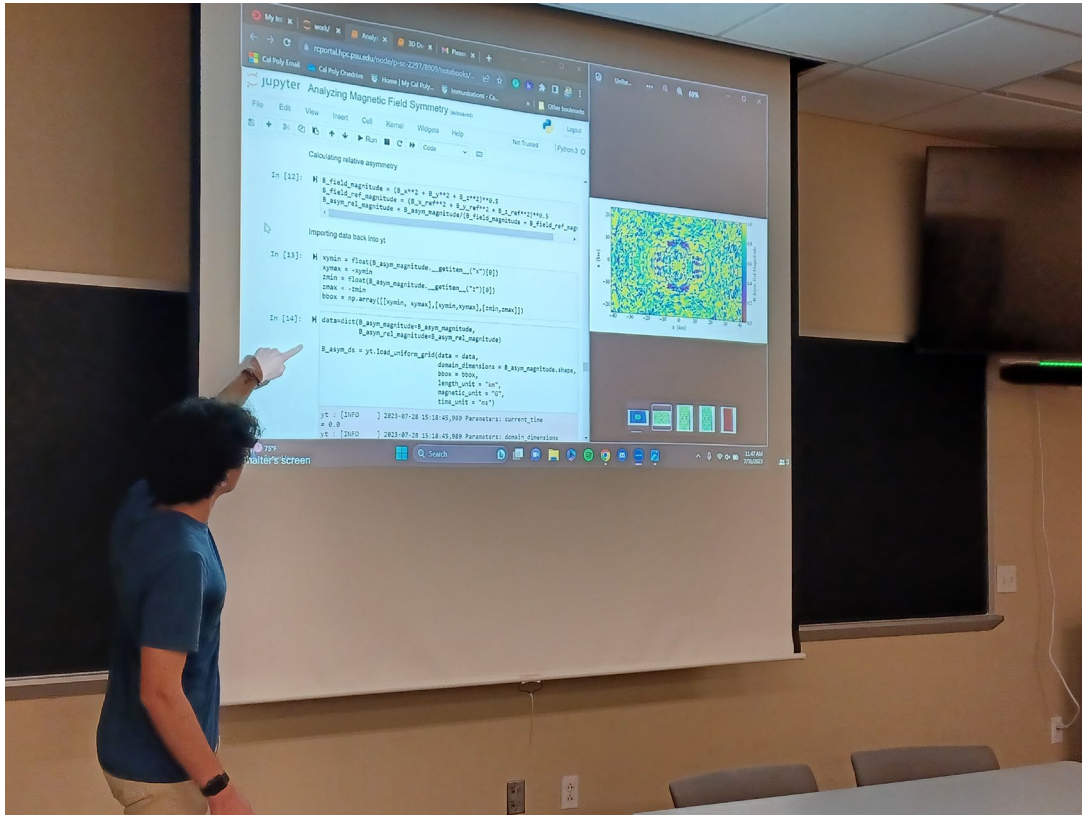
Using Python and C, I generated neutrino light curves varying different physical parameters of a type II circumstellar (CS) interacting SNe. These light curves would then be passed on to another member of the research group to be put through likelihood-based methods to conclude if such SNe correlate with IceCube events. This summer research project gave me insight into the world of theoretical physics. This project displayed that research doesn't follow a linear path but is comprised of a function with ups, downs and brick walls at times. Overall, I gained communication, programming, and teamwork skills that will be used in my future research.

Spontaneous Symmetry Breaking in Simulations of Binary Neutron Star Mergers

Louis Buchalter[1], Dr. Eduardo Gutiérrez[2], and Dr. David Radice[2,3]
[1]Department of Physics, California Polytechnic State University, San Luis Obispo, [2]Department of Physics, Penn State University, [3]Department of Astronomy and Astrophysics, Penn State University

My project was to write scripts using a Python package called *yt* to visualize data from a general-relativistic magnetohydrodynamics simulation of a Binary Neutron Star (BNS) merger. Neutron stars are one of the densest objects in our universe and studying the matter in a neutron star allows us to create better models for matter in a broad range of conditions. BNS merger simulations allow us to study the highly dense matter within a neutron star and test current theoretical models for its behavior. My project allowed for the data to be analyzed and the Python scripts I wrote can continue to be used in the future.

My contribution allowed for the data from the simulation to be visualized and I computed new quantities which could then be plotted for further analysis. The goal of this project was to study the breaking of symmetries in the magnetic field throughout the simulation as well as the magnetic field structure after the stars merge. I was able to visualize the structure of the magnetic field in 2D slices and within a 3D volume. I also created visualizations of the asymmetry in the field and the growth of this asymmetry as the simulation progressed. This project has allowed me to further my computer programming skills and better understand how one analyzes data, both of which are useful skills for a researcher.



Improvement of the antenna array for Beamforming Elevated Array for COsmic Neutrinos (BEACON)

Andres Interiano-Alvarado, Department of Physics, California State University, East Bay
Andrew Zeolla, Dr. Stephanie Wissel, Department of Physics, Penn State University

In BEACON, we wish to detect cosmological air showers of tau neutrino particle combinations created within the atmosphere of the Earth. This project is important in the aspect of cosmological detection as neutrinos are rarely detected and BEACON seeks to set up antennas in a mountain range to get a better detection rate of said neutrinos. With later runs we wish to increase the cost effectiveness of BEACON by replacing costly parts with viable replacements to create arrays all over the world.

My contributions to this project was to research find and test potential new materials then design and build a new antenna model while also adding two more antennas to the angular reconstruction data to better improve its reconstruction. This fits with the goals of BEACON as we seek to increase the effectiveness of the antenna array in stability of the antenna to the reconstruction data of the antenna. The summer project impacted my development as a researcher as it made me understand not all projects are alike and each will have different deadlines, goals, and work type. As well this helped me better my networking skills as I met physicists of all types and understood the background of my fellow researcher.

Conducting and Self-healing Polytetrahydrofuran/Graphene Nanocomposites by In-Situ Polymerization

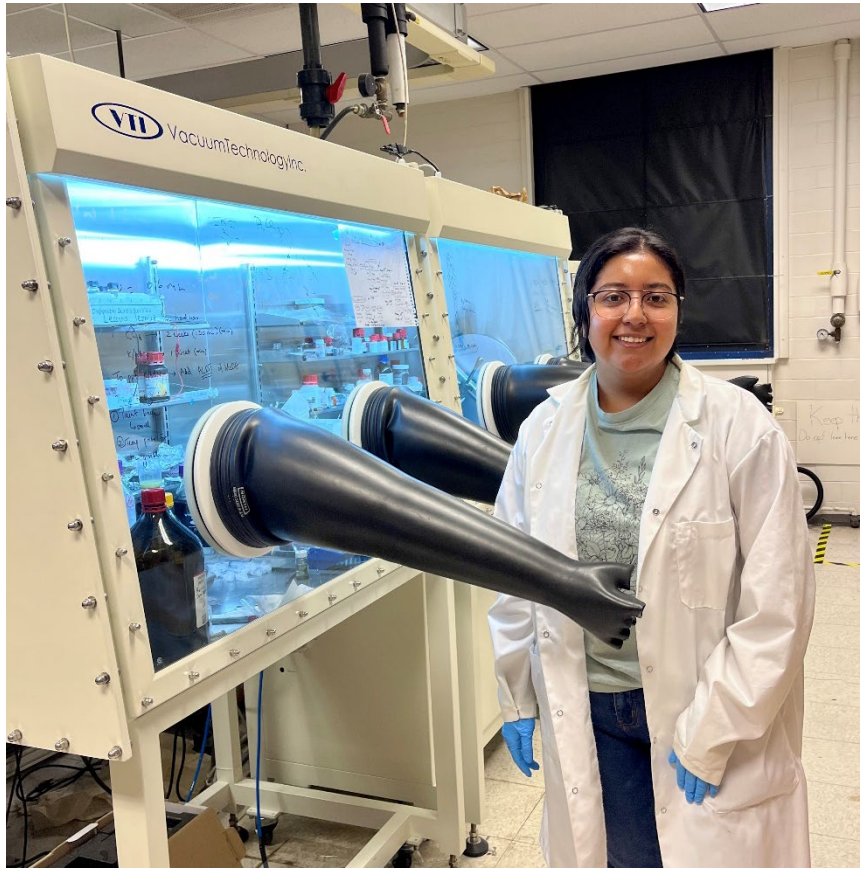
Sofia Sanchez Lemus[1], George Bepete[2,4] , Conghang Qu[3], Gothamie Ratnayake[4], and Mauricio Terrones[234]

[1]Department of Chemistry and Biochemistry, North Carolina Central University; [2] Department of Physics, Penn State University; [3]Department of Materials Science and Engineering, Penn State University; [4] Department of Chemistry, Penn State University

Poly-tetrahydrofuran, also known as PTHF, is commercially used in flexible fabrics and has a potential application in wearable electronics. Previous work has shown different polymers with carbon-based materials to improve electrical conductivity, despite this there are no current reports on graphene-PTHF composites, due to the difficulty of dispersing graphene in THF (tetrahydrofuran).

This project takes the properties of PTHF and combines them with that of graphene to obtain a conductive polymer while also making this a simpler synthesis compared to other polymers.

I was able to successfully exfoliate graphene via alkali metal intercalation and suspended in THF. Graphene interacted with PTHF during the synthesis producing a PTHF/graphene nanocomposite that demonstrated promising capabilities of self-healing, flexibility and conductivity, with more room to explore.



Synthesis and ROMP of Isopentoxy/Methoxy Paracyclophanediene

Justin Lin, North Carolina Central University, Department of Chemistry and Biochemistry, Benton Bickerton, Penn State University, Department of Chemistry, Dr. Elizabeth Elacqua, Penn State University, Department of Chemistry

Conjugated donor-acceptor polymers have gained a lot of attention because of their interesting optical and electronic properties. This makes them attractive for application in organic electronics such as organic solar cells and organic field-effect transistors. The limited synthetic methodology for achieving these sequence defined polymers calls for new methods, which is why we are exploring Ring Opening Metathesis Polymerization. Previous research done by Dr. Elacqua demonstrated living polymerization using ROMP on the 4- methoxy-1-(2-ethylhexyl)oxy)benzene– benzothiadiazole paracyclophanediene (pCpd). Our question is how does steric bulk impact living ROMP? In my research we look to explore ROMP on the Isopentoxy/methoxy paracyclophanediene, which has a less bulky Isopentoxy chain then the pCpD Dr. Elacqua worked with. Over the past two months, I was able to take the Isopentoxy/methoxy benzene ring and run it through an eight step synthesis and synthesize the Isopentoxy/methoxy paracyclophanediene.

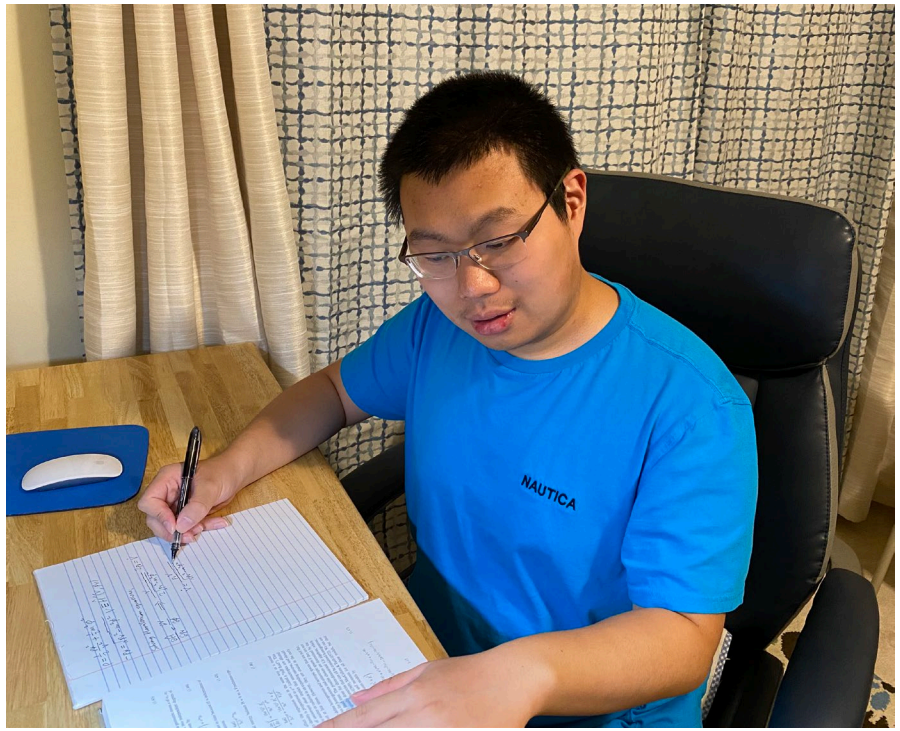
Over the past two months I synthesized the monomer needed for polymerization testing. This experience has taught me a lot about chemistry techniques and about expectations for phD. programs. This REU has also made me start considering organic chemistry as a field for me to go in, which I originally had no interest in.

Summer undergraduate researcher "hosts" funded by local funds

Analysis of Local Clocks and Turning Points in Quantum Cosmology

Henry Li, Department of Physics, Pennsylvania State University
Dr. Martin Bojowald, Department of Physics, Pennsylvania State University

Over the summer, we studied the **expansion of the universe** from the perspective of **quantum cosmology**. We investigated how the volume of the universe varies with respect to a local clock (a timelike parameter that, unlike proper time of classical cosmology, is intrinsic to the universe). Our research sheds light on how quantum mechanics and general relativity interact on a cosmological scale.



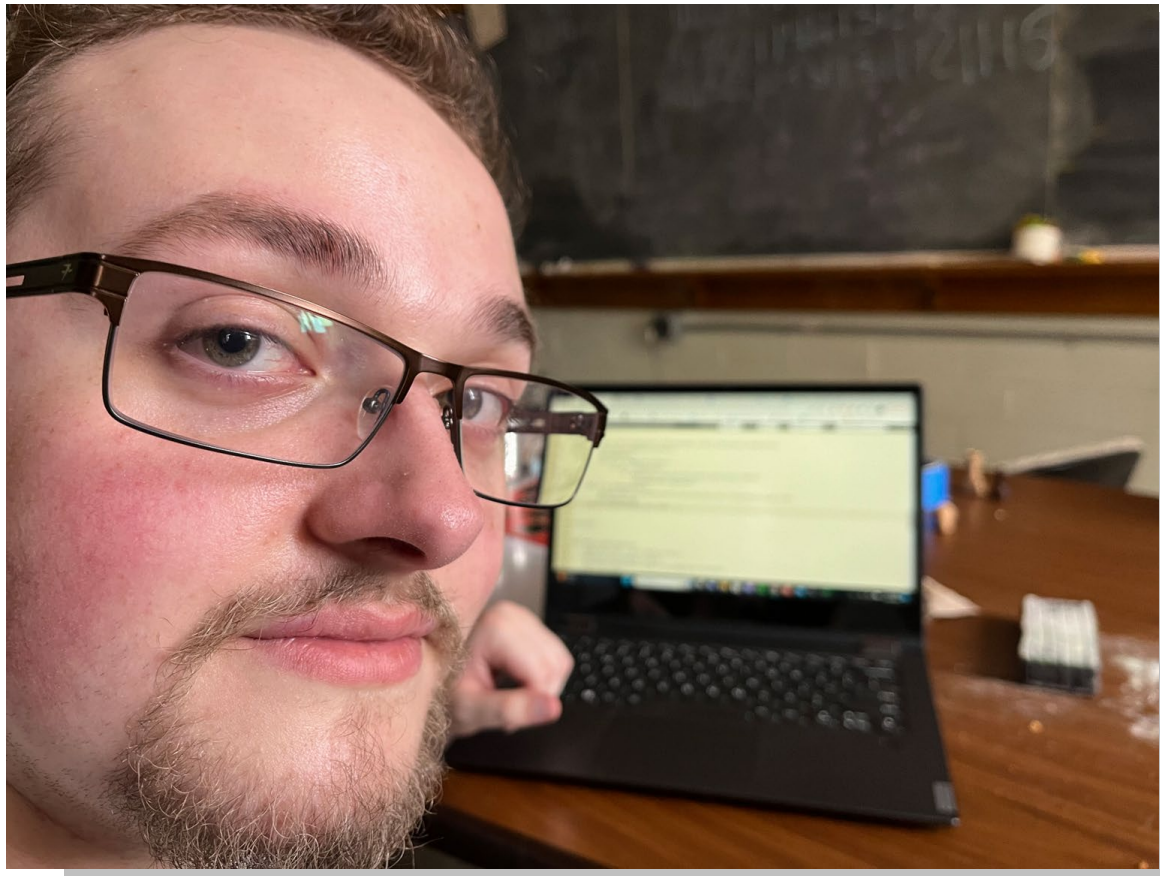
We **formulated a Hamiltonian** that describes the energy content of the universe and takes the self-interaction of scalar fields into account. Using this Hamiltonian, we **obtained numerical solutions** for the volume of the universe as a function of a local clock. These solutions show that the universe's expansion speeds up and slows down periodically throughout its own evolution. Overall, I've learned much about the quantum cosmology during the REU. The results of our research inspires me to continue investigated quantum cosmology (as well as related physics fields) in my future graduate studies.

Exact Calculation of Entanglement Entropy

George Fagan, Department of Physics, Penn State University
Rohit Patil, Dr. Marcos Rigol, Department of Physics, Penn State University

The project's goal is to calculate the entanglement entropy of random (gaussian) pure states in spin ½ systems with SU(2) symmetry. We want to do this because the entanglement entropy of non-integrable hamiltonian eigenstates behaves very similarly to such random pure states.

I was in charge of the first time implementation of an exact sum for the reduced density matrix of these random pure states. I did so successfully using python, and we are now working on a paper to utilize my gathered data. As a researcher, this project really improved my understanding of how computers utilize, store, and process data, as well as gave me insights on just how challenging research can be.

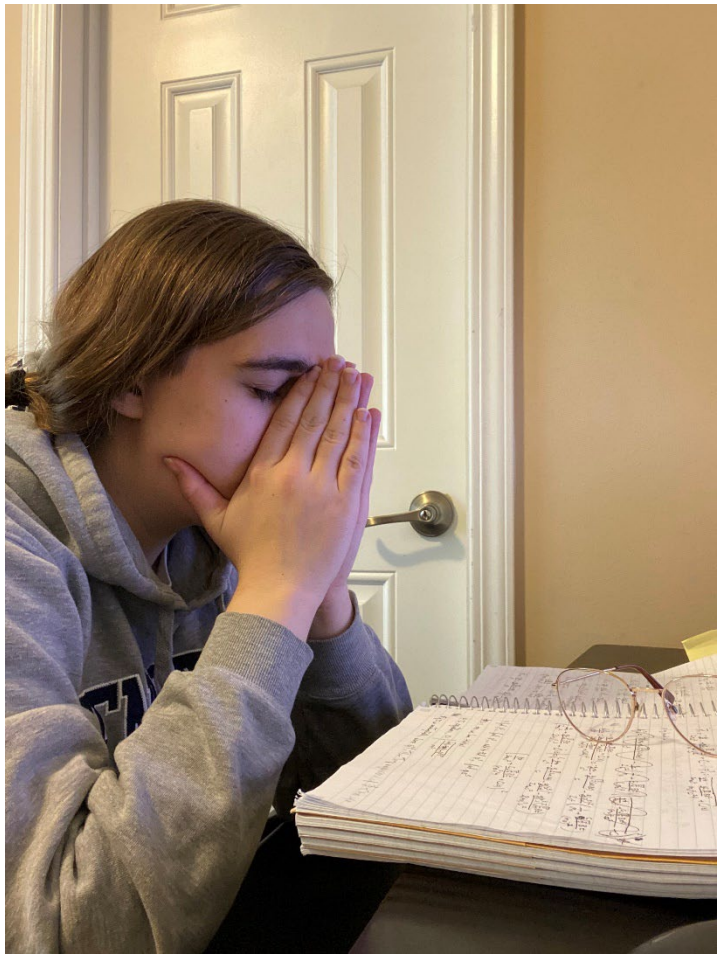


Geodesic of a Quantum Clock

Lily Weintraub, Department of Physics, The Pennsylvania State University
Dr. Martin Bojowald, Department of Physics, The Pennsylvania State University

The project was analysing how the geodesic of a quantum clock changed as the mass of the clock's particle changed in comparison to a typical fall. If the effect was substantial, then it would have to be accounted for in measurements.

My work in the project was in creating the equations that described the particle's position and momentum, and the resulting energy and proper time equations. Overall, as a result of the project, I have found how to work underneath someone, taking in their input and working to results. Additionally, I have found that while this line of work is stressful, it is rather rewarding in the end and that research is something I would like to continue.



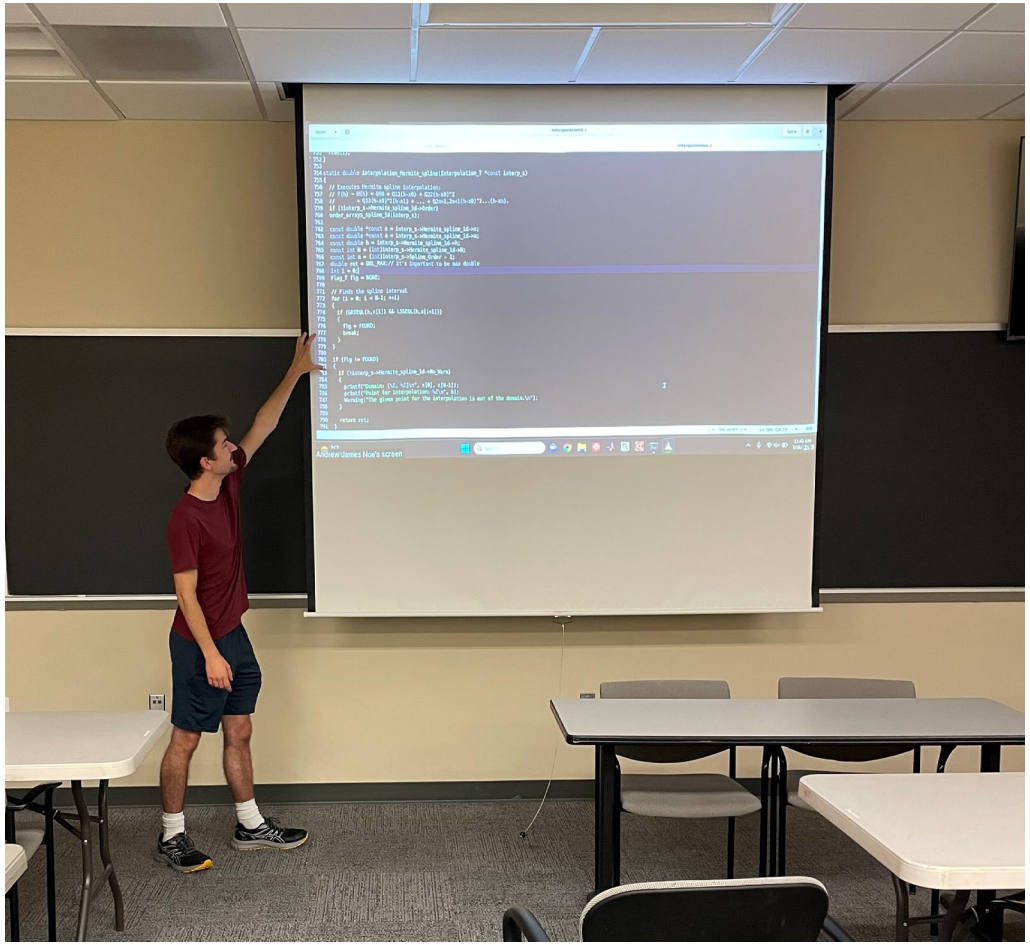
Pictured: me contemplating a bug in Mathematica

Generation of Initial Data in Compact Binary Mergers

Andrew Noe[1], Alireza Rashti[1], and David Radice[1,2]
[1]Department of Physics, Pennsylvania State University
[2]Department of Astronomy and Astrophysics, Pennsylvania State University

Numerical solutions of Einstein's equations allow us to simulate gravitational radiation from compact binary mergers, e.g. between black holes and neutron stars. Simulated gravitational wave signatures may be compared against observational data to constrain microphysical neutron star models.

I expanded the code of our initial data solver to incorporate new neutron star models, allowing us to test new theories of matter at ultra-high densities and pressures using an array of numerical methods. This has been my first experience in research, and has motivated me to continue research in graduate school.



Electronic transport properties of Ultrathin Transition Metal Carbides and Nitrides

Yuxin Gao,[1] Da Zhou,[1] Alexander Sredenschek,[1] David Sanchez,[2] Le Yi,[1] Morteza Kayyalha,[3] Nestor Lopez,[1] Mauricio Terrones[1,2,4]

[1]Department of Physics, [2]Department of Materials Science and Engineering, [3]Department of Electrical Engineering, [4]Department of Chemistry
The Pennsylvania State University, University Park PA, 16802, USA

Two-dimensional (2D) materials' quick development has revolutionized nanoscience and nanotechnology and opened up intriguing new possibilities for a range of uses, including electronics and energy storage. The goal of the REU program is to shed light on the desirable electronic transport properties of high-quality, single-crystal molybdenum nitride (MoNx) and tungsten carbide (W2C), which are renowned for their high conductivity in the ultrathin limit.

To achieve this goal, we use liquid-metal-assisted chemical vapor deposition (LMCVD) to precisely synthesize molybdenum nitrides and tungsten carbides, transfer onto SiO2/Si wafers using the poly (methyl methacrylate) PMMA-assisted method, and expose using SEM-based nanometer pattern generation system (NPGS) as part of device fabrication, which also includes develop, metal deposition, and lift-off for the subsequent steps. Several characterization techniques are utilized to reveal the dimensional characteristics of the crystals as shown at top center section. We probe the surface morphology and lateral size by using SEM and AFM, and confirm the crystal phases and structures with combination al use of TEM and XRD. Electronic transport properties will be explored using four-probe and Hall-bar devices, along with the physical property measurement system (PPMS) for temperature-dependent resistance and critical magnetic fields.