Spectral Analysis of StrayLight Data From 1A 0535+262 During the 2020 Outburst
Cole Aedo
Mentors: Fiona Harrison and Brian Grefenstette

X-ray outbursts occur in High Mass Neutron Star Binaries (HMNB) when the neutron star siphons matter from the accretion disc of its companion. We examine the outburst occurring in November-December 2020 using data from the Nuclear Spectroscopic Telescope Array (NuSTAR). In particular, we use the StrayLight data obtained through indirect observation of the source in an attempt to utilize its higher sensitivity, spectral resolution, and exposure time. We examine the spectral variations over time in the power law parameters, iron K_α line, and Cyclotron Resonant Scattering Feature (CRSF) as well as investigating a high energy feature discovered in the spectrum.

TDA2: A Topological Approach to Outlier Detection in Astronomical Time Series
Riti Agarwal
Mentors: Matthew J. Graham and Niharika Sravan

This project aims to apply topological data analysis (TDA) to astronomical time series from the Zwicky Transient Facility (ZTF) to find outliers. It is motivated by the large collections of astronomical data now available where the identification of anomalous objects is an area of much interest. We are investigating TDA as a more accurate way to perform outlier detection on astronomical time series. TDA techniques have never been applied to astronomical data sets for outlier detection and it is exciting to explore its results and see what kind of anomalies are detected. Our method consists of generating persistence diagrams for time series in a data set. A distance matrix based on the Wasserstein distance between persistence diagrams is then constructed. Known outlier detection methods, such as isolation forest, minimal spanning tree, and DBScan, can then be applied to this distance matrix to identify outliers. This process has proved to be very effective so far in detecting anomalies on a simulated data set of sinusoidal time series, giving over a 99% true positive rate. The method has also been applied to real data.

Exploring the Innermost Region of Accreting Black Holes With Quasi-Periodic Oscillations
Sanyukta Agarwal
Mentors: Javier A. García and Guglielmo Mastroserio

Black hole X-ray Binary (BHXB) are binary systems that are luminous in X-rays which usually consist of a black hole primary (accretor) which attracts matter off the secondary (donor), usually a main-sequence star. The infalling material forms an accretion disk around the black hole which emits in multiple wavelengths. We are mainly interested in X-ray emissions which often show Quasi-periodic oscillations, an important characteristic of transient BHXBs that are studied via the inspection of the power density spectrum (PDS) and are often described with a phenomenological Lorentzian shape in the PDS. QPOs result when hot gas piles up near the inner disk region of the black hole and helps in probing the innermost region of black holes. We perform a detailed timing analysis of the newly reported BHXB, MAXI J1803-298, observed by the Nuclear Spectroscopic Telescope Array (NuSTAR) and Monitor of All-Sky Image (MAXI) in its first recorded outburst in 2021. We study the source in its intermediate state, transitioning from a hard to a soft spectral state. We use Stingray software to correct the dead time of NuSTAR and find the presence of strong QPOs in the PDS at about a frequency of 0.4 Hz. We study the evolution of QPO over time and analyze its dependence on energy.

Probabilistic Analysis of Sufficient Scattering in Polytopic Matrix Factorization
MohammedSaid Alhalimi
Mentors: Alper T. Erdogan, Deniz Yuret, and Chris Umans

Matrix factorization is a fundamental step in many machine learning tasks. A recently introduced approach, Polytopic Matrix Factorization (PMF), models input data as linear transformations of latent vectors taken from a polytope. The generative property of PMF is conditioned on the ”identifiability” of a given polytope. The identifiability criterion requires the polytope to be invariant under permutation and/or sign. If the factor matrices are concentrated in a tiny subregion of the polytope, then the topology of the polytope is not well-represented. A sufficient condition on the spread of latent vectors inside the polytope uses the maximum volume inscribed ellipsoid (MVIE) where sufficient scattering corresponds to the convex hull of the samples containing the MVIE of the polytope with some tightness constraints. In this paper, we investigate the number of samples needed in order that the sufficient scattering condition is satisfied, deriving theoretical results as well as running numerical experiments to confirm our finding.

A Quantitative Approach for Characterizing the Evolution of Antibiotic Resistant Bacteria
Lorenzo Antonelli
Mentors: Rob Phillips and Tom Röschinger

The rise of antimicrobial resistance in bacterial pathogens is acknowledged by the WHO as a major global health crisis, and from many it is regarded as the next epidemiological challenge after the COVID-19 pandemic, if no efficient countermeasures are implemented. Evolution of pathogens lies at the very core of this crisis, which enables rapid adaptation to the selective pressures imposed by antimicrobial usage in medical treatment. This project aims to build a quantitative model, given the knowledge of behavior of bacterial cultures in conditions of exponential growth, to explain the relation of antibiotic-dependent growth and the strength of the antibiotic resistance gene *tet*(A). Knowledge of the quantitative rules underpinning the behavior of a bacteria culture under the pressure of drug will hopefully led in the future to I) the creation of more refined methods to control the spread of antibiotic resistance II) highlight new clues regarding the possibility to predict the evolution of microbial population, given the knowledge of certain parameters such as the DNA sequence and the concentration of drug in the environment.

SMC X-1 in Excursion: Exploring a Changing Accretion Disk
Wasundara Athukoralalage
Mentors: Fiona Harrison and McKinley Brumback

SMC X-1 is a neutron star X-ray binary with a high mass companion. As matter from the companion accretes onto the neutron star, it forms an accretion disk and the material locks onto the magnetic field lines, producing X-ray pulsations. SMC X-1 exhibits super-orbital period variability (45-60 days) due to obscuration by a warped, precessing accretion disk. It undertakes excursions where the period decreases to ~45 days every ~10 years. In this project, we study SMC X-1 using observations from *NuSTAR* (Nuclear Spectroscopic Telescope Array) and *XMM-Newton* (X-ray Multi-Mirror Mission) to perform, for the first time, broadband spectral and timing analysis during excursion. We disentangle the high energy emission of the pulsar beam from the low energy emission of the accretion disk by creating energy-resolved pulse profiles. By modeling the shape of energy-resolved pulse profiles with a warped disk model, we investigate the geometry of SMC X-1's accretion disk and search for changes to the disk shape. We also examine the broad-band X-ray spectrum to understand accretion rates during excursion. Studying the unstable accretion disk geometry of SMC X-1 allows us to study similar phenomena in other sources, particularly the ultraluminous X-ray pulsars showing irregular changes in brightness with time.

Development of Stake-Driving System for Cable Based Lunar Infrastructure
Diego Attra
Mentor: Soon-Jo Chung

The development of lunar infrastructure is a critical next step in space exploration for organizations in the space industry such as NASA. To harbor lunar bases, an important puzzle piece in the transportation of materials needs to be developed. This however poses a challenge, as important cargo such as water is found in treacherous craters in permanently shaded areas of the moon. These craters can have up to 40 degree slopes that span as far as 8 kilometers which is impassable for current wheeled rovers. A team of Caltech students, as a result, is developing the Lunar Architecture for Tree Traversal in-service-of Cable Exploration (LATTICE). This project will allow for the traversal of these craters by placing stakes into the ground and stringing cables across them, allowing for a robotic shuttle to travel across with cargo. The driver system of LATTICE needs to be able to robotically drive 2 meter long stakes 1 meter into icy regolith, which is difficult as regolith is ultrafine and corrosive. This paper discusses the methods and results of the initial earth-based drive system design and testing.

Characterizing Background Sources in Sub-GeV Dark Matter Detection Experiments
Angel Rodrigo Avelar Menendez
Mentors: Maria Spiropulu, Anthony LaTorre, and Jamie Luskin

The existence of dark matter is implied by cosmological and astronomical observations. However, there are yet to be any direct detections of dark matter, and the nature of its physical interaction on small scales remains unknown. Searches for dark matter have had a large emphasis on weakly interacting massive particles (WIMPs). Specifically, past experiments have mainly focused on looking for particles with masses above the GeV scale, even though various theoretical frameworks for sub-Gev dark matter have been developed. The Spiropulu group along with Jet Propulsion Laboratory collaborators have combined an n-type GaAs target with a Superconducting Nanowire Single-Photon Detector to make a novel detector for dark matter. But before we can find low-energy dark matter, we must be able to distinguish dark matter detections from everything else. For example, muons and decaying silicon-32 atoms can transfer kinetic energy to an electron inside the target and leave it in an excited state. Our approach towards characterizing the backgrounds is to simulate the detector using Geant4, a toolkit developed by CERN to simulate particles moving through matter, in order to find the number of photons expected per day for each background.

Animal Behavior Quantification Through Self-Supervised Learning
Pablo Backer Peral
Mentors: Pietro Perona and Jennifer Sun

Animal behavior recognition and classification has become increasingly prominent within the rapidly growing field of computer vision. Typical machine learning algorithms used for this task involve large amounts of manually annotated data, often proving an expensive and time consuming process. One such model is the Mouse Action Recognition System (MARS), which provides a pipeline for the classification of social behavior between interacting mice and may take hundreds of thousands of annotated frames to accurately predict behavior. The Trajectory

Embedding for Behavior Analysis (TREBA) attempts to address this issue with the use of small expert-defined programs that characterize animal behavior, trading off substantial amounts of annotation effort for a small amount of these “tasks” with little to no loss in accuracy. In this study, we integrate TREBA’s functionality within MARS, allowing for a streamlined way to take advantage of expert-defined tasks and reduce total annotation requirements. Our results show a noticeable improvement in the accuracy of our MARS model when trained using TREBA. The next steps in our research involve retraining TREBA using novel machine learning models, such as the transformer, to see if these can further improve performance.

Understanding the Origin of Color in Minerals Through Visible and Infrared Spectroscopy
Jonathan Bennett
Mentor: George Rossman

Visible and infrared spectroscopy can be used to identify metal ions present in a mineral sample and their crystallographic sites. These metal ions are often the origin of color in minerals. Samples of pyroxmangite, a rare polymorph of rhodonite, and sphalerite, the primary zinc-bearing ore, were identified and examined using Raman, visible, and infrared spectroscopy. The chemical composition of each sample was obtained using a scanning electron microscope and used to determine the conditions needed for certain colors to occur. Outside of studies done on pyroxmangite and sphalerite, visible and infrared spectroscopy is shown to have numerous other applications to mineralogy, including the construction of libraries for mineral identification purposes and insights into the infrared transparency of certain opaque materials.

Long-Period Seismicity at Long Valley Caldera
Natalia Berrios-Rivera
Mentors: Zachary Ross and Jack Wilding

Monitoring seismic activity in volcanic settings is significant to assessing regional hazards and forecasting potential eruptions. Detection of long-period earthquakes, events characterized by a high density of low-frequency (1-2.5 Hz) spectral energy, may indicate the movement of hydrothermal or magmatic fluid within a volcanic plumbing system. Long Valley Caldera (LVC) is an active volcanic region in eastern California where episodes of unrest including earthquake swarms and intermittent long-period seismicity have been observed throughout the past four decades. Using a 21-year earthquake catalog, we analyze seismic waveform data recorded by 27 stations in the LVC region, and classify over 10,000 earthquakes as either volcano-tectonic or long-period events based on their relative proportion of recorded low-frequency energy. Within the last five years, most LP events have occurred at shallow crustal depths (<8 km below sea-level) and are concentrated near the southern rim of the caldera.

Optimization of Kidney Stone Fragmentation in Burst-Wave Lithotripsy
Brynja Marín Bjarnadóttir
Mentors: Tim Colonius and Shunxiang Cao

The only current extracorporeal procedure for kidney stones is shock-wave lithotripsy (SWL). SWL focuses shockwaves generated outside the body to pulverize kidney stones. This procedure is not fully effective at pulverizing the stones and can cause kidney injuries. A new method called burst-wave lithotripsy (BWL) uses safer, lower amplitude pulses of focused ultrasound at frequencies that excite resonances in the stone. While effective, there are opportunities to optimize BWL by altering the ultrasound waveforms. Here we use a previously developed mathematical model of the problem to solve the corresponding optimization problem. Specifically, we examine the effect of posing different optimization criteria on the stresses generated in the stone. We find specific optimizations that excite higher stresses near the surface of the stone which could be effective in giving better fragmentation per unit of input energy.

Building a Spectral Library of Iron-Bearing Brucites
Claire Blaske
Mentors: Rebecca Greenberger and Bethany Ehlmann

Serpentinization is a geochemical process that has implications for the past and present habitability of locations where its products are found. The Oman ophiolite on Earth has rocks actively undergoing this process, and serpentinized materials have also been found on Mars. On Earth, when ultramafic ocean crust interacts with water under obduction conditions of decreasing pressure and temperature, serpentinization reactions occur. This produces iron-bearing brucite and molecular hydrogen. Brucite containing Fe^{2+} may withhold hydrogen from the initial reaction and release it later on, modulating the availability of chemical energy for microbial communities. To better understand the serpentinization process and prepare for mission results that might find unique serpentine environments, we have built a spectral library of both natural and synthetic brucite samples. These spectra illustrate trends due to exposure to certain compounds and oxidation level. Analyzing three key features (the OH overtone at 1.4 μm, the H_2O absorption feature at 1.9 μm, and the Mg-OH absorption feature at 2.3 μm) will allow us to constrain observations of serpentinized material across the solar system.

Early Language Development in Children With Agenesis of the Corpus Callosum as Compared to Children at High- and Low-Likelihood for ASD
Ella Bohlman
Mentors: *Ralph Adolphs, Lynn Paul, and Jasmin Turner*

Congenital malformations of the corpus callosum include agenesis (complete or partial callosal absence, AgCC) and hypoplasia (thin callosum). Evidence to date suggests better outcomes for children with isolated AgCC than for children with hypoplasia or agenesis combined with other developmental brain malformations (AgCC-plus). This study explores early language development (timepoints 12, 18 and 24 months) of both subgroups of children with congenital callosal malformations (isolated AgCC and hypoplasia/AgCC-plus) in comparison with neurotypical children and children at familial risk of autism spectrum disorder (ASD). Preliminary review of summary statistics and group-wise data visualization indicates that neurotypical controls produce a higher number of words and gestures than participants at risk of ASD and participants with AgCC. Statistical comparisons between groups will clarify the robustness of these preliminary findings.

Structural Insights Into HyMurG With Park's Nucleotide, Murgocil, and Lipid II
Helen Brackney
Mentors: William M. Clemons Jr. and Anna K. Orta

The peptidoglycan layer in bacterial cells is a popular target for antibiotic development. The essential peripheral membrane protein MurG is part of a critical step in the synthesis of peptidoglycan. The lipid substrate, Lipid I, is thought to be recognized by MurG through its soluble domain. Currently, there is no structure of MurG with bound lipid substrate, and the residues required for this interaction have not been conclusively defined. Crystallographic methods, MicroED, and CryoEM were applied to study the interactions between MurG and the soluble domain of Lipid I through the substrate mimic Park's Nucleotide, Lipid II, and a Lipid I analog. By adding Park's Nucleotide, Murgocil, Lipid II, the Lipid I analog, or a combination of the listed additives to concentrated MurG, crystals formed under optimized conditions. We aim to obtain electron-density maps from these techniques to model the structure of MurG.

Discovering Materials to Enable Solar Generation of Fuels
Ja'Nya Breeden
Mentors: John Gregoire and Dan Guevarra

Climate change is currently an issue that is being exacerbated by the use of fossil fuels, requiring the discovery and utilization of renewable energy sources. Electrochemical methods are pivotal in discovering effective catalysts to generate solar fuels from earth-abundant resources. Given a substantial amount of data generated through electrochemical processes, data-driven methods are an effective way of parsing data and providing statistics for high-performing samples within the database, thus allowing for the automated determination of future experimental design. By utilizing a graph database containing experimental provenances with sample process nodes that point to successive processes and adjacent sample data and process details, we determine how effective a sample is at a specific pH and design the next experiment with unique parameters.

Developing the First Cleave and Rescue Gene Drive in the Plant Female Line
Rosie Bridgwater
Mentors: Bruce Hay and Georg Oberhofer

Gene drive is a naturally occurring phenomenon in which selfish genetic constructs increase their transmission to the next generation at the expense of alternative alleles. This can be harnessed for genetic engineering at the population scale. Cleave and Rescue gene drive encodes CRISPR Cas9 which cuts an essential gene, meaning inheritance of the rescue-bearing ClvR construct is essential to offspring survival. This results in spread of ClvR into a population, which can be linked to a cargo gene for population modification or suppression. Hay lab is pioneering ClvR in plants, with potential applications including weed eradication for the improvement of crops or biodiversity. However, while ClvR gene drive is successful in the male line (transgenic pollen), crossing the female line (transgenic ovules) with wild type results in Mendelian, rather than 100% gene drive inheritance. This is likely to be due to the promoter causing insufficient expression of the ClvR system in the female reproductive tissue. Therefore, using Gibson assembly, we are trialling a different promoter, the second intron of AGAMOUS with a Cauliflower Mosaic virus enhancer, and conducting test crosses to observe if there is an inheritance bias, thus whether a successful female line gene drive has occurred.

Variability in Spitzer ch2 and WISE W2 With the Addition of a New Technique for Discovering Brown Dwarf Binary Candidates
Hunter Brooks
Mentor: J. Davy Kirkpatrick

We used a sample size of 361 objects to search for variability in nearby brown dwarfs, on the timescales of over 12 years. Our findings have shown that using Spitzer ch2 and WISE W2 photometry does not show variability, resulting in the conclusion that these bands either see through the clouds of these object or that the majority of brown dwarfs have clouds that are uniformly distributed over the surface of the brown dwarf's atmosphere. Furthermore, in analyzing the data, a new technique was made for indicating brown dwarf binary candidates. Using Spitzer's ch2 IRAC aperture and point response function flux measurements, it can be concluded that a brown dwarf could have a possible companion. This is done by looking at the separation between the two different measurements, if the ch2 point response function is dimmer in all the points compared to those of the aperture measurements, an object can be declared as a possible binary system.

Effect of Turbulence on Hot Surface Ignition
Isaac Broussard
Mentor: Joseph E. Shepherd

Hot surface ignition has been extensively investigated for the case of laminar flow in the Explosion Dynamics Laboratory. Some examples of the investigations for laminar natural convection around hot cylinders in a quiescent flow are described in Jones and Shepherd 2021, and Boeck et al. 2017. Engineering applications usually involve turbulent flow and it is important to quantify how the effects of turbulence influence the ignition threshold. Studies of spark ignition (for example, Jiang et al. 2018 and Toepe and Blunck 2022) show a decrease in the probability of ignition with increased turbulent intensity. The effect of turbulence on hot surface ignition temperature thresholds is unknown and needs to be determined. The project will involve the design and operation of a miniature concentric wind tunnel that will surround a vertical heated element. The wind tunnel will be constructed out of an array of computer fans that will form a hexagonal or octagonal structure with all the fans pointing inward. The turbulence will be characterized with a commercial hot wire anemometer (for example, the DANTEC miniCTA). After characterization, the window tunnel will be placed inside a combustion vessel and the dependence of ignition threshold determined as a function of turbulent intensity.

Design of a Shuttle Robot for Cable Transport on Lunar Architecture for Tree Traversal in-service-of Cable Exploration (LATTICE)
Matticus Brown
Mentor: Soon-Jo Chung

Craters near the lunar south pole host permanently shadowed regions which contain useful resources such as water ice which could be very beneficial in manned exploration of the moon and beyond, both as an essential part of maintaining human life and also as a source for rocket propellant. However, traversing the steep walls of these craters without error and transporting large amounts of material from the crater depths requires a lunar transportation system which does not yet exist. We propose a system in which a lead rover places a set of cables on stakes down the crater walls on which a shuttle robot can traverse quickly while transporting large amounts of material. Specifically, the shuttle robot tensions the cable in order to account for slack and thermal fluctuations, drives along the cable to transport the load, and accomplishes vertical and horizontal turns at different stakes in order to navigate the difficult terrain. We prototyped this shuttle in a medium fidelity system, and then completed a high fidelity prototype that was able to accomplish the aforementioned functions as a proof of concept in a technical demonstration in the desert. The completion and functionality of this shuttle prototype demonstrates how the general system would be possible as a lunar resource transportation system, and thus could work as an effective way for future lunar missions to access water and other resources.

A TSIX LncRNA Knockout for Studying X-Chromosome Counting and Choice
Alex Burr
Mentors: Mitch Guttman and Drew Honson

X-chromosome inactivation (XCI) is the process female (XX) mammals use to adjust the expression of X-linked genes to match that of males (XY). XCI is accomplished by transcribing the long noncoding RNA (lncRNA) Xist from a single X-chromosome. Xist recruits heterochromatin effectors to that X-chromosome, leading to gene silencing. How the cell determines which allele of Xist to express, however, is poorly understood because no known features distinguish the X-chromosomes prior to XCI. Previous work has shown that deleting the X-linked lncRNA Tsix causes a subset of cells to express Xist from both X-chromosomes. How Tsix maintains normal X-chromosome counting, however, is unknown. Here, we generate novel Tsix knockouts to investigate the role of Tsix in counting X-chromosomes and structuring chromatin.

Developing a Mosaic Nanoparticle Capable of Eliciting Cross-Reactive Immune Responses Targeting a Broad Range of Merbecoviruses
Sergio Zafra Butron Jr.
Mentors: Pamela Bjorkman and Alexander Cohen

The global 2012 MERS-CoV outbreak demonstrated the imminent risk merbecoviruses pose to public health, suggesting that such coronaviruses could follow a similar fate as SARS-CoV-2 in becoming a pandemic-level threat. Therefore, we sought to develop a mosaic nanoparticle vaccine presenting merbecovirus spike receptor binding domains (RBDs) capable of triggering broad immune responses as a countermeasure to future merbecovirus-spillover events. We constructed mosaic-8 nanoparticles co-displaying eight varying merbecovirus receptor binding domains (RBDs) alongside eight homotypic nanoparticles displaying one of each type of the eight RBDs. Immune response data from mice immunization of the mosaic-8 MERS-RBD vaccine (Mosaic-8M) against the eight homotypic nanoparticles and an admixture of those eight will demonstrate whether or not Mosaic-8M is effective at eliciting cross-reactive antibody response against the entire merbecovirus lineage. We will conduct enzyme-linked immunosorbent assays (ELISAs) and neutralization assays to characterize and detect antibody specificity and presence in the mice study. Supporting results would suggest that immunization with the mosaic-8 MERS-RBD vaccine could protect against future infection and spillover events involving a broad range of merbecoviruses.

Towards Producing Realistic LHC QCD Simulation Using Quantum Generative Adversarial Network Through a Quantum Circuit Ansatz Search
Yiyi Cai
Mentors: Maria Spiropulu, Jean-Roch Vlimant, and Samantha Davis

Classical generative models have been shown to hold the promise for being surrogate generative models that may replace part or all the detailed simulation chain of collider data, in particular at the LHC. Quantum-classical hybrid generative models might provide improved accuracy and performance thanks to the exponential scaling of the size of the Hilbert space of initial state, and the intrinsic stochasticity of quantum systems. One limitation of such an approach is the arbitrary selection of an ansatz for the quantum circuit used. We investigate the performance of quantum-classical generative adversarial models to simulate features of hadronic jets at the LHC using variational quantum circuit for the generative part of the model, and further search the space of circuit ansatz to find the best performing circuit. We draw conclusions on the performance of quantum-classical hybrid generative adversarial models for the hadronic jets dataset and provide prospects on usability of such methods at the LHC.

Prototype of an Autonomous Tracked Vehicle for Inspection of Vertical Steel Surfaces
Lydia Calderon-Aceituno
Mentor: Joel Burdick

The regular surveilling of structures such as windmills and oil storage tanks is a task currently performed manually and is both high-risk and time consuming for human inspectors. Existing solutions to this issue include various types of remotely controlled clinging robots. Our principal objective is to develop a low-cost prototype for a tracked vehicle equipped to perform structural integrity checks on inclined and vertical steel surface. We hope to advance this area of research through designing a fully autonomous vehicle capable of generating variable cling. To this end, an RC car chassis has been modified with a custom sensor track, enabling the mounting of various sensors and computing power, and with magnet mounts which house permanent magnets on the nerf bars. We are currently working towards completely automating the inspection process and designing a mechanism to generate a controlled magnetic field using an actuated array of permanent magnets.

Characterizing Hazardous Near Earth Asteroids Observed by NEOWISE Using an MCMC Thermophysical Model
Joahan Castaneda Jaimes
Mentor: Joseph Masiero

The Wide-field Infrared Survey Explorer (WISE) telescope has been scanning the sky for over a decade, uncovering a vast population of Near Earth Asteroids (NEAs) as part of the NEOWISE mission. NEAs are of interest to the scientific community due to their proximity and chaotic nature, making them a potential threat to Earth while also promising targets for future missions. In this study, we assess asteroids by first recovering observational epochs missed by NEOWISE's detection software and then using all valid observational epochs to run a triaxial ellipsoidal thermophysical model utilizing Monte Carlo Markov Chain (MCMC) techniques. We present predictions of the diameter, albedo, thermal inertia, and other physical characteristics for these asteroids. Additionally, we report newly discovered epochs for these objects to the International Astronomical Union's Minor Planet Center and develop software tools for discovering more missed epochs by NEOWISE across the entire WISE database in an automated fashion.

Production of Sugar Precursors on Early Mars
Rachel Caulfield
Mentor: Yuk Yung

The Mars group at Caltech, led by Dr. Yuk Yung, is investigating the question of whether Mars may have once had the conditions necessary for the evolution of life. Recent studies include "Long-term drying of Mars by sequestration of ocean-scale volumes of water in the crust" and "Nitrogen Fixation at Early Mars." The first paper concluded that Mars once had large amounts of water, equivalent to a global layer 100-1500 meters deep. Meanwhile, the second paper calculated the precipitation rates of HCN, a molecule important for protein synthesis, and HNOx, which are strong electron acceptors, in an early Mars environment. Additionally, it reported the resulting aqueous concentrations of nitrate and cyanide. To continue this exploration of the conditions that existed on early Mars, I modified KINETICS, a Caltech/JPL atmospheric chemistry model, to handle aqueous species with the ultimate goal of solving for the production of sugar precursors. To this end, I inputted reactions R1-R11 from "Stability of Nitrogen in Planetary Atmospheres in Contact with Liquid Water" and R1-R39 from "Production of Formate via Oxidation of Glyoxal Promoted by Particulate Nitrate Photolysis."

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Designing an mRNA-Based Vaccine Against HIV-1
Christian Cepeda
Mentors: Pamela Bjorkman and Magnus Hoffmann

The efficacy of mRNA vaccines on SARS-CoV-2 during the pandemic has added extra interest to the global-scale production of an mRNA vaccine against HIV-1. The HIV-1 epidemic has been addressed for decades, and the problem is that we still do not have an effective vaccine for it because HIV-1 has a rapid mutation rate and enormous genomic diversity. The solution is the development of broadly neutralizing antibodies (bNAbs) that recognize conservative epitopes on the HIV-1 Env surface protein. For this project, mRNA vaccine candidates that induce bNAbs against HIV-1 were designed. The difficulty with creating an mRNA vaccine for HIV-1 is that the surface protein does not express well. To combat this, the 20-30 HIV-1 Env-based immunogen constructs created have included the addition of stabilizing mutations and the removal of endocytosis motifs to improve HIV-1 Env expression. Following Gibson Assembly cloning, the DNA plasmids were transfected into mammalian cells, where they were transcribed and translated into HIV-1 Env proteins. HIV-1 Env expression was measured via flow cytometry. Several HIV-1 Env-based constructs have shown surface protein expression comparable to that of SARS-CoV-2. The best constructs will be synthesized into mRNA and packaged into lipid nanoparticles to measure immune responses in mice.

Understanding the Interactions Amongst Solvents, Dispersants, and Powders in Suspensions for Tape/Freeze-Cast Battery Separators
Shivani Chatterji
Mentors: Katherine T. Faber, Chun-Wei (Vince) Wu
With the safety issues at extreme operating conditions and depleting sources of lithium, non-lithium-ion batteries like sodium-ion batteries (SIBs) are promising. However, a required component in batteries to separate the cathode and anode while still facilitating ion transfer, the separator must be compatible with SIBs. Through a collaboration with battery startup TalosTech, the Faber Group has designed a method to tape/freeze-cast separators with tunable pore size, wettability, and ion transfer. The addition of ceramic nanoparticles (alumina, Al_2O_3) as reinforcements was shown to improve the mechanical properties and thermal stability of these separators. This current work focuses on understanding well-dispersed suspensions composed of alumina powders in either dimethyl sulfoxide, 1,4-dioxane, or water, with one of two commercial dispersants. Dispersants work to separate particles and avoid their agglomeration in suspensions. The stability of these solvent-ceramic-dispersant ball-milled suspensions was tested through sedimentation tests and particle size analysis. The compatibility between the solvent and alumina were assessed with a contact angle goniometer. The electrical characteristics of the suspensions was analyzed through electrophoresis deposition, electrical conductivity tests, and zeta potential measurements. From the sedimentation tests, the dried sediment was extracted and ran under Fourier transform infrared spectrometry, and the composition was obtained from energy-dispersive X-ray spectroscopy. The presence of sulfur impurities in alumina, and its effect on dispersion, was explored in order to provide guidance on processing of battery separators.

Categorical Models of Dynamical Neural Information Networks
Hannah X. Chen
Mentor: Matilde Marcolli

To develop a mathematical setting for modeling neural network architectures in the brain, we want a topological space that describes all consistent ways of assigning (computational or informational) resources to a population of neurons, while also keeping track of both constraints on and conversions between resources across any subsystem of the network. Such a configuration space can be modelled using category theory, particularly in the form of categories of compositional network summing functors. By introducing a categorical reformulation of the Hopfield equations (a fundamental model in neuroscience for how networks of neurons function) on this space, we then obtain a dynamical system where the variables are summing functors (assignments of resources), and the dynamics are determined by endofunctors of a given category of resources as well as a threshold nonlinearity defined by the measuring semigroup associated to that category. This project investigates the properties of these categorical dynamical systems, focusing on categories of computational resources (for instance, categories describing deep neural networks, other automata, and concurrent/distributed computing architectures). Various choices of endofunctors are examined to analyze the existence of fixed points, the structure of orbits, and how patterns of connectivity can shape the nonlinear dynamics of a network, with the overall goal of demonstrating behavior analogous to the phenomena shown for classical Hopfield networks.

Variable Length Codes With Sparse Bursts of Full-Feedback
James Chen
Mentors: Victoria Kostina and Recep Can Yavas

Modern communication systems are becoming increasingly interconnected and layered, significantly tightening constraints on delay and power. Feedback dramatically increases the amount of information that can be communicated quickly, but constant feedback is impractical. While sparse feedback codes exist, they lack theoretical guarantees on performance at short blocklengths. To address this, we are designing and analyzing variable length codes in which bursts of full-feedback occur at pre-scheduled times, during which a receiver feeds back everything it has received since the last feedback instance. We first adapted existing posterior matching schemes to use uniformly delayed feedback; numerical simulations showed that our schemes performed poorly compared to their counterparts with constant feedback. Next, we created a coding scheme using multiple cycles of communication and confirmation, each followed by a single feedback instance. We derived tight bounds on performance parameterized by when the feedback instances are scheduled and performed numerical optimization over these parameters.

Shift Current Response in Twisted Multilayer Graphene
Sihan Chen
Mentors: Cyprian Lewandowski, Swati Chaudhary, and Gil Refael

Twisted bilayer graphene (TBG) has shown to be an excellent material for photovoltaic applications in the terahertz range due to its nontrivial band topology of flat bands. In twisted multilayer graphene (TMG), we observe the presence of multiple flat bands hybridizing with each other through a self-generated displacement field. We investigate the role of these additional flat bands in TMG in enhancing the shift current response. Our numerical calculation indicates that the additional transitions among different flat bands and to the dispersive Dirac cone led to an overall enhancement of shift current response as well as a new dominant peak formation in shift current conductivity for a wide range of fillings at the frequency determined by the mean energy of the two bands near K and K’ points. In addition, we wish to explore the connection between charge inhomogeneity in the moiré unit cell and the magnitude of shift current response. Specifically, we want to understand how (or if) shift current response relates to the spatial charge inhomogeneity present in the moiré system. By answering this question, we could potentially reverse-engineer materials with large shift current, thus, finding better solar cell candidates.

Multi-Person Pose Detection for Interactive Video Acquisition and Learning System for Motor Assessment of Parkinson’s Disease
Yishu Pearl Chen
Mentors: Sui Yanan and Alusi

Parkinson's Disease (PD) is diagnosed and treated by evaluating the patient's motor functions. However, this is not always accessible to be performed in clinics, but patients' video recordings are often shot incorrectly without professional guidance, or in low lighting and low quality which makes evaluations difficult. PD-Guider is a mobile phone app which aims to guide users to film correct videos for PD evaluation through machine learning. However, the current model only supports single-person detection. In this project, we implement and examine different pipelines to achieve multi-person pose detection, which would be very helpful for when for example the patient benefits from having assistance performing the motor tasks to be evaluated such as gait.

Development of Chiral Catalyst Libraries via Supramolecular Assembly
Danielle Chew-Martinez
Mentors: Hosea Nelson and Chloe Williams

This project aims to efficiently synthesize a library of catalysts capable of being used in asymmetric ion pairing catalysis of carbocation reactions. Previous studies involve laborious and time-intensive catalyst synthesis to optimize enantioselectivity. To be effective in both time and cost, ion-pairing will be used as a platform to generate new complex chiral catalysts via supramolecular assembly to generate confined chiral environments. By using ion-pairing of chiral dianions and chiral cations, a net anionic chiral supramolecular complex can be paired with a Lewis acid cation, enabling synthetic chiral molecules to induce enantioselectivity in reactions of carbocation intermediates via Lewis acid ion pairing catalysis. In the present work, various chiral quaternary ammonium salts and chiral dianions were synthesized to constitute different combinations of the net anionic complex resulting in a variety of catalysts that mimic enzyme active sites and have a tunable chiral environment. We hypothesize that this new approach toward catalyst library development will accelerate enantioselectivity optimization broadly in various carbocation reactions of interest. These catalysts will be especially useful in developing drug-like small molecules. The chiral anion and dianions structures were confirmed via LC-MS and ^{1}H NMR. Future work will be focused on developing conditions to induce ion pairing of the complex ionic components, and screen for catalysis in reactions of interest.

AI-Assisted Bayesian Optimization: Discovering and Predicting Extreme Events
Haeyoung Chloe Choi
Mentors: Themistoklis Sapsis, Tim Colonius, and Ethan Pickering

Extreme events, such as rogue waves, can have devastating effects in society. Characterizing extremes is challenging because of the rarity of their occurrence, the infinite-dimensionality of their dynamics, and the stochastic perturbations that excite them. In this study, we combine Bayesian optimization (BO) that accounts for the importance of the output relative to the input with an ensemble of deep neural operators (DNOs) that approximates infinite-dimensional nonlinear operators. Using this model-agnostic and computationally tractable framework, we assess the viability of DNOs and extreme acquisition functions to predict several extreme phenomena, and explore higher dimensions and ubiquity among different test case scenarios.

Carbon Isotope Fractionation During Core Mantle Differentiation in Rocky Protoplanets and Planets
Paras Choudhary
Mentors: Francois Tissot, Paul D. Asimow, and Damanveer S. Grewal

Iron meteorites sample the metallic cores of the earliest formed planetesimals. They are primarily composed of iron-nickel along with other trace elements. Amongst these trace elements, carbon (a life-essential element) is also present in small quantities in iron meteorites. As these planetesimals were likely the seeds of rocky planets, understanding the origin of carbon in iron meteorites has important implications for its delivery to Earth. To understand the origin of carbon isotopic compositions of iron meteorites, we performed high pressure-temperature experiments using metallic and silicate mixtures (analogs of cores and mantles, respectively) at conditions which simulated core formation in planetesimals. We will measure the carbon isotopic compositions of the quenched metallic and silicate melts using an Elemental Analyzer - Isotope Ratio Mass Spectrometer. We will compare the measured isotopic fractionation of carbon between metallic and silicate products with the meteorite data to better understand the fate of carbon during planetesimal differentiation.

Benchmarking SPAdes and MEGAHIT
Katelyn Chu
Mentors: Niema Moshiri and Leonard Schulman

The primary goal of this project is to benchmark algorithms involved in genome assembly. To do this, I ran two genome assembly tools, SPAdes and MEGAHIT, on a standard *E. coli* dataset. I used QUAST on both resulting assemblies to evaluate the accuracy with respect to the reference *E. coli* genome, and several metrics indicated that SPAdes was more accurate than MEGAHIT. MEGAHIT's assembly had over 4 times as many mismatched base pairs as SPAdes' assembly. However, over 10 runs SPAdes had a median runtime of 3:46:53 (h:mm:ss) while MEGAHIT had a median runtime of 4:50 (m:ss). SPAdes also had a median CPU usage of 418% while MEGAHIT had a median usage of 2645%.

Predicted Three-Dimensional Structure of TAS2R50 Including Associated G-Protein and Agonists
David Clancy
Mentors: William Goddard III and Soo-Kyung Kim

Bitter taste receptors (TAS2R) are a member of the expansive G-protein coupled receptor (GPCR) super family of proteins. There are 25 different TAS2Rs found dispersed around the human body in both smooth and cardiac muscle cells. This includes TAS2R50, which has been associated with cardiovascular diseases. So far, there is no known experimental structure for TAS2R50. However, the Goddard group has developed a complete sampling method (GEnSeMBLE) for predicting the 3-D structure of these GPCRs. Bitter taste receptors TAS2R4, TAS2R5, and TAS2R14 were used as templates for GEnSeMBLE because they have known experimental structures. There are two known ligands for TAS2R50, Amarogentin and Andrographolide, which were both prepared for docking. This study not only provides an atomistic understanding of the mechanism for the TAS2R50 bitter taste receptor, it also identifies new drug candidates to treat cardiovascular diseases. The best structures will be experimentally validated by collaborators at the University of Arizona and the University of Southern Florida. Future studies will optimize the binding to enable experimental investigations into its role in cardiovascular disease

Methods and Implications of Rove Beetle Mimicry of Ant Cuticular Hydrocarbon Profiles
Danny Collinson
Mentors: Joseph Parker and Tom Naragon

The myrmecophilous (ant-associated) rove beetle species *Platyusa sonomae* and *Sceptobius lativentris* are social parasites of the ant species *Liometopum occidentale*, able to infiltrate colonies to access their resources by overcoming the ant nestmate recognition system based on the specific blend of cuticular long-chain hydrocarbons (CHCs). CHCs coat the outer surface of insects' bodies to prevent desiccation and serve as communication signals, and it has previously been shown that *Platyusa* synthesizes its own CHC blend to closely resemble that of host ants, whereas *Sceptobius* silences endogenous production of CHCs in order to steal CHCs off of *Liometopum* while grooming them, giving a near-perfect match. We identified key desaturase enzymes involved in *Platyusa* CHC production from prior RNA-Seq data, verified them with hybridization chain reaction (HCR), and used RNAi to knock them down, altering the CHC profile, as assessed by GC-MS. Further experiments hope to show increased ant aggression towards *Platyusa* with knocked down desaturases. We also use PCR to look for DNA from *Liometopum* and *Drosophila melanogaster* in the gut of *Sceptobius* living with *Liometopum* fed with *Drosophila*. Results from this experiment will help determine if *Sceptobius* eats the brood of *Limoetopum* or if it is fed by ants through trophallaxis.

Characterizing Friction in Miniature Pulleys With High Speed Motion Capture
Caitlyn Coloma
Mentors: Sergio Pellegrino and N. Harshavardhan Reddy

Caltech's Space Solar Power Project (SSPP) has created lightweight, thin-shell structures designed to elastically unfold themselves in space. In order to study the dynamics of this deployment on the ground, a suspension system using miniature pulleys to support the unfolding of SSPP structures has been designed for its low inertia and friction. The focus of this work is characterizing the friction these pulleys contribute in ground experiments in order to properly study SSPP structures as they would behave in space. Two masses were vertically suspended in one-pulley and two-pulley experiments for several mass combinations in the range [20, 100] g. High speed motion capture cameras were used to track the vertical displacement of each mass with respect to time, from which the acceleration of each mass was determined and used in the final frictional moment calculation. While it is expected that a pulley's moment friction increases linearly with increasing radial force, data indicate that bearing friction and unwanted slipping of the pulley cord contribute to deviations from this relationship. Nonetheless, this work demonstrates that a simple force analysis of a pulley can be used to experimentally determine its friction and ultimately support deployment dynamics studies for SSPP.

Investigating the Decay of Long-Lives Particles
Samantha Contreras
Mentors: Maria Spiropulu, Christina Wang, and Si Xie

This project aims to complete a feasibility study of the use of muon detector shower objects combined with displaced tracks for the detection of hidden valley dark showers. To do this, an algorithm needs to be designed to define the muon detector shower and the displaced track (dark shower object). The hidden valley dark shower model simulation samples will be used to measure detection efficiency to obtain a rough estimation of search sensitivity. The simulated samples of LLPs with different lifetimes are studied by analyzing decay particle showers in the Cathode Strip Chamber (CSC), the Drift Tube (DT), and the Tracker in the Compact Muon Solenoid (CMS).

Smart Lenses: Using Inductive Coupling to Detect Changes in Convergence of the Eyes
Matthew Crespo
Mentor: Azita Emami

It is a notable occurrence that as most people age, their eyesight diminishes for nearby objects which leads to many people eventually owning reading glasses, bifocals, or multi focal lenses; this age-related deterioration of vision for short distances is known as presbyopia. The goal of our project is to develop contact lenses that provide a more "natural" experience by adjusting according to the convergence of the user's eyes. To detect the convergence of the user's eyes we will be using the inductive coupling of coiled wires that will be place on the circumference of the contact lenses. Since the coils will be inductively coupled, changes in convergence of the eyes will lead to changes in peak voltages which will then prompt the adjustments of the contact lenses. First, simulations were run in order to understand how strongly the coils will be coupled and to understand the transient response of the system. Next, initial experimentation was performed which yielded no conclusive results due to signals being in the micro-volt range, however, methods will be used to amplify the signal. The successful completion of this project could not only improve the peoples' lives as they age, but also lead to more projects implementing similar sensing techniques for a variety of other applications.

Optimal Coding Scheme for MIMO Colored Gaussian Channels With Feedback
Sultan Daniels
Mentors: Victoria Kostina and Oron Sabag

Much work has been done on the problem of finding the channel capacity of MIMO channels with additive gaussian noise including work by Cover-Pombra, Kim and more recently Sabag who was able to discover an expression for it that is practically computable . This expression allowed Sabag to discover a coding scheme that has been proven to achieve the capacity for scalar channels. However, this proof has not yet been extended to general MIMO channels. Currently, we have two possible approaches to this problem: applying invertible transformations to a general MIMO channel that turn it into an equivalent set of parallel and independent channels, and running simulations of Sabag's scheme for general MIMO channels to gain insight into how its estimation error behaves along each of its coordinates. For the latter approach, we hope this increased insight will lead to the analysis of the scheme's probability of error.

SustainGym: Benchmarks for Measuring Reinforcement Learning Algorithms Performance on Sustainability Goals
Rajeev Datta
Mentors: Adam Wierman, Christopher Yeh, and Yisong Yue

Recent advances in deep reinforcement learning (RL) algorithms have shown the approach's efficacy over many applications. Despite the field's rapid growth, deep RL has remained relatively untested on relevant and realistic sustainability-focused tasks, stalling progress of deep RL in sustainability adjacent domains. We look to rectify the landscape of deep RL and provide a RL gym, SustainGym, containing a suite of realistic environments with a sustainability tilt. This project focuses on one of the gym's environments: battery-storage-in-grid environment. The battery-storage-in-grid environment models the dynamics of a 5 minute interval settlement electricity market and an associated electric grid which contains generators and battery storage systems. We show the environment simulates a realistic scenario and a sustainability task due to the penalization of carbon emissions in the reward function. Simulations of the environment provide researchers a sufficiently hard control task for current state-of-the-art deep RL algorithms and a wide range of possible distribution shifts for transfer learning evaluation.

DNA-guided Genome Mutations by Fusion Proteins of Cytidine Deaminase and Argonaute
Dominic Davis
Mentors: Stephen Mayo and Shan Huang

Previous studies demonstrated that prokaryotic argonaute proteins generate guide-directed double-stranded DNA breaks that induce chromosomal recombination. This motivated research to explore whether argonaute could be used to introduce additional types of genomic mutations. We first showed that the fusion protein of a cytidine deaminase, rApo1, and an argonaute protein, (d)CbAgo, functions as a global mutagen in vivo. We further demonstrated that the fusion protein can be directed by plasmid-derived DNA guides to mutate the genomic rpoB gene which leads to significantly increased survival rates under rifampicin selection. We will use exogenous DNAs as guides to minimize the off-target mutation rate. The prokaryotic argonaute-based fusion proteins can potentially be used as highly programmable active mutators that mutate specific target sequences in the E. coli genome designated by arbitrary DNA guide sequences.

Untangling the Neural Fly Code
Isabel de Luis
Mentors: Soon-Jo Chung, Matt Anderson, and Mike O'Connell

Currently, most uninhabited aerial vehicles (UAVs) use linear control, and while they have been taught to fly impressive demos such as formation flying, these flights occur under ideal conditions. Neural Fly is a deep-learning method that allows UAVs to adapt to real world wind conditions, enabling more accurate control than traditional methods. Currently, there are three prongs to Neural Fly—the hardware, the software in the loop (SITL) simulator to test the hardware virtually, and the code simulator. However, the code simulator is written in Python while the hardware and SITL simulator are operated with ROS in C++. While prototyping is done in Python due to the ease of development, the vehicle runs on C++ due to the performance benefits. Thus, the code developed for the simulator cannot interact with the SITL and hardware directly. My task for this summer is to figure out how to integrate Python and C++ so that we can use the controller for the code simulator in the SITL and hardware, removing the need to reimplement the controller developed in Python in C++ for deployment.

An Investigation Into the Scope of a Novel Iron-Catalyzed Method for the Formation of C-C sp3-sp3 Bonds via Alkyl Hydrogenation of Primary Alkenes
Carlos Del Angel Aguilar
Mentors: Gregory Fu and Robert Anderson

Cross-coupling reactions have ushered in a major leap forward in both organic synthesis and pharmaceutical development in the last 50 years. However, cross-coupling reactions typically rely on toxic, environmentally unsustainable metals. Prior work in this lab has discovered a novel cross-coupling reaction that both yields typically challenging-to-make carbon-carbon sp^3-sp^3 and uses environmentally benign iron. This project begins the work on additive and substrate scope to test the limitations of this reaction. So far, the project has revealed the reaction is sensitive both to substrate structure and is possibly intolerant of heteroatom functional groups such as ethers and amines. However, interestingly, the reaction seems highly selective to primary over secondary alkyl iodides. This and future substrate work will determine the practicality of this reaction for use in synthesis and drug development.

Dual-Tag Mass Spectrometry Elucidation of Proteome Dynamics in HEK293 Cell Lines
Roland Del Mundo
Mentors: Tsui-Fen Chou and William Rosencrans

Spatial proteomic techniques have been developed in order to identify proteins within groups of cells or within a subcellular location, however, these methods capture only static snapshots of protein states and do not directly inform on protein dynamics. Proteomes are known to traffick within different parts of cells and between different cells to mediate various signaling pathways. Mitochondrial gene and protein regulation are important in coordinating cell metabolism and important in initiating programmed cell death. The mitochondria itself produces important precursors for different physiological components of the body such as hormonal regulation and different steroid hormone precursors. Therefore, it is important to come up with new proteomic strategies to describe and elucidate these protein trafficking pathways that coordinate mitochondrial function to the rest of the cell. Using Proximity-Dependent Biotin Identification (BioID-chimera) we can biotinylate interacting and proximate proteins over a period of hours. We can also use ascorbate peroxidase (APEX) tagging technique as a genetic tag for electron microscopy. With the dual tag Mass Spectrometry (dtMS) technique, we can identify trafficked proteins both intracellularly and intercellularly using these tags to reveal the dynamics of protein trafficking history of mitochondrial translocation. This includes tracking their locations from where these proteins begin in the cell, to destinations where these proteins may translocate.

Greywater Decontamination and Recycling by Reactive Electrochemical Membrane Anode Coated in Nickel and Antimony Doped Tin Oxide
Parker Deptula
Mentors: Michael Hoffmann, Clement Cid, Leo Dobelle, Heng Dong, and Sam Zhang

Abstract withheld from publication at mentor's request.

Pushing the High-Energy Boundary of NuSTAR
Argen Detoito
Mentor: Brian Grefenstette

The Nuclear Spectroscopic Telescope Array (NuSTAR) is a NASA small explorer mission capable of focusing X-rays in the 3-79 keV energy band. NuSTAR's telescopes consist of a two-by-two array of solid-state cadmium zinc telluride detectors. These detectors can determine the depth of photon interactions to discriminate between source photons and background events. During data reduction, the depth cut identifies background events using the depth-of-interaction effect and rejects them. However, the depth cut can incorrectly filter out source photons from observational data if the source dominates over the background at high energies. We examine the depth-of-interaction effect in NuSTAR's detectors and investigate how the depth cut affects analysis in the hard X-ray band. We study the depth cut using five observations of well-documented X-ray sources. We quantitatively determine if the depth cut can be disabled for these sources by calculating observational quantum efficiency ratios and extracting power law parameters. Our results indicate extra signal-to-noise ratio can be obtained with the depth cut off for Cygnus X-1 in its soft and hard states and A0535+026, but not the Crab and MAXI J1820+070. These results establish a solid foundation for further investigation of the depth cut on a wider population of X-ray sources.

Love to Fight: Studying the Role of the "Love Hormone" Oxytocin in Mediating Aggression Neural Circuitry
Bryan Dong
Mentors: David J. Anderson and Amit Vinograd

Previous studies on the neurobiology of aggression have indicated that the hypothalamus is a key structure in the regulation of aggressive behavior [1, 2], with aggression-specific neural ensembles identified in ventrolateral ventromedial hypothalamus (VMHvl) [3, 4]. While it was shown that estrogen receptor 1-expressing (Esr1+)

neurons in VMHvl are necessary and sufficient to drive aggression [5], the mechanisms by which different neurochemicals affect Esr1+ neurons, and consecutively the formation and modulation of aggressive behaviors have yet to be fully characterized.

One prominent candidate for modulating VMHvl Esr1+ neuronal activity is the neuropeptide oxytocin (OT). OT is known to affect aggression in mammals [6, 7], and application of OT has been shown to excite VMHvl cells in female rats [8]. Furthermore, single-cell RNA sequencing of VMHvl has also indicated that Esr1+ neurons coexpress the OT receptor mRNA [9]. Interestingly, OT has been shown to enhance the plasticity of neurons in the hypothalamus [10], and enable sex recognition in the amygdala [11]. Additionally, OT is expressed differentially in paraventricular hypothalamus between male and female rats during aggression [7], as well as being released in male mice during sex [12]. Taken together, OT may have a key role in regulating the activity of aggression-associated Esr1+ neurons in VMHvl during aggressive behaviors that follow sexual experience in male mice.

My project will apply both two-photon calcium imaging and optogenetics in live brain slices of male mice to: 1. Examine the influence of OT administration on VMHvl Esr1+ neuronal activity and excitability. 2. Examine whether the effects of OT on VMHvl Esr1+ neuronal activity are through the vasopressin receptor and oxytocin receptor or through the oxytocin receptor alone. 3. Elucidate the differences in VMHvl Esr1+ neuronal activity and excitability between naïve, non-aggressive male mice and experienced, aggressive male mice. 4. Examine the effects of OT administration in experienced male mice on VMHvl neuronal activity and excitability. Should OT play a prominent role in the neuromodulation in VMHvl, I expect that lesser OT administration in experienced male mice compared to naive mice will result in VMHvl excitability, which may imply a role of OT signaling in the formation of aggression in the VMHvl substrate.

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C-quester: CO_2 Mitigation System

Luana Dos Santos
Mentors: Michael Hoffmann and Clement Cid

The United States emits over three gigatons of Carbon Dioxide(CO_2) annually, substantially contributing to global warming. The goal of the research is to be extracting CO_2 and other effluents from different point source emitters. Other techniques have used K_2CO_3 as their primary absorption product but we are aiming to use $CaCO_3$ since initial testing showed a higher absorption rate. $CaCO_3$ is a greener absorbent than other available technology, it also costs less per ton of CO_2 sequestered. The system will be utilized for industrial use where temperature, humidity and pressure will be monitored and controlled. While the final model incorporates these variables, the prototype has a humidifier and monitors flow rate. A small scale reactor design was used to determine what conditions, and absorbent product worked best for this system. The CO_2 absorption was tested with various products: $CaCO_3$, K_2CO_3, and Na_2CO_3. Data was collected by running CO_2 through a reactor filled with an absorbent product, using

Gas Chromatography and Mass Spectrometry to track absorption of CO_2. Results show a large difference in absorption between the two primary products K_2CO_3 and $CaCO_3$. The latter has a higher rate and shows promise for future application.

Ab-initio Density Functional Theory Simulations of Floquet-Engineered Kitaev Material Candidate α-$RuCl_3$
Mathias Driesse
Mentors: David Hsieh, Omar Mehio, Yuchen Han, and Ryo Noguchi

Kitaev materials, physical implementations of the Kitaev Honeycomb Model, are spin–orbit assisted Mott insulators which may provide a way to realize quantum spin liquids (QSL), valuable for their topological order, long-range entanglement properties, and anyon excitations. Recent efforts within the group have focused on realizing the QSL phase in α-$RuCl_3$ using Floquet engineering, as opposed to existing literature which relies on strong magnetic fields. Density functional theory simulations of using Quantum ESPRESSO have reproduced zig-zag antiferromagnetic order and band structure. In agreement with recent literature but in disagreements with older literature, spin-orbit coupling Mott insulation is found not to be the insulation mechanism. Bandwidth broadening was achieved by modifying the crystal structure, simulating the effects of Floquet engineering.

PTZ Induced Whole-Brain Neuronal Activity Changes of Wild-Type Zebrafish and ASD-risk Gene Mutants
Emily Echevarria Perez
Mentors: David Prober and Jin Xu

Autism spectrum disorder (ASD) is caused by both environmental and genetic factors, with the heritable contribution estimated at 60-80%. Previous genome sequencing studies identified multiple ASD-risk genes containing rare inherited mutations with unknown roles in neurodevelopment and behavior. Epilepsy is observed in 8%-26% of individuals with ASD compared to ~1% in the general population. Here we are trying to identify if the affected brain regions involved in ASD and epilepsy are correlated. We utilized zebrafish models because they are anatomically and molecularly similar to the mammalian brain, and also, they are social animals. To study ASD, we used pentylenetetrazol [PTZ; a GABA(A) receptor antagonist] to induce seizures in the wild-type and ASD zebrafish mutants. We pick mutants that show a different behavioral response to PTZ treatment. Subsequently, we mapped the neuronal activity across the whole brain, using phosphorylated extracellular-signal-regulated kinase (pERK) as a proxy for neuronal activity. With these results, we plan to make a cross-comparison of the whole-brain neuronal activity during the seizure induction between the wild-type and ASD-risk zebrafish mutants. We expect that the brain regions respond differently in ASD mutants compared to wildtype zebrafish.

Redesigning Adeno-Associated Virus Serotype 9 to Efficiently Deliver CRISPR/Cas9 Proteins
Anthony Ayoola Fadonougbo
Mentors: Viviana Gradinaru and Tim Miles

Adeno-associated virus (AAV) is a vector for systemic gene therapy applications. Prolonged expression of AAV-delivered genes that express gene editing proteins can result in off-target gene editing. To address this, I am reengineering AAV to encapsulate CRISPR/Cas9 proteins by shortening its genome to make space for protein cargo and mutating the AAV capsid interior for protein encapsulation. By packaging a protein instead of a gene, I aim to deliver a pulse of CRISPR activity and hopefully reduce the likelihood of off-target editing.

I designed and cloned 3 experimental AAV genome plasmids (base pair lengths: 2439, 1427, 841), transfected them in HEK293T cells, and produced AAV capsids with each genome. Then, I titrated each variant to determine genome yield and ran a protein gel of the capsids to determine capsid yield and purity. Titration and gel results showed that the genome and capsid yields were similar to the positive control (CAG MNG: 3285 base pair long AAV genome plasmid); these results imply a genome to capsid ratio of 1:1 and that opening space for protein cargo is possible. I made 7 mutation designs on the AAV capsid interior to create a protein binding site which will be tested experimentally.

LFP Dynamics of Recovery After Perturbation of a Premotor Circuit
Jordan Feldman
Mentors: Carlos Lois and Zsofia Torok

Understanding how behaviors and their underlying neural circuits are resilient to perturbation is crucial for treating neurodegenerative disease. Previous studies identified the Zebra Finch HVC as critical for song production. We muted about half of the inhibitory neurons in Zebra Finch HVC to test for resilience of the circuit and song. Following the perturbation, we chronically recorded neural activity with silicon probes to understand local field potential signatures of the recovering circuit. Knowing that the Zebra Finch song can largely recover without practice, we hypothesized that sleep plays a vital role in circuit restructuring. Due to the loss of inhibition, we also believed that sleep may contain abnormal seizure-like discharges. Supporting our hypothesis, we detected an increased rate of large amplitude negative deflections during sleep in manipulated birds compared to controls. The deflection rate increased with days from perturbation. Deflections in experimental but not control birds, exhibited broadband power increases and phase-amplitude coupling between high and low frequencies. The largest power increase relative to control was in the 20-40Hz gamma range consistent with increased interneuron activity. Characterizing how rate and time-frequency characteristics of deflections change over the recovery period, will provide insight into what these deflections mean for circuit resilience.

Analyzing Biological Processes of F_1-ATPase to Create Enhanced Probability Distribution Equations to Determine Chemical States
David Enzo Florendo
Mentors: Sándor Volkán-Kacsó and Rudolph A. Marcus

F_1-ATPase, the minimal component of the enzyme which produces ATP molecules, serves as a biological rotary motor, rotating unidirectionally counterclockwise in rotational steps of 40° and 80°. A nanoprobe is elastically attached to the probe to analyze the length of each dwell and transition state of the enzyme, with each species of F_1 possessing varying lengths for each of these states. At a microscopic level, there are many variables which lead to inconsistency such as angular tilt, Brownian motion, and uneven surfaces, so numerous algorithms are being developed to mitigate this, since the behavior of the enzyme should be repeatedly chemically consistent. The goal is to reduce the effect of external variables on the enzyme in order to create a more accurate representation of the chemical behavior of ATP synthase. Further research will include implementing these correctional algorithms on new sets of data which seek to further reveal the behavioral patterns of F_1-ATPase in order to understand, control, and potentially manipulate its behavior in the future.

$Li_5B_7S_{13}$ as a Solid-State Lithium-Ion Electrolyte
Dawn Ford
Mentors: Kimberly See and Kim Pham

The energy density of commercial lithium-ion batteries is limited by the flammability of liquid-based lithium-ion electrolytes. The use of a nonflammable electrolyte allows for the integration of a lithium-metal anode into the traditional battery, increasing the battery's energy density. Solid-state electrolytes (SSEs) can overcome issues associated with traditional liquid-based lithium-ion electrolytes while exceeding their ionic conductivity. Of particular interest are super- ionic conductors, which have conductivities in the range of 10^{-1} – 10^{-6} S/cm. Materials in the Li-B-S (such as $Li_5B_7S_{13}$) phase space are promising alternatives to liquid-based electrolytes due to their high ionic conductivity and degradation into other fast-ion conducting phases at the electrode/electrolyte interface. The objective of this study was to synthesize $Li_5B_7S_{13}$, characterize its ionic conductivity using electrical impedance spectroscopy, then improve the lithium-ion transport mechanism via Si substitution. Preliminary attempts to achieve this material has resulted in the synthesis of other materials in the Li-B-S phase space, specifically Li_3BS_3 and $Li_2B_2S_5$. The current work has allowed our group to understand the thermodynamics of this phase space and the conditions required to synthesize materials in the Li-B-S phase space. Future work will build upon these results to obtain the pure phase $Li_5B_7S_{13}$.

Acoustic Lens for Underwater Ultrasonic Focusing
Serafina France Tribe
Mentors: Chiara Daraio and Danial Panahandeh Shahraki

Sound travels as pressure waves by disturbing the medium they are propagating through; the elasticity and closely packed structure of solids results in a larger sound speed compared to that of a fluid. This disparity can be utilized in a partially open solid structure to create a gradient of sound speeds, focusing the pressure waves to a point. The resulting acoustic lens offers an affordable alternative for ultrasonic focusing. Computational simulations for a basic periodic structure with rectangular holes show promising results for controlling sound speed, as well as feasibility in 3D printing. Once printed, the sample will be tested in underwater conditions. The sound field output will be measured and used to find the dispersion curve in order to validate the numerical results.

Scanning Tunneling Microscopy on Strained Graphene
Holland Frieling
Mentors: Nai-Chang Yeh and Aki Park

Scanning Tunneling Microscopy (STM) is a spatially-resolved imaging technique that uses electron tunneling to characterize surface topography of semiconducting and conducting materials; if mechanical vibrations and electrical noise are sufficiently minimized, atomic resolution can be achieved with this technique. Scanning to atomic resolution on strained graphene, in which the two-dimensional material is layered over an array of nanopillars, can depict the discrete energy levels, called Landau quantization, that form with strain-induced pseudomagnetic fields. By building an STM with ultra-high vacuum capabilities, we can easily and consistently achieve atomic resolution scans to characterize the Landau quantization in strained graphene with various nanopillar patterns. While future work is required to complete the refurbishing of this UHV STM, in the meantime we can scan strained graphene at a variety of resolutions through Atomic Force Microscopy (AFM), Scanning Electron Microscopy (SEM), and STM at ambient pressure and compare the features in these images.

Incorporating Soil Biogeochemical Processes Into Vadose Zone Hydrological Models
Genevieve Gandara
Mentors: Ruby Fu and Nathan Jones

Soil organic matter is the second greatest reservoir of carbon in Earth's carbon cycle. In order to predict the future land carbon sink, it is critical to understand the longevity and storage capacity of soil organic carbon. Microbes that produce high rates of biogeochemical fluxes cluster around soil organic carbon, forming "hotspots". We develop a hotspot model dependent on aerobic and anaerobic microbial growth rates inside a soil aggregate. The microbial growth rates and formation of the anoxic zone at the center of the aggregate are a function of oxygen and carbon concentrations. We use finite element methods to simulate 1D and 2D oxygen and carbon concentration profiles. To consider soil heterogeneity, we parameterize simulations with different geometries. We also analyze different carbon sources by modeling hotspots with an internal carbon source, an external carbon source, and both sources. Furthermore, soil saturation plays a key role in determining the fate of organic carbon, as it can support substrate diffusion but limit oxygen diffusion. Subsequent work will couple the hotspot model with hydrology for consistency with experimental data and physical phenomena.

Simulation of Exoplanet Spectroscopy With Photonic Spectrographs
Abhinav Ganesh
Mentors: Dimitri Mawet and Pradip Gatkine

The main aim of this project is to use simulations to evaluate the performance of AWGs in measuring the exoplanet spectra. In other words, the main aim is to extract the spectrum from an AWG and analyze these spectra. Currently, we are using python code to extract the spectrum from data obtained from an AWG with low resolving power of 1000 and an AWG with high resolving power of 12,000. Originally, I extracted a spectrum for a 1000 resolving power spectrograph. Now I'm modifying the code to extract a spectrum for a 12,000 resolving power spectrograph. Extracting the spectrum from data obtained from an AWG is the first step to characterize the exoplanets using an astrophotonic spectrograph. For a 12,000 resolving power spectrograph, we extracted a spectrum and removed noise using regulation methods such as Tikhonov regularization and other methods. However, what remains is inconsistent shifts that require linear fitting to match the shifts.

Deep-Sea Corals as a Paleo-Redox Proxy During the Last Interglacial Period
Annabelle Gao
Mentors: François Tissot, Michael Kipp, and Haoyu Li

Understanding how oxygen levels in the ocean change across glacial-interglacial cycles over the last 200 thousand years can provide insight into how the ocean may change in the future. Uranium isotope measurements ($^{238}U/^{235}U$) from deep sea corals, when combined with inverse modeling, can be used to estimate the degree of ocean anoxia. In this project, we implement experimental physical and chemical cleaning procedures to remove external sources of uranium, particularly the FeMn-oxide coatings found on older corals. Column chromatography was utilized to isolate uranium in each sample and isotope ratios were measured via MC-ICP-MS. The inverse model used isotope ratios from a total of 8 coral samples spanning thousands of years. Preliminary results suggest that there may be a trend between the intensity of the cleaning procedure and the concentration of elements prominent in FeMn-oxide coatings, Mn and Th in particular. As such, it may be possible to forgo certain cleaning steps in favor of other steps known to be more effective in removing the coatings. Higher precision measurements to be taken in the next couple weeks will provide better evidence to support or reject this emerging trend.

Characterizing a SQUID Amplifier for Low Noise Magnetic Measurements
Jiawei (Vivian) Gao
Mentors: Thomas Rosenbaum and Daniel Silevitch

The SQUID (Superconducting Quantum Interference Device) can make very sensitive magnetic measurements. It acts as an amplifier with low noise properties. We characterize the SQUID amplifier at cryogenic temperatures by designing and building an insert to fit into the PPMS (Physical Property Measurement System). Using both the internal and external feedback loops, I measured the upper limit of the frequency response as well as the noise of the SQUID amplifier. The external feedback loop is being designed and built so that the inductance of the pick-up coil matches the SQUID inductance, and the drive coil is designed to limit the current to microAmps in a magnetic field of 0.5 Gauss. We plan to test the SQUID sensitivity on a superconducting material.

Investigating the Role of SPFp Neurons in the Integration of Sensory and Emotion Information
Karlton Gaskin
Mentors: David J. Anderson and Lindsey Salay

Innate social behaviors such as mating and aggression require the integration of sensory and arousal state information. The subparafascicular nucleus (SPFp) of the thalamus in mice may serve as an integration center given that it receives inputs from somatosensory areas and the medial preoptic area (MPOA), a region known to elicit mating behaviors. Previous research has also demonstrated that SPFp shows an increase in cells labeled by cFos after mating behaviors; however, which cell-types and what functions they serve remain unknown. We performed a cFos screen to identify genetic markers for SPFp neurons that are active during mating behaviors. We then performed fiber photometry experiments to monitor neural activity in SPFp neurons during mating and aggression. We found that glutamatergic SPFp neuron activity significantly decreased during the duration of mating. These data suggest thatSPFp neurons may represent an important node downstream of the hypothalamus for regulation of state-dependent behaviors.

Achieving the Heisenberg Limit Using Quantum Error Correction Codes With Few Ancillas
Argyris Giannisis Manes
Mentors: John Preskill and Sisi Zhou

It is well-established in Quantum Metrology that the Heisenberg Limit can be achieved using Quantum Error Correction (QEC) codes that require an ancilla with the same size as the probe system. However, implementing such a large ancilla is often unrealistic or experimentally costly. We propose an Approximate QEC Code that requires an ancilla exponentially smaller in comparison to the probe system size, and prove that it can be used to achieve the Heisenberg Limit under the most general possible condition. Future work would include constructing ancilla-free QEC codes that achieve the same result, and using similar codes to achieve the optimal Standard Quantum Limit when the conditions of our setup are not satisfied.

Developmental Self-Assembly of a DNA Trefoil Knot
Allison Glynn
Mentors: Lulu Qian and Sam Davidson

Constructing knotted topologies within DNA is relevant to both the exploration of the three-dimensional design space of DNA as a structural and computational material, and furthermore in understanding and modulating the knotted molecular topologies that exist within nature. The creation of knots using DNA has already been extensively demonstrated; indeed, previous work has successfully constructed trefoil knot from single stranded DNA by utilizing the base pairing properties of DNA. However, the implementation of this knot design required enzymatic assistance in the form of ligase and an additional denaturing step to produce the final product. Our project introduces and preliminarily demonstrates a system that leverages responsive developmental self-assembly to construct a DNA trefoil knot. We expand upon the previous design for the trefoil knot by introducing a responsive element into its construction, making assembly dependent upon the input of a DNA trigger into the system, and also by eliminating the need for the enzymatic and denaturing steps in the construction process with the implementation of a self assembly program. The introduction of responsive developmental self-assembly to this design also enables future investigations into creating a system of molecules that will output knots of varying complexity in response to unique inputs.

Optimizing WebAssembly Library Sandboxing With Single Instruction, Multiple Data Intrinsics
Jacob Goldman
Mentors: Deian Stefan, Tal Garfinkel, and Shravan Ravi Narayan

Sandboxing is a computer security practice in which untrusted code is exported to an isolated environment where its execution can be observed and analyzed for potential vulnerabilities. The WebAssembly (WASM) module provides a target for sandboxing C/C++ libraries and applications that guarantees safety and efficiency in the isolation process. RLBox, a sandboxing API for C/C++ library code, employs WASM as a sandboxing target and ensures code security in browsers such as Firefox. Single Instruction, Multiple Data (SIMD) intrinsics aim to optimize code execution by vectorizing CPU instructions to perform operations in parallel. Machine code generated by the compiler is executed concurrently to take full advantage of the CPU's resources. Evidence links SIMD implementation to execution speedup for a variety of applications. We analyze the relative speedup when implementing SIMD intrinsics to WASM sandboxing. To maintain the vectorized instructions in the library build process and application cross-compilation, we introduce a translation unit from the native SIMD intrinsics, such as SSE and AVX, to the WASM SIMD128 implementation. Resultantly, executing sandboxed application code with the SIMD128 instruction set provides considerable speedup, motivating the implementation of SIMD intrinsics to the RLBox framework.

Structural, Biochemical, and Evolutionary Relationships of Kap-α:NLS Binding Sites
Wendy Granados Razo
Mentors: André Hoelz and George Mobbs

Embedded in the nuclear envelope, protein superstructures called Nuclear Pore Complexes (NPCs) mediate the macromolecular transport in and out of the nucleus. The NPC is comprised of ~30 different proteins termed as nucleoporins (nups). NPCs create a diffusion barrier that small molecules can easily pass through while nuclear transport factors (NTF) assist macromolecular passage. NTFs, like karyopherin-α (Kap-α), recognize nuclear localization signals (NLS) and bind to proteins that display such signals. Interestingly, we see that some nucleoporins display similar sequences of Kap-α recognized NLSs. To further explore these binding interactions, we use chromatography, isothermal titration calorimetry, and x-ray crystallization to reconstitute/validate the Kap-α:nup complexes. By studying these binding events, we pave the path for better understanding the NPC and its assembly/disassembly mechanisms.

Constraint of Neutrino Flux in DUNE Near Detector Using Electron-Neutrino Scattering Events
Juan Granieri
Mentors: Ryan Patterson and Zoya Vallari

Neutrino-electron scattering events have an incredibly well-known theoretical cross-section. This gives these events the capability of constraining the neutrino flux uncertainties in the DUNE near detector. Through an analysis of these events in the DUNE near detector, one can provide a strong constraint on one of DUNE's larger uncertainties. Both a counting analysis involving selection cuts and a χ^2 fit analysis were used to investigate how well the neutrino flux was constrained.

Fluid Futures: Visual Histories of Water in the Central Valley
Reggy Granovskiy
Mentors: Brian Jacobson and Hillary Mushkin

Understanding visions of water infrastructure in California's Central Valley over time allows for a better understanding of ongoing groundwater loss and impacted communities. By assembling and examining visual archival documents related to water infrastructure in the San Joaquin Valley, I investigate the history of the thought processes that went into the region's water infrastructure, and along the way explore the relationship between these structures and vulnerable communities. A focus on visual elements can provide insight into how these projects were seen and framed over time, revealing different ways of seeing the land and comparing how those making the infrastructure see the world against how those impacted see this world. To reveal these thought processes and what visions of the world are being communicated or sold, I focus on the choices that go into photographs, drawings, diagrams and maps. I am also interested in the stories and experiences that can't be represented by these materials, especially indigenous ontologies that are absent from archives. Along the way, I ask: What emotions are these visuals meant to evoke? What is being included or obscured? What larger picture is being painted? What vision of the future is created? Through these questions, I trace how these overlapping and conflicting visuals interact to create the current imaginary of the Central Valley's water: one focused on progress towards control and optimization at the expense of mutualistic relationships with land and `water such as those prioritized by indigenous ways of knowing.

Simulated Models of Bursty Human Behavior Analyzed With Underused Statistical Tests
Henry Graven
Mentors: Colin Camerer and Sean Hu

Burstiness is a phenomenon observed in many physical systems like earthquakes and solar flares but has more recently been noticed in various human behaviors. It is characterized by inter-event times which fail to be modeled by common Poissonian distributions. Instead, bursty behaviors are modeled via a power law distribution. We seek to uncover a behavioral/psychological paradigm which can explain and eventually provide predictive power for these bursty behaviors using various ideologies from behavioral economics. From this model, we then hypothesize how its parameters will map onto individual or group characteristics to allow for prediction in the future. In this analysis we uncovered and adapted previously used statistical tools to understand and compare the degrees of burstiness in our real-world datasets as well as our simulated model. The range of slopes which our simulation reaches almost exactly cover the range of slopes that real world data creates. We also have intuitively strong backing to the connection between groups of our parameters and differences across behaviors.

Cheap and Accessible Dynamic Appendage Module for Robotic Manipulation and Increased Control Authority
Brad Greer
Mentors: Aaron Ames and Min Dai

Developments in the study of control of legged robots have frequently been in the direction of increasingly dynamic movements. However, many robotic platforms only have their legs with which to influence themselves, leaving them significantly underactuated. Common hardware-oriented solutions to this problem have been reaction wheels and other low degree of freedom (DoF) systems which are simple and easy to implement, but highly limited. Humanoid appendages are also commonly used and tend to be less dynamic and more complicated, but also allow for more versatile behaviors such as object manipulation and force-controlled environmental interaction. Between these two extremes, there is room to explore the use of a system with an intermediary number of DoFs. This paper has two objectives. One is to outline the model-based design methodology and performance of a scalable, cheap, mechanically robust, and easily manufactured robotic appendage design with a flexible driving apparatus that makes it easy to implement on robotic systems. The second objective is to detail the use of this design methodology in the development of a functioning apparatus for the bipedal walking robot Cassie. This appendage is not meant to have the same size and geometry between implementations. The model-based design approach allows for the system to be parameterized and customized for a particular robotic platform. The Cassie implementation showcases this by featuring a appendage that is proportional to the robot itself with unique geometry that simplifies the control of the tail and decreases risk of self-collision. The inertial properties of the appendage are also tuned to be effective on Cassie. The per-link cost comes out to less than $10 and can be manufactured entirely with the use of only an abrasive water jet. The moderate complexity of the appendage also opens it up to basic manipulation techniques and the Quasi-Direct Drive (QDD) nature of the roll axis actuator on the Cassie implementation allows for limited force control applications. The accessibility and robustness of this system makes it attractive for adoption into other robotics research efforts.

Looking for X-Ray Outbursts From Black Holes and Neutron Stars With NuSTAR Telescope
Tanmay Grover
Mentor: Murray Brightman

The NuSTAR (Nuclear Spectroscopic Telescope Array) telescope has a range of 3-79 keV and is used to analyze many types of X-ray sources such as black holes and Neutron stars. With several observations in the NuSTAR catalog, there are many which haven't been analyzed and may contain some sources for which we have no prior knowledge. Using deep learning techniques such as Artificial Neural Networks (ANNs), we developed a new method to look for new X-ray sources. Using this method, we look through observations available for new unidentified X-ray sources. Upon discovery of a new potential source, we cross-reference the source with existing catalogs, use standard NuSTAR analysis techniques like pipeline, extract the light curve, and perform the necessary spectral analysis to determine its nature.

Spectral Modeling of X-ray Reflection From a Galactic Center Molecular Cloud
Yash Gursahani
Mentors: Javier García, Riley Connors, and Guglielmo Mastroserio

The Galactic Center is a region of many diffuse X-ray reflection nebulae. Here, we study reflection from Galactic Center molecular clouds (GCMCs) in the Bridge region ~18 pc in projected distance from Sgr A*, a supermassive black hole of mass approximately 4×10^6 $M_\odot$. The source of the reflected emission is hypothesized to be a Sgr A* flare on the order of 100 years ago with luminosity ~10^{38} erg s^{-1}. Various models fit to the spectra from GCMCs each reveal unique characteristics of the reflecting medium. We use 5 observations of the Bridge from the Nuclear Spectroscopic Telescope Array (*NuSTAR*) with exposure time totaling ~323 kiloseconds in the 3-79 keV bandpass. Models used to fit spectral features assume toroidal, plane-parallel, or other geometries for clouds which differ from their true configuration. However, by fixing sensible values for parameters outside our interest, we obtain a range of photon indices, hydrogen column density values, ionization states, and other constraints characterizing the Bridge. Using these values in future modeling efforts may in turn assist with refining aspects of the black hole flare theory, such as the required luminosity and time elapsed since the increased activity.

Traffic Congestion Control in a Grid Network of Intersections With Poisson Arrivals
Johanna Gustafson
Mentors: Soon-Jo Chung and SooJean Han

This project investigates the effectiveness of pattern-learning and prediction within a grid network of four-way intersections with Poisson arrivals. Here, patterns refer to intersection snapshots in the distribution of traffic, e.g., the number of vehicles in each lane. For a single intersection, it is found that vehicle traffic congestion is considerably improved when using adaptive traffic lights with camera sensors that recognize previously occurred patterns, as opposed to periodic traffic lights. We also investigate the trade-off between congestion improvement versus the costs of installing sensor hardware and consider the implications when extended to a network of multiple intersections, where it may be necessary to limit the number of sensors and use estimation methods for the unobservable intersections.

Hardware-in-the-Loop Simulation of the POMCPMF Fault Detection Algorithm
Tom Hagander
Mentors: Soon-Jo Chung and Jimmy Ragan

To increase the robustness of autonomous spacecraft in time-critical settings, the POMCPMF fault detection algorithm has been proposed. This algorithm finds any combination of sensor- and actuator-failures on a spacecraft by sending a set of control commands, or actions, and evalu- ating the observations sent back to determine the failure. A Monte Carlo Tree Search to find actions that look promising, and the observations sent back are used to update the belief on the failure. This algorithm has been shown to work in non-real-time simulation, in the sense that the belief on the failure converges to the correct failure. The next step in validating the robustness and performance of this algorithm is implementing it in a real-time Hardware-in-the-Loop simulator. The main goal of this project has therefore been to build a Hardware-in-the-Loop simulator for space- craft, as well as implementing the algorithm as a controller. Doing this brings the fault detection algorithm one step closer to being implemented in a real autonomous spacecraft. Another aspect of this project has been to improve the time the Tree Search needs to find a promising action by using heuristics and prior knowledge of the system's dynamics and the nature of the possible failures.

Generation of Optical Barcodes for Use in Multiplexed Cellular Imaging Assays
Jadon Hale
Mentor: Morgan Schwartz

Live cell microscopy is an essential screening modality for observing dynamic phenotypic changes in cells. Pooled screens can be used to increase the throughput of live cell microscopy, but they introduce a challenge of associating each cell with the perturbation it received. Optical barcoding is a method of encoding a unique identifier associated with each perturbation that can be optically visualized. Optical barcodes allow us to identify each perturbation in the pool by imaging the optical barcode present in the cell. In order to create spatial barcodes, our lab has used CRISPR-Display to target repetitive sequences in the genome and create distinct speckle patterns in the nucleus. The use of CRISPR display allows for a vast number of possible barcodes, and significantly increases the extent of barcoded multiplexing available. Because some gRNAs are difficult to synthesize, we are testing better ways of performing this synthesis, including one-click DNA-ligation and ultramer cloning. Additionally, we are investigating methods of signal amplification such as RollFISH to enable lower magnification imaging for increased throughput.

Is Genetic Differentiation of Symbiotic Beetles Tied to Their Host Ant?
Robert Hall
Mentors: Joseph Parker and Sheila Kitchen

Rove beetles comprise Metazoa's largest family: 64,000 mostly solitary, predatory species. From this ancestral state, many lineages have convergently evolved into social symbionts of ants. One symbiotic beetle, *Sceptobius lativentris,* integrates with their host ant, *Liometopum occidentale*, by procuring ant pheromones during intense grooming. Here we asked how do host-symbiont interactions impact each species' genetics and gene flow? Since *S. lativentris* are obligate symbionts and flightless, we predicted their dispersal range was limited to the ant foraging trails, reducing gene flow and increasing inbreeding. Resequencing genomes of both species*,* we identified single nucleotide polymorphisms in 126 *S*. *lativentris* and 47 *L*. *occidentale* from 16 nests covering Southern California. Preliminary results revealed distinct populations of symbionts and ants as well as loci under selection suggesting local adaptation. Moreover, the beetles exhibit high gene flow despite being wingless. This study highlights the region's demographic mosaicism and will help illuminate this host-symbiont evolution.

Linear MMSE Coding of a Markov Source Over White Gaussian Vector Channels
Barron Han
Mentors: Victoria Kostina, Nian Guo, and Oron Sabag

We study instantaneous causal coding over the additive white Gaussian noise (AWGN) channel and propose a novel innovation encoder used to transmit a Gauss-Markov source given perfect feedback at every time. The encoder transmits the innovations of the estimate at every time, scaled to satisfy an average power constraint. Using a Kalman filter-inspired method, the code generates the optimal linear minimum mean square error (MSE) estimate at each time. We derive source and channel conditions for the MSE to be bounded and find optimal bounds for the MSE. The second part of the paper studies a vector generalization of the code which operates on a source and channel with arbitrary dimensions. Applications of this work in anytime coding are also investigated. An achievability bound is derived which demonstrates that the code perform at least as good as the state-of-the-art methods.

Flatness Based Kinodynamic Trajectory Generation of Aerial Manipulators
Peder Hårderup
Mentors: Joel Burdick and Skylar X. Wei

This paper shows that a general class of aerial manipulators, consisting of a planar multirotor base with an arbitrary k-linked fully actuated manipulator, is differentially flat. Flatness theory enables a kinodynamic trajectory generation in the systems flat outputs: the overall center-of-mass position, rotorbase yaw and relative joint angles. Given end effector pose waypoints and state constraints, a unit-time kinematically feasible path is first determined which translates the system between two equilibrium states. Using time dilation, a trajectory with viable velocities, accelerations and torques is then determined. Finally, by employing nonlinear programming with above trajectory as initial guess, the motion planning is optimized offline with respect to certain mission-based objectives such as minimizing torques, energy and/or rotorbase movement. The optimized trajectory is demonstrated experimentally on a custom aerial manipulator with a hexacopter base carrying a 4-DOF manipulator with a camera as its end effector.

Exploring Mechanisms of Brain Asymmetry and Neuronal Connectivity
Arsalan Hashmi
Mentors: Carlos Lois, Aubrie De La Cruz, and Ting-Hao Huang

The asymmetrical body (AB) in the *Drosophila melanogaster* brain contradicts the convention that both sides of the brain are symmetrical. The AB is a neuropil (a dense network of axons and synapses) that is located on the left side of the brain and roughly fourth the size of the adjacent right neuropil. This study investigates the possible causes of the asymmetry and explores the mechanism of neural communication in this asymmetrical neural circuit. This includes studying the asymmetrical morphology of the major AB input neurons. In addition, an image analysis system was developed to accurately calculate the volume of the AB based on fluorescence of GFP. Future studies will explore the behavioral implications of the asymmetry using a *Drosophila* courtship behavior assay. We strive to enhance the understanding of the brain using *Drosophila* as a model organism to study neuronal networks, specifically, how the coordinated activity of connected neurons in circuits gives rise to brain function.

MinCE: Fast Quantification of Large Metagenomic Datasets Along With Species and Strain Abundance
Thorhallur Audur Helgason
Mentor: Lior Pachter

Dramatic cost reductions in genome sequencing coupled with improvements in accuracy during the past two decades have facilitated broad sequencing efforts to catalog all genomes of living organisms. In particular, large public databases now house hundreds of thousands of bacterial genomes, most of which have been obtained through sequencing of cultured bacteria. However many bacteria are difficult to isolate and/or culture. To study them, "metagenome" sequencing approaches have been developed that rely on sequencing of short fragments from environmental samples to identify microbes in their natural habitat. The associated computational problems are manifold and complex, starting with the need for algorithms to align hundreds of millions, or even billions of DNA fragments to large existing databases.

We introduce MinCE, a method for quickly identifying bacterial species and strains in metagenomic samples. MinCE preprocesses a reference genome database to facilitate rapid lookups. Subsequently, the relevant genomes serving as the source for a collection of DNA fragments can be identified. At present, MinCE can be used to identify genomes from a 13.5Gb reference database containing 258,339 genomes of Eubacteria and Archaea. We present results on simulated data that suggest that MinCE has high sensitivity and specificity, making it suitable for metagenomics analyses.

A Holistic Look at Exoplanet Phase Curves
Jillian Henkel
Mentor: Jessie Christiansen

The influx in the volume of available exoplanet data in the past few years provides the opportunity to study exoplanets as populations. By analyzing secondary eclipse data in conjunction with phase curves from a given exoplanet, it is possible to determine the planet's day-night temperature contrast. As a large temperature contrast corresponds to an absence of atmosphere, this parameter, along with various markers found in phase curves, allows us to detect whether a planet has an atmosphere. Using these methods, we reproduced data analysis of exoplanet CoRoT-2b, and are analyzing unpublished data of hot rocky exoplanet TOI-141. By determining whether these planets have an atmosphere, we will facilitate the further study of exoplanets by allowing researchers to draw correlations between exoplanet type and the presence of an atmosphere. Such understanding of exoplanets as populations will expedite the search for Earth-like planets.

War of the Words: An Exploration of the Literary Battlefield During the Age of Discovery
Erica Hightower
Mentor: Nicolas Wey-Gomez

This project examines the role of literature in politics and public opinion during the Age of Discovery (1492-1600) as it relates to early American attitudes and ideologies. The materials for this project include the documents associated with the voyages of Columbus beginning in 1492 and the subsequent histories written by European authors. I employ a close-reading literary analysis that includes Aristotelian *Poetics* and *Rhetoric*, and I compare this information with the policies of their day. My findings reveal how dominate national narratives serve imperial goals, and I conclude by providing an updated version of the story of Columbus that exposes previously redacted information. Future considerations include analyzing previously under-studied and untranslated texts. The results of this research project challenge the progressive assumption that we live in a "modern" world, and I hope that it serves as a reminder that words are humanity's foundational technology—and our most dangerous weapon.

Towards Structural Characterization of *Mycobacterium tuberculosis* MraY in Complex With Novel Inhibitors
Manuel Holguin
Mentors: William M. Clemons, Jr., and Jessica Ochoa

Growing antibiotic resistance poses a significant threat to human health, thus alternative treatments must continue to be developed. Peptidoglycan, which comprises the bacterial cell wall, is an essential polysaccharide produced by all bacteria. The membrane-bound MraY enzyme plays a crucial role in the biosynthesis of peptidoglycan and has been a target for developing novel antibiotics. Recently, a capuramycin phenoxypiperidinylbenzylamide analogue (CPPB) has been shown to inhibit MraY and impede the growth of dormant *M.tuberculosis*. In order to understand the mechanism by which these compounds inhibit MraY, our lab is interested in pursuing structural studies of MraY in complex with this CPPB inhibitor. Understanding its mechanism of inhibition will guide future drug development to improve efficacy or broaden target treatments. We have begun work to structurally characterize MraY from *Mycobacterium tuberculosis* (MtMraY). Thus far, we have optimized expression and purification conditions to overexpress recombinant MtMraY in *E. coli*. We have used immobilized nickel affinity columns and size exclusion chromatography to purify MtMraY. We have also begun optimizing freezing conditions and collecting data of purified MtMraY for single particle cryo-electron microscopy. Next, we will incubate the inhibitor with purified protein to determine the structure of the MtMraY complex with novel inhibitors.

A New Way to Model the Pre-Supernova Evolution of 8-11 $M_\odot$ Stars
Beryl Hovis-Afflerbach
Mentors: Jim Fuller and Shing Chi Leung

While <8 $M_\odot$ stars are known to end their lives as white dwarfs and >11 $M_\odot$ stars undergo supernovae and become neutron stars or black holes, the fates of 8-11 $M_\odot$ stars are less well understood. Stellar models could help, but the later evolutionary stages of these stars take a prohibitively long time to model, on the order of months or even years. This is in part because these stars ignite oxygen/neon and silicon on the edge of the core, rather than in the center. A convective flame then propagates inwards, requiring very high resolution to model accurately. We create a miniature model using the stellar evolution code MESA, with conditions that match the degenerate core, and determine the flame speed as a function of temperature and density. These results will allow us to model the final stages of evolution and determine how 8-11 $M_\odot$ stars end their lives.

Radio-Frequency Modulation of Optical Metasurfaces
Ian Huang
Mentors: Harry Atwater and Prachi Thureja

We demonstrate radio-frequency modulation of space-time modulated optical metasurfaces for dynamic control of reflected light, including switchable diffraction and the generation and steering of frequency sidebands. Metasurfaces—antenna arrays with subwavelength spacing—are used to control various properties of electromagnetic radiation such as its amplitude, phase, polarization, and momentum. Previous work involved a 2-electrode metasurface that was limited to modulation frequencies up to 1 MHz. This project focuses on pushing that modulation to higher frequencies by overhauling and optimizing the electronic circuit. We use our findings to design the control circuit for a new 32-electrode metasurface. In accomplishing this, a total of four printable circuit boards of varying complexity were designed. In particular, we implemented an 8-to-32 analog multiplexer to feed each of the 32 electrodes by one of eight signals from a waveform generator. Experimental results demonstrate updated frequency limits and the capabilities of 32-electrode modulation.

Measurements and Simulations of Light-Activated Matter
Catherine Ji
Mentors: Rob Phillips, Ana Duarte, and Heun Jin Lee

Non-equilibrium active matter consumes energy to form self-organizing structures. For example, microtubules and motors assemble to form polar and nematic structures that facilitate cell division. Here, we investigate properties of varying aster geometries such as energy consumption and shape fidelity during contraction. We run experiments, agent-based simulations, and field-based simulations of an in-vitro, light-activated system of microtubules and kinesin motors. Moving forward with the project, we continue taking data and refining our simulation to match the scales of our experiment. We aim to construct an order parameter describing geometry preservation of asters and combine experimental and simulation results. We also aim to compare experimental ATP consumption with a reaction-diffusion model.

Developing an absolute quantitative sequencing framework for fungi
Jenny Ji
Mentors: Rustem Ismagilov, Reid Akana

Fungi are instrumental players in the functioning of many ecosystems and biological systems, yet tools for quantitative analysis of fungal community composition are lacking. To address this need, we developed a quantitative-sequencing (Quant-Seq) method for fungi. Fungal Quant-Seq leverages the Quant-Seq method the Ismagilov Lab previously developed for absolute quantification of bacteria and archaea by combining highly sensitivity digital-droplet PCR with next-generation sequencing. To extend the Quant-Seq method to fungi, we explored numerous potential genes and identified the ubiquitous single-copy *TEF* gene as the most promising. However, primers for the *TEF* gene also bind to the human genome, limiting the utility of quantitative sequencing in samples with large amounts of human DNA. To mitigate this problem, we used restriction enzymes to selectively cleave sections of the human genome capable of producing amplicons. By performing an initial restriction digestion with HpaI, amplification of human DNA was reduced to nearly zero whereas efficiency of fungal amplification was only reduced by a factor of two. Fungal Quant-Seq will next be validated on a range of complex sample types, including clinical samples to survey fungal communities associated with disease.

A Matter of Reflection: Studying the Inner Accretion Flows of Black Hole x-ray Binaries
Qunfeng Jiang
Mentors: Javier Garcia and Riley Conners

A black hole binary (BHB) consists of a black hole and a companion star. X-ray reflection spectroscopy (XRS) is a useful tool to study the properties of accreting black hole binaries and their inner gaseous flows. H 1743-322 is a stellar-mass black hole and shows regular outbursts in the X-ray band with an average interval of nearly 200 days. In this paper, we use Rossi X-Ray Timing Explorer (RXTE) observations from 2003 to 2011 and Nuclear Spectroscopic Telescope Array (NuSTAR) observations in 2016 to conduct a phenomenological spectral analysis and then full reflection spectroscopic modeling of the source, to measure the key quantities of the inner accretion flow and black hole including spin, inclination angle, inner disk radius, and iron abundance. We first plot the evolution of the physical parameters of the source during its outburst between 2003 and 2011. We then use the relxill and relxilllp model to analyze its spectra in the hard state, and constrain a relatively low inclination angle of ~20°, contradicting the results in previous studies. We also find the spin cannot be constrained well in these observations.

Examination of Cluster Membership and Optical Variability of the Young Stellar Population in Mon R2
Sally Jiang
Mentor: Lynne Hillenbrand

Monoceros R2 (Mon R2) is one of the closest large active star-forming regions and provides an excellent laboratory for exploring star formation and early-stage stellar evolution of young stellar objects (YSO). One defining property of YSOs is their spectroscopic and photometric variability, caused by the object's environment and erratic properties. Our objective is to isolate the likely cluster member stars from the foreground and background stars using astrometric and kinematic values then examine and classify the optical photometry of these member stars. We used a list of candidate stars for Mon R2 from the YSOC catalog and estimated the proper motions: RA:-3.08 ±0.86 mas/yr and Dec:0.71±1.08 mas/yr and distance of $909.091^{+267.379}_{-168.35}$ parsecs. We then calculated statistical and variability metrics of the photometric light curves from the Zwicky Transient Facility to explore the variability of Mon R2 YSOs.

Investigating the Parallel Molecular Mechanisms Governing T-cell and ILC Development
Jolie Jones
Mentors: Ellen Rothenberg and Tyson Lager

T-cells and Innate Lymphoid Cells (ILCs) possess a significant similarity in function despite going through different pathways of specialization. T-cells develop in the thymus and express specific T-cell receptors that recognize different antigens introduced in the body. Comparatively, ILCs are not developed in the thymus and lack specific receptors which implies that these cells will be equally responsive to an introduced antigen. Due to their similarity in function and specific factors, we hypothesized that we could reprogram the identity of a T-cell to an ILC by expressing ILC lineage specific transcription factors in T-cells and vice versa using retroviral infection. This will help us further understand the molecular mechanisms and gene regulatory networks in relation to both cell types. We will analyze the changes in gene expression to observe the progress in cell reprogramming and whether the transcription factors can modulate the gene regulatory network governing both cells' identities.

Analysis of NPC Interactions With Mobile Transport Machinery
Jack Jurmu
Mentors: André Hoelz and George Mobbs

Sequestration of DNA in the nucleus represents one of the great hallmarks of eukaryotic evolution but creates the necessity for selective bidirectional transport across the nuclear envelope. This function is achieved by the Nuclear Pore Complex (NPC), a protein super-complex embedded in the nuclear envelope. The near-atomic structure of human and yeast NPCs have recently been resolved. However, the precise mechanism and machinery of NPC assembly remain unclear. Nucleocytoplasmic transport factors, also known as karyopherins, have been shown to bind to the nucleoporin proteins that constitute the NPC, functioning as chaperones during NPC assembly. We characterized interactions between nucleoporins and their karyopherin chaperones through fast-protein-liquid-chromatography, x-ray crystallography, and affinity-measuring biochemical assays. Moreover, we extended our analysis to demonstrate evolutionary conservation of karyopherin-nucleoporin binding interactions by solving crystal structures of complexes from different species.

Using a Beta-Binomial Bayesian Model to Analyze the Impact of Stereotype Threats on Penalty Shot Performance
Shevali Kadakia
Mentors: Nils Rudi, Yetsa A. Tuakli-Wosornu, and Tapio Schneider
Stereotype Threat is defined as a "socially premised psychological threat that arises when one is in a situation or doing something for which a negative stereotype about one's group applies." Its affect in sports has been studied, but minimal research on its impact on soccer players' performances during penalty shots has been conducted. Thus, we created a multi-leveled hyper parameter Beta-Binomial Bayesian Model using CausalNex to analyze the effects of race, salary, and player experience on player performance during a penalty shootout. Data about players and goalies on national teams were web scraped from Transfermarkt using the BeautifulSoup Python package. Future goals include integrating the DoWhy package for a more in-depth analysis of these causal relationships.

Modeling Habit Formation Using Novel "Neural Autopilot" Model
Ishan Kalburge
Mentor: Colin Camerer

In classical economics literature, habit formation denotes an increase in present utility with past consumption of a good. However, such theories do not capture definitions of habit in cognitive neuroscience. In reinforcement learning literature, behavior is separated into goal-directed and habitual modes. A goal-directed actor makes decisions by using all available information to create a model of their environment, whereas habitual actors exhibit automatic behavior derived from reward processing. Studies have shown that arbitration between these two modes is mediated by reward prediction error (RPE) – the difference between (objective) realized utility and (subjective) predicted reward of an action – and the reliability of rewards. Thus, this study uses a novel behavioral algorithm that uses RPE to update a doubt stock function that stores the reliability of rewards for each consumption choice. We simulate habit formation using both a hard and a stochastic doubt stock threshold and examine the plausibility of such models in simulation. Moreover, we aim to incorporate theories from bursty human dynamics to better understand stochasticity in consumer choice, both in simulation and in field data.

Stochastic Linear Bandits Under Safety Constraints
Nithin Varma Kanumuri
Mentors: Anima Anandkumar and Sahin Lale

Many real-world problems require the agent to make sequential decisions under uncertainty to optimize the total payoff while satisfying safety constraints. Therefore, the decision-making algorithms must provide safety guarantees while performing well. In this work, we study stochastic linear bandits under unknown safety constraints. In this framework, the agent gets noisy observations of the reward and the safety information for the action it takes at each time step. The expected reward and the expected safety information are modelled as unknown linear and nonlinear functions of the action, respectively. Based on the information gathered over time, the agent aims to choose the actions that achieve the highest reward while prohibiting safety violations with high probability. We design a novel reinforcement learning algorithm for this setting and provide theoretical guarantees. In particular, we show that our algorithm attains sublinear regret with respect to the agent that has access to the unknown reward and safety function. We empirically study our algorithm in various scenarios and verify our theoretical findings. Our study provides insights for future research in more complicated decision-making scenarios, e.g., safe adaptive control or RL, where the reward and safety depend on an evolving dynamical system.

Development and Characterization of Solid State Electrolytes Using $ZnPS_3$
Ubaid Kazianga
Mentors: Kim See and Shaoyang Lin

Inorganic solid-state electrolytes are of interest for usage in the reduction of CO_2 to fuel and chemical stock due to increased durability and potential product selectivity. The proton conductivity of $ZnPS_3$ shows promise as a potential solid-state electrolyte, but despite the advantage in ionic conductivity, the mechanical properties of inorganic electrolytes like $ZnPS_3$ are less favorable when compared to already existing polymer organic electrolytes like Nafion. By creating composite electrolytes of polymers and inorganics, it is possible to maintain high levels of ionic conductivity without sacrificing mechanical durability. In this project, we tested $ZnPS_3$-based electrolytes for CO_2 reduction and prepared and characterized $ZnPS_3$-Nafion composite solid electrolytes. We observed the importance of proper cell design and developed a cell design to optimize the performance of solid-state electrolytes and the impact of the polymer composite membrane preparation on electrolysis.

Optical Fiber-Waveguide Coupling at Cryogenic Temperatures for Quantum Transduction Applications
Abhishek Kejriwal
Mentor: Mohammad Mirhosseini

High fidelity and low-noise quantum transduction between microwave and optical photons would allow connecting remote superconducting quantum processors, acting as a stepping stone towards a global quantum internet. SOI-based electro-optomechanical devices are the primary candidates for microwave-optical quantum transduction. A task of fundamental importance in achieving reliable transduction is coupling the electro-optomechanical device to an optical fiber through an intermediate optical waveguide. Of the various coupling schemes, the adiabatic coupling scheme poses as the most efficient. However, optimal fiber-waveguide alignment in dilution refrigerators is challenging. We propose and perform detailed FEM simulations for a passive alignment approach and obtain optimistic coupling efficiencies. We also develop FEM simulation techniques for an end-fire coupling scheme and observe high efficiencies. Based on phenomenological phonon occupancy models discussed in the literature, we model the efficiency and number of added noise photons for our electro-optomechanical transducer and observe high efficiencies and low noise for a continuous-wave scheme. We realize these SOI devices by implementing nanofabrication techniques. Future tasks include an experimental demonstration of the passive alignment technique in a dilution refrigerator and designing nanofabrication CADs for superconducting qubit-optical photon transducer devices.

A More Precise Method for Measuring Isotopic Ratios With Laser Ablation
Anna Kitagawa
Mentors: Claire Bucholz and Juliet Ryan-Davis

Isotopic ratios are often necessary in geology for researchers to understand their samples and the source materials which contributed to the magmas. Strontium isotopes in particular are used to trace source materials with potentially different isotopic ratios. Although several methods currently exist to measure isotopic ratios in a sample, the method of laser ablation which is currently under development would make for a more efficient process. In order to create this new method, however, samples must be prepared for use in the laser through several processes. To prepare the samples, I used previously crushed rocks from various locations across the Sierra Nevada and picked clinopyroxene crystals out of them so that we could measure the $^{87}Sr/^{86}Sr$ ratios within that particular mineral. Then, I mounted the clinopyroxene crystals so that the samples could be analyzed both by scanning electron microscope and laser. I will measure Sr isotopes using a femtosecond laser coupled to the Neptune multi collector mass spectrometer (MC-ICPMS) in the Tissot Lab. These results will hopefully show which sources contributed to the ancient volcanic arc that existed during the creation of the Sierra Nevada.

Developing the Substrate Scope of Biocatalytic One-Carbon Ring Expansion of Azetidines to Pyrrolidines
Catherine Ko
Mentors: Frances Arnold, Ravi Lal

The pyrrolidine backbone is highly sought after for its stereogenicity, which lends itself to escaping the current landscape of flat aromatic drugs and exploring the three-dimensional pharmacophore space. The versatile pyrrolidine scaffold can also be substituted to create proline derivatives. Substitutions at each of the chiral centers allow for finetuning of biological properties. Proline derivatives can also be used as non-canonical amino acids in peptide synthesis. The chiral centers introduced by substitutions on the ring pose a challenge for selectively synthesizing certain enantiomers in excess. The globular dimensionality of pyrrolidines is difficult to control with small molecule catalysts. Enzymes are a promising solution to complement traditional synthetic catalysts, as they are known to display heightened activities and selectivities. The Arnold lab has evolved an enzyme variant, ApPgb C10.3, to perform a one-carbon ring expansion of azetidines to pyrrolidines enantioselectively. Here, I am describing my efforts toward the synthesis of a diverse substrate scope and authentic standards to probe the promiscuity of this enzyme's activity. My goal is to shed light on the mechanism of the biocatalytic ring expansion as well as assess the generality and substrate limits of the laboratory-evolved protoglobin.

The Study of Geometric and Material Imperfections of Gas Vesicles and Their Effects on Buckling Pressure
Rohan Kolhe
Mentors: Mikhail Shapiro and (Amir) Hossein Salahshoor

Gas vesicles are air-filled hollow nano compartments that have been proven to be ideal contrast agents for biomedical ultrasound applications, due to their mechanical deformation under ultrasound pressure. Material and geometric imperfections significantly influence mechanical instabilities such as buckling. To understand the effects of these imperfections on buckling, we recourse to finite element simulations of gas vesicles. Through these simulations, we were able to understand which material properties were more significant and how specific geometric properties of the gas vesicles such as their corrugated shells or small dents in the shells affected the buckling pressure. We have shown that circumferential stiffness is the dominating factor among different material properties. Moreover, we demonstrated that corrugations within the GV, accompanied by different thicknesses at different points within the shells, lead to lower buckling pressures. Understanding these properties will help engineer imaging agents for ultrasound applications.

Human Impacts on Coastal Eutrophication
Ethan Kondev
Mentor: Rob Phillips

Eutrophication (the over-enrichment of aquatic ecosystems with nutrients leading to excess algal growth followed by anoxic events) is one of the greatest threats to the health of marine ecosystems worldwide. Over the course of the 20th century, anthropogenic inputs of limiting nutrients, namely nitrogen and phosphorus, have become the biggest driver of eutrophication. While eutrophication is now primarily a human problem, many papers written on this phenomenon fail to explain the extent of our role in it intuitively. In the context of *the Human Impacts By The Numbers* project, we've taken the approach of using simple, comprehensible numbers, and order of magnitude (OEM) estimates to more effectively answer this question. This approach requires an exhaustive literature review, sifting through relevant numbers, and producing OEM estimates, time series graphs, and other relevant figures for describing the topic without any charged language. This work is then organized and presented in the form of a vignette. The specific question we were concerned with was, *how much does anthropogenic nutrient loading to coastal watersheds influence eutrophication?* Further research concerning humans' impact on eutrophication should focus on developing our understanding of how anthropogenic nutrient loading interacts with other ecosystem pressures contributing to eutrophication.

Development of Non-Intrusive Microwave Radar Measurements of Shock Speed for the Hypervelocity Expansion Tube at Caltech
Levente Kovacs
Mentors: Joanna Austin and Ying Luo

Expansion tubes play an important role in recreating hypervelocity flight conditions on the ground for re-entry and flight testing of hypersonic vehicles. Knowing initial pressures and gas compositions is not always enough for determining test conditions due to losses from imperfect diaphragm burst and viscous effects. To compensate for this, accurate measurement of the secondary shock velocity is necessary. The present report outlines the implementation of a microwave interferometry technique for the Hypervelocity Expansion Tube (HET) at Caltech. The method allows measurement of the evolution of shock speed along the whole length of the expansion section with better accuracy than traditional time of arrival measurements. Practical considerations and design factors such as operating frequency and power selection and their influence on accuracy and resolution of the measurement, expected attenuation, expected quality of reflection, antenna design, and design of a low-cost detector system are explored in detail to aid the implementation of the technique in other facilities.

Developing Assignments for CS 01: "Intro to Computer Science"
Eli Kugelsky
Mentors: Adam Blank and El Hovik

CS 01, Introduction to Computer Science, is one of the most important courses a student can take. Computer science is becoming increasingly important in this world. As we move towards an even more technologically advanced world, we must incorporate these advancements into our teachings. Like a course in English, it is equally vital for students to take a course in computer science. Introductory computer science courses are often, however, limited to skills courses not designed for building computational and programming knowledge for problem solving in other disciplines. The current CS 01 course is taught with an aim towards students who are pursuing a computer science degree, however that leaves out all the other students who take the course to utilize computer science in other fields of study. The research is an ongoing study into Computing as Literacy and the proper application of this concept into a course. Computing as Literacy curricula will engage all students at their respective institutions with the conceptual and practical tools needed to use computing-for-problem-solving across all fields: the natural sciences, social sciences, humanities, the arts, as well as computing's traditional targets.

Bounds on Expected Cluster Size for Long-Range Percolation on the Hierarchical Lattice
Jana Kurrek
Mentors: Tom Hutchcroft and Philip Easo

We study long-range percolation on the d-dimensional hierarchical lattice $\mathbf{H}_L^d$ with side length L. This model is defined as the random graph with vertex set $\mathbf{H}_L^d$ and edge inclusion probabilities equal to $1 - \exp(-\beta\|x-y\|^{-(d+\alpha)})$. Percolation is typically studied on the d-dimensional Euclidean lattice, but it is particularly interesting to consider the hierarchical case because of the symmetry and recursion that this object exhibits. We focus specifically on estimating $\chi(\beta)$, which represents the expected size of the cluster of the origin. It has been proven that $\beta_c < \infty$ if and only if $\alpha < d$, so the case where $\alpha = d$ raises questions about the growth rate of $\chi(\beta)$. We adapt the methods from Hutchcroft (2021) to prove bounds on $\chi(\beta)$ when $\alpha > d$ and $\alpha = d$.

AGN Galaxy-Halo Connection From Galaxy-Galaxy Lensing With the Dark Energy Survey
Caleb Lammers
Mentors: James Bock and Ami Choi

Understanding the connection between galaxy properties and their surrounding dark matter halos is crucial for a complete picture of galaxy evolution. The galaxy-halo connection plays a particularly important role for galaxies with an active central supermassive black hole (termed an "active galactic nucleus" or "AGN"). However, observational constraints on the galaxy-halo connection are difficult to obtain, primarily due to the challenge of measuring halo masses. Galaxy-galaxy lensing, which involves the light from background galaxies being distorted by foreground galaxies, allows for direct halo mass measurements. In this project, we used high-quality lensing data from the Dark Energy Survey to measure the halo mass properties for a large sample of AGN galaxies from the WISE AGN catalog. We found significant relationships between halo mass and AGN galaxy physical properties (e.g., stellar mass, AGN luminosity), providing some of the most significant observational constraints on the AGN galaxy-halo connection.

The Role of Surface Chemistry and Etch Pit Geometry in the Formation of Pinhole Defects in TiO_2 Protective Layers
Nuren Lara
Mentors: Nathan S. Lewis and Jake M. Evans

In order to increase the efficiency of solar water-splitting cells, GaAs containing photoanodes must be placed in highly corrosive acidic or basic solutions. While amorphous TiO_2 has shown promise in serving as a protective layer, small (~100 nm) pinhole defects are known to form. These defects leave GaAs exposed and allow the solutions to corrode the substrate. The nature of these defects was studied using atomic layer deposition (ALD), galvanic gold displacement of exposed GaAs, scanning electron microscopy (SEM), photolithography, and electrochemical passivation. Chemical treatment and passivation were used to vary the substrate composition. Subsequent deposition of TiO_2 and pinhole quantification suggests that defect formation is independent of surface composition. Photolithographic patterning and scratch tests followed by qualitative inspection of SEMs suggest that etch pit geometry influences the formation of pinhole defects.

Elucidating Structure-Property Relationships in Metal/Semiconductor Materials for Solar-Driven Carbon Dioxide Conversion
César A. Lasalde-Ramírez
Mentors: Harry Atwater and Aisulu Aitbekova

Carbon dioxide (CO_2) is the main driver of climate change because it is the primary greenhouse gas. One approach to decrease the concentration of this pollutant is to capture and convert it into useful products. My work focuses on performing this process using metal/semiconductor materials and solar energy. To perform this process, we use photoelectrochemistry: a process where a semiconductor under a light source illumination triggers a chemical reaction. This route was chosen because it provides the opportunity to harness the abundant solar energy to convert the harmful pollutant gas into fuels and chemicals. This process, however, suffers from poor selectivity because it makes undesirable side products. To solve this challenge, I study how the properties of gold (Au) nanoparticles supported on p-type gallium nitride (p-GaN) semiconductors affect the performance of these materials in the solar-driven CO_2 conversion. In this talk, I will describe (1) the fabrication process of Au/p-GaN; (2) the characterization of these structures; and (3) their testing. Understanding the interactions between light, semiconductors, and metal nanoparticles in a photocathode is essential to creating a device that can solve the greenhouse gas emission problem.

Parcel-Level Disaster Recovery in the Florida Panhandle: An Analysis of Hurricane Michael
Kushnerniva Laurent
Mentors: R. Michael Alvarez and Danny Ebanks

Hurricanes and other tropical cyclones constitute a major hazard to human life and disruption to the functioning of society. This article shows evidence about the economic shock related to Hurricane Michael (2018) in the Florida Panhandle concerning single-family, mobile home, and multi-family property parcels. Although data analysis indicates that country aggregate parcel-values have recovered from economic losses associated with Hurricane Michael, disaster recovery has been inequitable. Mobile home and multi-family home parcels suffered particularly acute long-term effects from Hurricane Michael, supporting the findings of prior parcel-level research and reinforcing the need for further scholarship related to long-term disaster recovery outcomes.

Characterization of the Sensorimotor Pathways That Engender Phenotype-Specific Behaviors During Interspecies Interactions in Insects
Jonayet Lavin
Mentors: Joseph Parker and Jessleen Kanwal

The survival and reproduction of individuals of any species is highly dependent on the outcome of their interactions with other individuals. Notably, as insects traverse the world, they repeatedly engage in behavioral interactions with other species which are efficiently categorized by the insects' sensorimotor pathways. The generalist, free-living Dalotia Coriaria rove beetle was used as the model organism to procure insight into this categorization that induces ecologically useful behaviors. Based on transfer learning with deep neural networks, 3D markerless pose estimation with the DeepLabCut software was utilized to quantify interactions between Dalotia and a diversity of other organisms, identifying behaviors such as generalized predation, physical and chemical defense maneuvers, or fleeing. Additionally, this study examined the role of neuromodulation on foraging behavior in a predatory beetle by performing RNA interference to knock down genetic precursors for tachykinin and olfactory receptors in Dalotia and analyzing subsequent alterations in prey recognition behavior.

Improved Learning Algorithm for Predicting Ground State Properties
Laura Lewis
Mentors: John Preskill and Hsin-Yuan Huang

Finding the ground state of a quantum system specified by a Hamiltonian is a fundamental problem in quantum physics. Recently, it has been proven that there exist classical machine learning algorithms that can solve this problem in polynomial time and sample complexity in the number of parameters describing the Hamiltonian. Despite this theoretical efficiency, the polynomial scales poorly in the approximation error. In this work, we show that machine learning algorithms can achieve an improved efficiency under an additional assumption on the local structure of the Hamiltonian. In particular, we prove that a machine learning algorithm based on feature mapping can predict ground state properties given training data scaling logarithmically in system size and with no explicit dependence on the number of parameters of the Hamiltonian.

Generation and Characterization of Time-bin Encoded GHZ State for a Scalable Quantum Network
Chang Li
Mentors: Maria Spiropulu and Raju Valivarthi

We report on an experimental demonstration of generation of the time-bin encoded Greenberger-Horne-Zeilinger (GHZ) state by interfering one of entangled photon pairs with another photon in a qubit state. These entangled photons are generated at telecom wavelength (1536nm) using spontaneous parametric down-conversion. In the experiment, our highly time-resolved detection using superconducting nanowire single-photon detectors with low dark counts and timing jitters and indistinguishability of photons even with the spatial separation of sources asynchronously emitting photon pairs ensures high fidelity generation of GHZ states. The observed fidelity of our two-photon entangled state is as high as 0.998 ± 0.0665. This report will focus on the Z-basis measurements of the final GHZ state and analyzing its fidelity. We shall finally perform quantum state tomography (QST) on the generated GHZ states to reconstruct its density operator, and seek to experimentally verify genuine tripartite entanglement by using different entanglement witness operators.

SustainGym: A Benchmark Suite of Reinforcement Learning for Sustainability Applications
Victor Li
Mentors: Adam Wierman, Chris Yeh, Nicolas Christianson, and Yiheng Lin

Recent advances in reinforcement learning (RL) algorithms have demonstrated state-of-the-art performance across many control tasks; however, there has been limited exploration in how RL can be used in sustainability applications, making it difficult to both track progress on specific domains and identify bottlenecks for researchers to focus their efforts on. In this paper, we present SustainGym, a suite of environments designed to test the performance of RL algorithms on realistic sustainability tasks. Currently, SustainGym has two environments. The EV charging environment simulates the charging dynamics of an electric vehicle (EV) charging station, and the battery-storage-in-grid environment simulates an electricity market consisting of generators and battery storage systems. We describe the structure and features of the environments, benchmark state-of-the-art RL algorithms, and discuss current major challenges in introducing RL to real-world sustainability tasks, including high-dimensional state and action spaces, hard safety constraints, and distribution shift.

Constructing Stabilized Occluded-Open HIV-Env Proteins as a New Research Model and Potential Immunogen
Nathaniel Liendo
Mentors: Pamela Bjorkman and Andrew DeLaitsch

An effective HIV vaccine has remained elusive due to many factors including a highly diverse and heavily glycosylated viral surface protein. This protein, called HIV-Envelope (Env), is the only viral protein on the surface of HIV, and hence is the sole target of neutralizing antibodies. Recently, our lab identified heterologously neutralizing antibodies (NAbs) that bind specifically to epitopes that exist on a partially open conformation of this protein called "occluded-open". Our current studies are focused on creating stable occluded-open HIV-Env constructs to be used as immunogens. Towards this aim, we are covalently cross-linking an occluded-open specific bNAb to HIV Env. Site-directed mutagenesis (SDM) was used to introduce cysteine point mutations at the interface between the bNAb and Env. These cysteines should form disulfide bonds that irreversibly link the Env protein and bNAb, creating a stable construct. After protein expression of the SDM-altered plasmid DNA and various purifications of the expressed protein, the structure of our construct will be determined using cryo-EM. With the construct successfully expressed and structurally characterized, we then plan to attach them to nanoparticle cages and test their immunogenic potential in rodent models. Given that future immunization studies show high efficacy for these constructs, they will be implemented into mosaic-style HIV vaccines to protect against a wider variety of HIV strains.

Magellan Infrared Multi-Object Spectrograph Telescopic Lens Research
Alycia Lipscomb
Mentors: Alicia Lanz and Dimitri Mawet

Near-infrared multi-object spectrographs are a particular instrument well poised for development beyond the existing first generation versions currently deployed, which either have a narrow field of view in several wavelength bands or a wide field of view in a single wavelength band. Similar to the MOSFIRE project, Carnegie Observatories has sought out the next enhancement in astrophysical observations by implementation of a near-infrared multi-object spectrograph on the 6.5-meter Magellan telescopes at Las Campañas Observatory. One subset of this project includes verifying the reliability of epoxy bonds for lens mounting to the spectrograph. We sought to do so by prototyping, modeling, planning, and conducting a testing configuration with flexure mounts and conducting a pull test to see if the epoxy holds under stresses greater than the safety factor calculated when modeling (~100x the weight of the glasses). *In the end, we found that, when using a 95:5 epoxy to beads ratio, the epoxy does not hold under stresses higher than the calculated safety factor. Our findings indicate that a more reliable way of mounting the lenses of the spectrograph may be found with higher epoxy to bead ratios or with optomechanical designs (e.g. roll pin flexure design).*
** Note: italicized = unconfirmed/untested

Elucidating Composition-Structure-Property Relationships in Complex Metal Oxide Photoanodes
Daphne Lucana
Mentors: John Gregoire and Lan Zhou

Photocatalysts that operate in visible wavelengths are crucial for efficient use of solar radiation. Bismuth vanadate (Bi-V-O) has garnered attention due to its favorable band structure and carrier transport. Its large 2.4 eV band gap has motivated exploration of Bi-V-X-O materials, where X is an element that may lower this energy while retaining desirable properties. Bi-V-X-O composition libraries were prepared by co-sputtering metal targets onto a 100-mm-diameter glass substrate with a SnO2:F(FTO) conducting layer. The cation compositions were characterized by x-ray fluorescence, and x-ray diffraction was used to determine the crystal structure and phase distribution. Photoelectrochemical characterization was performed on the composition libraries using a custom-designed scanning droplet cell instrument. A computational tool was constructed to plot external quantum efficiency, optical absorption, and 2D heat maps to determine the composition-structure-property correlation that exists in thesecomplex high-order composition spaces. Identification of a photoanode material that efficiently absorbs the solar spectrum would enable a breadth of technologies for renewable synthesis of chemical fuels to combat the climate crisis.

Webcam Based Eye-tracking as a Tool for Characterizing Atypical Visual Attention in Autism Spectrum Disorder
Carla Adrianna Luna
Mentors: Ralph Adolphs and Na Yeon Kim

Eye-tracking has been suggested as an objective and quantifiable tool to diagnose and assess the severity of Autism Spectrum Disorder (ASD). Previous work has characterized atypical gaze patterns while individuals with ASD view pictures or movies of natural scenes. Common limitations of prior work, however, are small sample sizes and limited amounts of data per subject, which make it difficult to characterize between- and within-subject variability in gaze patterns. Here, we used WebGazer, an open-source software package for webcam-based eye tracking, to overcome such practical challenges. As a first step, we aimed to validate the use of this method in identifying ASD-related gaze patterns while viewing images and animations of social scenes. We will present results from a pilot experiment with 300 participants recruited online and discuss potential factors that may be able to improve the data collection process. With hopes of not only improving the accuracy of the characterization of autism on a spectrum but on a more personal level to be able to increase the accessibility of diagnosis.

LATTICE Lunar Transportation: Implementation of a Stake-Cable Interface
Moya Ly
Mentor: Soon-Jo Chung

To develop long-term lunar operations, in-situ resource utilization of lunar regolith is essential to minimizing materials that must be sent from Earth. A finalist of the NASA 2022 BIG Idea Challenge, the Lunar Architecture for Tree-Traversal In-service-of Cabled Exploration (LATTICE) team enables transportation of resources and scientific systems over rough terrain like lunar craters. A setup rover will rappel from a lunar lander near a crater and drive stakes into the steep surface. Shuttles will traverse cables connecting these stakes to and from the crater floor, carrying up to 80 kg payloads. The connection between cables and stakes is vital to our ability to transport resources via shuttles. We iteratively designed and prototyped a stake-cable interface with the flexibility to accommodate various angles between stakes and crater slopes and ensure a smooth shuttle ride. We will demonstrate proof-of-concept of the LATTICE system in the fall.

The Effect of Fe_2O_3 and Fe_3O_4 Nanoparticles on Electrical Conductivity and Mechanical Behavior of SiOC Ceramics for Bioremediation
Nyvia Lyles
Mentors: Katherine Faber and Laura Quinn

This project seeks to explore porous silicon oxycarbide (SiOC) ceramics as a model porous mineral to house Geobacter species. By incorporating iron nanoparticles into porous ceramics, this project seeks to create ceramic support with which microorganisms can colonize and interact. This research aims to study how incorporating iron-based nanoparticles into the porous ceramic affects the ceramics' electrical conductivity and mechanical behavior. Fe_2O_3 is a known electron acceptor with which the bacteria like to interact, and Fe_3O_4 allows us to make the ceramics conductive, allowing for in-situ investigation of electromicrobiological processes. Fe_2O_3 and Fe_3O_4 were synthesized through a mechanochemical process. Through characterization techniques such as scanning electron microscopy (SEM), X-ray diffraction (XRD), Raman spectroscopy, and Fourier-transform infrared spectroscopy (FTIR), the nanoparticles' oxidation states were analyzed and verified. After the synthesis, the nanoparticles were strategically incorporated into the pre-ceramic polymer to be freeze-cast, which allows easy manipulation of properties such as pore size and morphology. Following freeze casting, the impact of incorporating iron nanoparticles into the SiOC ceramic was examined using electrical conductivity measurements and mechanical testing. Ultimately this investigation hopes to provide a proof-of-concept study to colonize bacteria in porous materials.

MCMC Thermophysical Modeling of Recovered Data From the NEOWISE Mission
Isabella Macias
Mentor: Joseph Masiero

Identifying the composition and orbital path of near-Earth asteroids (NEAs) will provide a greater understanding of the origins of our solar system and improve our safeguards against these hazardous planetesimals. A survey of threatening NEAs is currently underway under the NEOWISE mission; however, we conducted a manual search of unreported epochs of asteroids from the NEOWISE archive to construct a complete framework of its characterizations. We recovered data from the NEOWISE mission to be inputted in a triaxial ellipsoidal model that will be utilizing a Monte Carlo Markov Chain (MCMC) approach, where the model will constraint thermophysical properties such as diameter, thermal inertia, and albedo. We reported the observed epochs to the International Astronomical Union's Minor Planet Center's (MPC) database and built tools for locating missing epochs in NEOWISE's search for NEAs.

Model-Based Reinforcement Learning for Bipedal Robots
Sai Advaith Maddipatla
Mentors: Animashree Anandkumar and Sahin Lale

Bipedal locomotion in robots like Cassie can prove to be a challenging control task to learn due to its high dimensionality and partially observable nature. Model-based reinforcement learning is a type of reinforcement learning problem which involves learning a predictive model of the environment to make optimal control decisions. In this project, we use model-based reinforcement learning for Cassie due to its sample efficiency and generalizability. Firstly, with the help of data collected from the Mujoco simulator, we approximate the dynamics of Cassie using deep learning techniques and use the learned dynamics model in a joint-level Cross-Entropy Based model predictive controller. Further investigation revealed that a sampling-based model predictive controller would be unable to plan the robot's locomotion over a finite horizon with random initialization of the planner due to the high dimensionality of joint-level actions and the action space. Therefore, good initialization is essential for the sampling-based planner to perform well in Cassie. Lastly, we studied different initialization methods and gradient-based methods combined with sampling-based methods to improve the performance in walking.

Density of Brine Shrimp and Impacts of Migration Organization
Shelby Madruga
Mentors: John Dabiri and Nina Mohebbi

The diel vertical migration (DVM) of zooplankton is one of the largest migrations by mass in the world. The hydrodynamic interactions of the swarm may impact the aggregate configuration and the nature of any swarm-scale flow features induced by the migration. Flow induced by these massive migrations may impact our climate through carbon sequestration and nutrient mixing of the ocean. To determine changes in swarm configuration we design and execute an experiment videoing vertical movement of swarms with different animal density. We use brine shrimp, *Artemia salina*, as a model organism. ImageJ and wrMTrck are used to count the number of shrimp added and determine the density of shrimp in the tank. We capture videos the of vertical migration of these swarms induced by positive phototaxis.

Gas Leak Detection Using Spectrally Filtered Infrared Imagery
Jón Kristinn Magnússon
Mentors: Axel Scherer and Taeyoon Jeon

Infrared imagery with mid-infrared filters can be used to detect a wide range of molecules. One application is the detection and quantification of gas leaks, essential for the safe and environmentally friendly operation of pipelines, refineries, and other installations in the oil industry. Using an inexpensive infrared camera, we applied a bandpass filter with a transmittance peak centered near the 7.8 micrometer absorption peak of methane. Because the methane absorption peak coincides with the transmission peak of the filter, methane will appear opaque and obscure the image. By observing a methane leak with this system, and comparing it to an unfiltered image of the same leak then subtracting the two, we were able to separate the methane centric portion of the image from the rest of the captured images. By applying a kernel averaging filter to the resulting image, we were able to reduce noise from the camera's bolometer arrays and further highlight the presence of methane in the image. We applied a threshold to the pixel intensity of the processed images, which provided even greater enhancement of the methane leak. In combination, these techniques delivered sharp contrast where methane was present.

ROIAL Toolbox: A Python Toolbox for the Region of Interest Active Learning Framework
Michael Maiden
Mentors: Yisong Yue and Amy Li

The Region of Interest Active Learning (ROIAL) framework works to characterize an individual's gait preference landscape by estimating an individual's utility function. This is accomplished by collecting preference and ordinal feedback from a user within the exoskeleton to locate a Region of Interest (ROI) along their utility function. The ROI ensures comfort when moving within an exoskeleton. The ROIAL Toolbox, a python toolbox for the ROIAL framework, will make using the ROIAL algorithm a more efficient and informative process for new users. The toolbox features visualizations such as modeling samples from the Gaussian process prior in multiple dimensions, visualizing the posterior mean estimating a true objective function, and visualizing a model posterior across user-defined dimensions where a slider can change the value of a specified dimension thus recalculating the posterior. ROIAL Toolbox also features documentation to help users understand how the toolbox's features operate making it a useful learning resource.

Effects of Elemental Substitution on Cuprous Oxide Crystallinity
Russell Martinez
Mentors: Nathan S. Lewis and Sean Byrne

Several semiconductors have been shown to exhibit inorganic phototropism, where films develop new morphologies in response to illumination, as shown by Sadtler et al. All examples so far have been materials that contain selenium, although growth modeling suggests that inorganic phototropic growth is largely material agnostic. Ongoing work has shown that cuprous oxide films exhibit inorganic phototropism only when a third element, either sulfur or iodine, is present in the film. The current hypothesis is that the inclusion of other elements disrupts the normally favorable growth of large cuprous oxide crystals, which overwhelm the growth of much smaller phototropic features, leading to the emergence of phototropic features.

This work investigates how the inclusion of small amounts of other elements, which substitute for copper or oxygen, affects the crystallinity and morphology of cuprous oxide films electrodeposited in the dark. The experimental conditions, including deposition solution components and electric bias, have been optimized for the deposition of (220) faceted cuprous oxide. The next experiments will introduce several other elements into the deposition solution, including bromine, iodine, nickel, and cobalt. It is hypothesized that the inclusion of these elements will result in smaller crystal grain sizes, which will be measured by x-ray diffractometry.

Three Pre-Main-Sequence Eclipsing Binaries in the Orion Nebula Cluster
Alexandra Masegian
Mentor: Lynne Hillenbrand

There is still much that is not known about the earliest stages of stellar evolution. Pre-main-sequence (PMS) stars are highly dynamic objects, and their internal structures change rapidly as they accrete material and contract towards the main sequence. To ensure that theoretical PMS models are properly calibrated, it is important to test them against a dense grid of PMS objects with well-measured properties. Eclipsing binaries (EBs) are especially useful probes of stellar evolution models because their high inclination and close separation allows for the radii, masses, and effective temperatures of both stars to be constrained via photometric and spectroscopic analysis. Previous work by Morales-Calderón+2012 contributed to PMS model calibration efforts by providing an initial characterization of six PMS EBs in the Orion Nebula Cluster. We present further constraints on the properties of three of these systems and discuss implications for theoretical PMS models.

Warm, Competent, Unequal: The Current State of Hiring Discrimination
Beatrice Maule
Mentors: Colin Camerer and Marcos Gallo

We examine all the factors that might result in discrimination towards the applicant during the hiring process by gathering papers from various authors and producing a metanalysis. Our paper is a database where all the papers written about the topic can be found grouped by ground of discrimination. The effect of this discrimination, either positive, negative, or neutral, is also reported. The novelty of our project is the inclusion of a warmth and competence analysis applied to different categories of individuals. Warmth can be defined as how friendly and amicable a person is, while competence is defined by their abilities and qualifications. We found, for example, that people with mental disabilities as seen as very warm but not very competent, while Asian people are seen as very competent but not warm.

Additive Manufacturing of Magnetic Microlattices for Functionalized Nanoparticle Capture
Robin M. McDonald
Mentors: Julia Greer and Sammy Shaker

Functionalized magnetic nanoparticles allow for *in vivo* controllable drug delivery, sensing, and small molecule capture. Among small molecular capture applications, DNA-coated magnetic nanoparticles have recently been applied to sequester chemotherapeutics administered during local cancer treatment. However, blood vessel filters to remove magnetic nanoparticles *in vivo* are yet to be realized. Such a filter must be magnetizable to attract the nanoparticles, have a high surface area for effective capture, and not disrupt blood flow. Additive manufacturing, notably the recently developed hydrogel-infusion additive manufacturing method, can produce filters with these requirements, but the resultant materials are not thoroughly characterized microstructurally or magnetically. Additionally, synthesis of samples in complex compositions is an underexplored aspect of this process. To produce filter prototypes that satisfy these requirements and further study this process we attempted to fabricate microlattices with compositions matching those of the commercial magnetic alloys, permalloy (Ni_4Fe) and Kovar ($Fe_{55}Ni_{15}Co_{30}$) in an architecture optimized for minimal flow disruption, the twisted honeycomb. We subsequently characterize the elemental and phase composition of filters for both targeted compositions using energy dispersive X-ray spectroscopy and powder X-ray diffraction, respectively. We also assess the magnetic properties of a permalloy filter by collecting a magnetic hysteresis curve at room temperature. By adjusting the thermal processing and by exploring alternate compositions, we can further optimize the structure and the magnetic properties of our filters.

GPU-Based Beamformer for 3D Real-Time Ultrasound Imaging
Kyle McGraw
Mentors: Mikhail Shapiro and Claire Rabut

Functional ultrasound imaging (fUSI) provides a highly sensitive method to image dynamic deep brain activation. fUSI was initially restricted to cross-sectional images but the recent extension of fUSI to 3D volumetric imaging using a 2D-array transducer has allowed the direct acquisition of 3D images of brain activity. However, volumetric imaging requires a substantial increase in the number of acquisition channels (1,024 compared to the typical 128 or 256) and computationally intensive image processing. Our goal was to develop a GPU-based beamformer for a 1,024-channel 2D-array transducer controlled by 256-channel ultrasound electronics connected to a 4:1 multiplexer. We show that our beamformer produces proper volumetric images in vitro and in vivo and allows reconstructing brain fUSI images from backscattered raw-frequency data 10 times faster than the built-in CPU-based beamformer provided by the ultrasound scanner software. Our results contribute to developing a versatile volumetric fUSI platform for future molecular- and neuro- imaging applications.

Synthetic Study Toward the Novel Diterpenoid and PTP1B Inhibitor (-)-Rhodomollanol-A
Giovan McKnight
Mentors: Sarah Reisman and Simon Cooper

(-)-Rhodomollanol-A is a novel diterpenoid isolated from the leaves of *Rhododendron molle*. This diterpenoid has been shown to exhibit protein tyrosine phosphatase 1B (PTP1B) inhibition. PTP1B is overexpressed in individuals with Type II diabetes (T2D). (-)-Rhodomollanol-A shares many structural features with grayanane diterpenoids, which also exhibit similar PTP1B inhibition. Thus, (-)-Rhodomollanol-A marks itself as a promising therapeutic for T2D. However, initial attempts to isolate (-)-Rhodomollanol-A from *Rhododendron molle* have resulted in poor yields of only 6 mg per 25 kg of plant material. Also, the only published synthesis of (-)-Rhodomollanol-A is 30 steps long, requires several circuitous redox reactions and doesn't access the crucial 5-7-5-5 carbon skeleton until the final steps. This latter point inhibits the array of (-)-Rhodomollanol-A derivatives that can be readily synthesized, making it difficult to create libraries of similar molecules which may exhibit even stronger PTP1B inhibition or be cheaper to produce. The goal of this study was to design and execute an efficient synthesis of (-)-Rhodomollanol-A. Starting from 2,2-dimethyl-1,3-cyclopentanedione, a 20-step synthesis was designed to reach the novel diterpenoid involving such reactions as a [2,3]-Wittig rearrangement, Pauson-Khand cycloaddition and an oxyallyl cation [3+2] cycloaddition. Reported here are initial efforts toward (-)-Rhodomollanol-A.

Electrolyte Engineering for Optimal Lithium Morphology in Li-Mediated Electrochemical Ammonia Synthesis
Erin McMurchie
Mentors: Karthish Manthiram and Channing Klein

Ammonia is an essential chemical for production of fertilisers and is a promising alternative fuel in the transition to net-zero. Lithium-mediated electrochemical ammonia synthesis (LiMEAS) is a viable technological alternative to the Haber-Bosch process, which is responsible for an estimated 1-2% of global CO_2 emissions. Recent LiMEAS systems have achieved faradaic efficiencies (FEs) of nearly 100% using carefully designed electrolytes which remain stable over several days. However, there continues to be a lack of understanding of the solid-electrolyte interface (SEI) and morphology of the Li-deposits. By changing key electrolyte components, a database of FEs and Li-morphology was collected. The use of gas-diffusion electrodes enabled reduced mass transport limitations, which increased FE for more accurate data collection. Scanning Electron Microscopy (SEM) was used to image the Li-deposits in an inert atmosphere to minimize Li-reactivity. SEM imaging indicates that the Li-deposits are diverse: features range from scales around 2μm to much less than 1μm. Elevated yields were measured for electrolytes containing $LiBF_4$ and LiTFSI salts, which had Li-deposits which were thinner and less uniform. This supports the working hypothesis that Li-deposits of this nature correspond to an SEI structure which has increased porosity and improved mass transport characteristics of N_2 to the plated Li-surface.

LATTICE Stake Design, Driving, and Anchoring in Lunar Regolith
Robert Menezes
Mentor: Soon-Jo Chung

In the search for volatile deposits on the lunar surface, permanently shadowed southern polar craters offer some of the most promising locations. However, descending into these craters poses a unique challenge of navigating rough terrain with up to 40° slopes. To overcome this challenge, the Caltech LATTICE team is prototyping an infrastructure system of 1m stakes connected by 30m spans of cable, to be deployed by a rover. These cables will be able to transmit energy and communications not in line of sight, and will be able to be traversed by shuttles with 80kg payloads These stakes must be able to be anchored directly in lunar regolith and must withstand a 2kN side load of cable tension. A helical auger design allows these stakes to be driven with sufficiently low torque and downforce provided by the rover. The braided carbon fiber composition of the stakes allows them to meet the mass and strength requirements.

Electromyography Sensors and Ankle Exoskeleton Human-in-the-loop Feedback System
Yash Mhaskar
Mentors: Aaron Ames and Kejun Li

The ongoing powered exoskeleton research has allowed exoskeletons to augment the human physical capabilities and assist with rehabilitation for locomotive impairments. To overcome the current ankle exoskeleton rehabilitation challenge of the need for heavily customized shoes, a front-actuating ankle exoskeleton research was initiated in AMBER lab. This study aimed to create a feedback loop to update the actuation timing for the ankle exoskeleton by using live-recorded muscle activity to assist the ankle exoskeleton. Surface IMU sensors were used to generate gait cycles for 3 muscles on each leg and the electromyography (EMG) readings was processed and averaged over 6 gait cycles to obtain reliable muscle activity data. The % gait cycle corresponding to the muscle activity peaks was used as an estimate for actuation time. The trends observed in muscle activity were used to improve the actuation time and check the effectiveness of the ankle exoskeleton.

Developing the GALACTICUS Dark Matter and Galaxy Formation Code
Ellen Min
Mentors: Ethan Nadler and Andrew Benson

GALACTICUS is an open-source software toolkit for semi-analytic galaxy formation modeling. GALACTICUS is a promising tool because it produces results consistent with N-body simulations while using a fraction of the computational resources. The model is primarily implemented in Fortran, with Python interfaces available for some, but not all, modules. Python interfaces were developed for a larger set of functions and classes in GALACTICUS by adding new functionalities to the Fortran and Python libraries and communicating between the two using C-compatible interface wrappers. A script was written to test for consistent output across the interfaces and indicated successful development of the new Python interfaces. Limited functionality was available to visualize data (such as subhalo populations) produced by Galacticus. We have developed general-purpose tools allowing a wide variety of halo and subhalo populations to be visualized in GALACTICUS, as an aid to data analysis.

Stabilization of Lanthanide-Binding Protein Lanmodulin
Wezi Mkandawire
Mentors: Stephen L. Mayo and Andres Orta

Lanmodulin is a recently discovered protein shown to effectively capture rare earth elements (REEs) through repeated adsorption/desorption cycles. Currently, small-scale experiments on the wild-type lanmodulin protein have elucidated its metal-binding behavior. However, it is desirable to improve the capture and release process to increase its economic and practical feasibility. Thus, we aim to computationally identify and experimentally verify lanmodulin mutants with increased thermal stability while retaining the wild-type protein's metal-binding properties. We express the wild-type protein from a lanmodulin gene inserted into the *pET-24a* bacterial expression vector using Gibson cloning. Assays are then developed to test the protein's thermal stability and metal binding capacity. By primarily accounting for alpha helix dipole and N-capping effects in the lanmodulin redesign algorithm and subsequent energy calculations, we obtain plausible mutants to compare with the wild-type protein. The design of lanmodulin mutants with increased thermal stability and metal binding activity promises the capture of REEs in large-scale processes utilizing the protein. Moreover, computational redesign favorably biasing alpha helical interactions offers a straightforward approach to improve commercially desired proteins.

Superconductor Hydrodynamics and the Universal Time-Dependent Ginzburg-Landau Theory
Luke Mrini
Mentor: Anton Kapustin

We develop a model of superconductor dynamics which is independent of microscopic considerations and assumes only local thermal equilibrium. This can be accomplished within the framework of Schwinger-Keldysh Effective Field Theory (EFT) by imposing KMS symmetry. We show that in the vicinity of the phase transition the most general leading-order EFT satisfying the appropriate symmetries is described by a mild generalization of the Time-Dependent Ginzburg-Landau (TDGL) equations of Gor'kov-Eliashberg (with stochastic terms added). Implications of the generalized TDGL for the existence of propagating collective modes in a superconductor are discussed. Within this approach, it is possible to include systematically the effects of non-uniform temperature and heat conductivity. We also construct an exotic hydrodynamics that arises naturally in the Schwinger-Keldysh formalism describing a phase of matter where heat can flow without dissipation.

Utilization of an ElectroMagnetic Actuation System (EMAS) to Initiate and Maintain the Team Flow Brain State
Madisen Murphy
Mentors: Shinsuke Shimojo and Mohammad Shehata

Team Flow is a brain state associated with enhanced information integration and interbrain synchrony within groups of people engaged in a task with an end goal. The lab has previously shown, via electroencephalogram (EEG) technology, that activity in the left middle temporal cortex (L-MTC) is highly correlated with Team Flow processes. However, the environmental conditions and cortical interactions underlying the initiation and maintenance of Team Flow still warrant further investigation. In this study, we will utilize an ElectroMagnetic Actuation System (EMAS) device, which allows for the modulation of motion transfer between participants, in adjunct with the music rhythm game StepMania to initiate and maintain Team Flow. Two EMAS modes-- intertwined and system-cue-- will be used to elicit Team Flow. The differing motion transfer capabilities of each of the two EMAS modes will allow us to determine if there are optimal conditions for Team Flow initiation and maintenance. High-density EEG will also be used to analyze neural activity and to determine the chronological order of cortical activation that contributes to Team Flow, which could elucidate whether Team Flow is a top-down and/or bottom-up phenomenon.

Engineering Fluorescent Cyclic di-GMP Biosensors for Dual Fluorescence and Electron Microscopy Imaging
Pat Mutia
Mentors: Ming Hammond, Nathan Ricks, and Bil Clemons

Cyclic di-GMP is a secondary messenger that is responsible for initiating fundamental cellular functions within bacteria such as motility, virulence, and biofilm formation. Interrogating when and where cyclic di-GMP is present allows for further insight on pathogenic interactions, intestinal bacteria in the gut, and general bacterial signaling. The Hammond Lab has previously developed a chemiluminescent biosensor for cyclic di-GMP, which we took inspiration from to design a genetically encodable biosensor to be imaged with scanning transmission electron microscopy. We utilize the binding protein DnYcgR, that performs a confirmational change when interacting with cyclic di-GMP, and a split version of miniSOG (mini Singlet Oxygen Generator), a fluorescent flavoprotein that activates when both halves meet. We inserted our designed biosensors into our pBAD plasmid with Gibson Assembly, and currently screening and sequencing is underway to identify successful integrants. We are further investigating variable flexible linker sequence configurations to connect DnYcgR and the split miniSOG pieces to restrict activation strictly due to the presence of cyclic di-GMP. This fluorescent biosensor provides an alternative method to add specificity in sensing cyclic di-GMP in bacteria due to the variability in chemical substrate initial concentrations that chemiluminescent biosensors depend on, which makes quantitative measurements challenging.

Computationally Analyzing Dry Snow Metamorphism
Prani Nalluri
Mentors: Ruby Fu, Adrian Moure, Nathan Jones, and Quirine Krol

Snow metamorphosis, the evolution of snow structure on a microscopic level, is key to predicting macroscopic properties of a snowpack, a large body of snow. Unfortunately, most theoretical models for snow metamorphosis are only reliable in certain conditions. To deepen our understanding of this process, I am studying a few specific cases of snow metamorphism to investigate how ice particle geometries can evolve due to different isothermal temperature boundary conditions. In order to do so, I co-developed a C code and utilized the finite-element method to approximate a solution to theoretical coupled partial differential equations for the system. I have also created a MATLAB script to post-process the data from this code and determine geometric parameters of ice particles in the system. Next, I hope to find the coarsening rates of ice particles across temperatures using the Lifshitz-Slyozov-Wagner theory. Through this process, I am able to add to the theory behind dry snow metamorphism and possibly advance the conceptual knowledge of scientists in the field.

Surface Constraints on the Strength and Structure of the Atlantic Meridional Overturning Circulation in Coupled Climate Models
Manali Nayak
Mentors: Andrew Thompson, Dave Bonan, and Emily Newsom

The Atlantic Meridional Overturning Circulation (AMOC), a branch of the ocean's global overturning circulation (GOC), plays an important role in regulating Earth's climate by transporting heat northward and ventilating the upper 2000 meters of the ocean. State-of-the-art general circulation models (GCMs), however, exhibit large mean-state biases in the strength and structure of the AMOC, varying between 10 and 30 Sv in strength and between 1500 and 3000 meters in depth. Here, we introduce a framework for understanding these biases in GCMs by assessing the surface buoyancy fluxes and the associated meridional buoyancy transport. We find that the magnitude of surface buoyancy gain and the strength of the AMOC are related: stronger surface buoyancy gain in the low-latitudes corresponds to stronger buoyancy loss in the high-latitude Atlantic, hence resulting in a stronger AMOC. Additionally, we find that the low-latitude Atlantic and Indo-Pacific basins account for approximately 80% of the intermodel variations in the surface buoyancy gain, and the heat and freshwater components contribute equally. Our results highlight the unique role that low-latitude surface heat and freshwater fluxes play in setting the strength and structure of the AMOC. These processes may provide a so-called emergent constraint on AMOCchanges under greenhouse-gas forcing.

Using Artificial Intelligence and Underground Camera to Identify and Track *Z. morio* Larvae in Soil
Paulina Naydenkov
Mentors: Changhuei Yang and Oumeng Zhang

Plastic production has almost quadrupled in the last 50 years, which has created an issue of waste disposal and pollution. It has been demonstrated that beetle larvae have the ability to degrade plastic. To better understand the efficacy of the beetle larvae as a tool to degrade plastic, we explored its attraction to and preference for plastic waste in a soil environment. A training model (COCO-detection) from a modular object detection library (Detectron2) is used to predict the location of arthropods. We have explored several image processing methods including brightening the image and subtracting two frames >1 second apart. We have been able to identify arthropods with an over 75% precision and 90% recall and track the center of each identified arthropod throughout time.

Enhancer Specific Expression of GABAergic Interneurons and Medium Spiny Neurons in Mouse and Macaque Tissue
Blessing Njoku
Mentors: Viviana Gradinaru and Cynthia Arokiaraj

Neurodegenerative and neuropsychiatric disorders often affect several areas of the brain, making widespread transgene expression necessary for neuron manipulation. To study the disrupted cell types in the circuitry, minimally noninvasive strategies like adeno-associated viruses (AAVs) are being used. Enhancer sequences are one way in which AAVs can be tailored to be delivered systematically. This study is testing recently identified enhancer sequences for the engineered variant Cap-Mac for their ability to drive expression of mRUBY2 specific to the forebrain GABAergic interneurons or MSNs in the macaque and mouse brain. Primarily using antibody staining and USeqFish to look at the overlap of mRUBY2 protein/mRNA expression with markers for GABAergic interneurons and medium spiny neurons, this study has observed specific expression of 2 different channels in the mouse cortex and plans to apply the modifications to the USeqFish procedure to the macaque tissue. With the application of the modifications described, it is expected that future work will illuminate increased specificity of the viruses.

Estimating the Risk Due to River Migration Using Probabilistic Modeling
Brayden Noh
Mentors: Michael Lamb and Kieran Dunne

Lateral migration of meandering rivers poses erosional risk to human settlements and infrastructure in alluvial floodplains. While there is a large body of scientific literature on the dominant mechanisms driving river migration, it is still not possible to accurately predict river meander evolution over multiple years. This is in part because deterministic mathematical models are not equipped to account for stochasticity in the system. Besides, uncertainty due to model deficits and unknown parameter values remain. For a more reliable assessment of risks, we, therefore, need probabilistic forecasts. Here we present a workflow to generate river-migration risk maps using probabilistic modeling. We start with a simple geometric model for river migration, Howard-Knutson in this case. We then account for model structure deficits using normal noise. Probabilistic forecasts for river channel position over time are generated by Monte Carlo runs, using a distribution of model parameter values inferred from satellite data. We demonstrate that such risk maps are more informative in avoiding false negatives, which can be both detrimental and costly, in the context of assessing erosional hazards due to river migration.

Creating a Promoter Library for *Pseudomonas synxantha* 2-79 for Fluorescent Expression Analysis
Madison Ochoa
Mentors: Dianne K. Newman, Elin Larsson, and Reinaldo Alcalde

This project aims to better understand and characterize the structure of the alkaline phosphatase (*phoA*) promoter from *E.coli* in *Pseudomonas synxantha* 2-79 to report on biologically available phosphorus using bacterial fluorescence. The bacterium *P. synxantha* is a rhizosphere bacterium that we have chosen for our project due to its ecological relevance. *P. synxantha* is abundant in the wheat rhizosphere (1) and promotes growth in wheat through its biocontrol properties. Phosphorus is our nutrient of choice because it is an essential nutrient for plant growth and non-renewable, making the management of phosphorus fertilization in agriculture particularly important from an ecological and economic perspective.

In-depth knowledge of *P. synxantha* may allow for the subsequent tuning of the promoter's strength and identification of other promoter regions on the genome outside of the ones we have chosen for this study. We aim to create a defined library of PhoA promoters and differentiate randomizations of said promoters by relative fluorescent output (green fluorescent protein expression) under limited phosphorus conditions.

Works Cited:
Mavrodi et al., 2020, *Pseudomonas synxantha* 2–79 transformed with pyrrolnitrin biosynthesis genes has improved biocontrol activity against soilborne pathogens of wheat and canola.

Rapid Synthetic Image Generation Using Neural Radiance Fields for Vision-based Formation Flying Spacecraft
Christine Ohenzuwa
Mentors: Soon-Jo Chung and Kai Matsuka

The development of vision navigation algorithms for formation flying spacecraft is hindered by the availability of real spaceborn images as well as the computational overhead of generating synthetic images. This project seeks to apply a deep neural network volume rendering technique known as neural radiance fields (NeRFs) to rapidly generate volumetric representations of spacecraft from a sparse set of images as input and, consequently, advance the validation of close proximity spacecraft vision navigation algorithms. Training datasets consisted of 50-150 images of a synthetic spacecraft generated using Blender. Information on the position, viewing direction and intrinsics of the camera in each image are used as the input into a neural network. The output after training is a volumetric representation of the target spacecraft that can be used for novel view synthesis with any lighting conditions. Visually legible volumetric reconstructions were produced in 10000 training iterations (~20 minutes) and images take seconds to render.

A Paradigm for the Study of Escape and Reward Computation Under Threat
Noah Okada
Mentor: Dean Mobbs

Fear broadly categorizes an array of cognitive and physiological states associated with present and identifiable threats. Understanding the processes that mediate fear can help to elucidate fundamental questions about human emotion and decision-making. Early research in psychology, ethology, and neuroscience has enabled the study of neural responses to predatory threats in animals. Building upon these non-human models, we developed a virtual predation paradigm to study human responses to predatory threats. This paradigm was developed using the Unity Game Engine to create immersive environments that could be deployed in fMRI experiments. The paradigm consisted of a hexagonal grid-based environment with varying levels of danger and reward relative to the proximity of an artificially intelligent predator. While immersed in the environment, participants were tasked with collecting maximal rewards while escaping the attack of the predator. The interplay of escape and reward-seeking behaviors prompted by this paradigm enables the study human reward computations under predatory threat. The development and preliminary testing of this paradigm will allow researchers to better characterize the neurobiological circuits that coordinate decision-making in the face of fear and anxiety.

Efficient Nearest-Neighbor Search Algorithms for Data-Driven Inelasticity
Zeynep Yaprak Onder
Mentors: José Andrade and Anna Gorgogianni

Data-Driven (DD) computing is an emerging field of computational analysis in which experimental data sets are directly used to predict mechanical behavior. Recently, approximate- nearest neighbor (ANN) algorithms have been implemented to speed up the DD nearest neighbor search, which aims to minimize the distance between the material states within the data set, and the mechanical states of a particular application. Such studies have mostly focused on the case of elastic material behavior. In this project, we investigate the performance of ANN algorithms for DD computations with inelastic material data. We implement the DD nearest-neighbor search using FLANN, a standard-library for ANN search. To account for the history-dependence of material behavior, we write a built-in method which allows the ANN search to be performed only within the time-dependent subset of thermodynamically admissible material states. We illustrate the performance of the algorithm in navigating through inelastic material data sets through material points simulations under non-monotonic loading paths.

A Non-Scissile Mechanophore Enabling Multi-Cargo Release
Liam Ordner
Mentors: Maxwell Robb and Tian Zeng

The use of mechanical force to selectively activate covalent bond transformations is emerging as a powerful method to access stimuli-responsive polymers for applications ranging from sensing to drug delivery. In polymer mechanochemistry, polymer chains transduce mechanical stress to force-sensitive molecules called mechanophores that can be designed to undergo a wide variety of chemical reactions. Our group has recently developed a general and modular mechanophore design that enables mechanically triggered release of a wide range of functionally diverse molecular payloads through a unique cascade reaction process. This mechanophore platform offers a potentially powerful approach to control molecular release using ultrasound with spatial and temporal precision. With only one mechanophore per polymer chain, however, the extent of cargo release in past studies is limited. We propose a new mechanophore capable of undergoing ring-opening metathesis polymerization (ROMP) with a comonomer. This would enable the incorporation of several mechanophores per polymer chain, vastly increasing the relative amount of cargo released by a given quantity of polymer. Furthermore, with this design, the polymer chain will remain intact upon mechanical activation at a mechanophore site. The polymer would thus retain its high molecular weight, permitting other mechanophores along the backbone to continue undergoing mechanical activation.

The Advancement of Autonomous Underwater Vehicles Through the Development of a Robotic Fish Fin Propulsor
Tyler Oribio
Mentors: Morteza Gharib and Meredith Hooper

The flapping motion of a fish fin efficiently propels the fish through water. The Gharib Research Group is integrating this idea with autonomous underwater vehicles (AUVs) to develop a fish robot, which consists of a body and a robotic fin propulsor that can orient itself according to a particular trajectory. The mechanism that controls the orientation of the fin is not yet completed. This consists of a motor that controls the rotation of the fin and a shaft that connects the motor to the fin. First, a motor needs to be carefully selected so the fin can produce an output torque of 3.4 Nm. and an angular speed of 180 rpm. Then, the apparatus that supports and connects the motor, shaft, and fin needs to be CAD modelled and machined. At the end of the 10-week period, the shaft should be able to orient itself 30 degrees from the center axis without colliding into the walls of the fish robot. Future work involves testing this mechanism in a water tank and measuring the forces the fin produces.

Prediction of Lift for Airfoil at Low Reynolds Number
Brandon Paez
Mentors: Jane Bae and Di Zhou

This project seeks to predict lift coefficient of a NACA 0012 airfoil at low Reynolds number with sparse pressure measurements along the airfoil surface. Time-resolved simulation of flow over a NACA 0012 airfoil was used to extract time-series of surface pressure and lift coefficients. The location of the pressure signals used for prediction was informed by a data-driven sparse sensor placement algorithm utilizing proper orthogonal decomposition (POD) [Manohar et al. 2018]. The extracted surface pressure data at the optimal sensor locations were used as input for the machine learning models. Two models with different machine learning architectures, long short-term memory (LSTM) and one-dimensional convolutional neural network (1D CNN), were compared on predictive capabilities of the lift coefficient. The predictive performance of the machine learning models increases when more pressure sensor data are inputted. Further work on optimizing the framework for predicting coefficient of lift values is needed to increase the accuracy of the utilized models.

Age Measurements for the Youngest Kepler Planets
Elsa Palumbo
Mentors: Lynne Hillenbrand and Luke Bouma

Young planets, those under a billion years old, have much to teach us about the formation, evolution, and habitability of planetary systems. However, only a handful of young planets with precisely known ages have been identified so far, in part due to difficulties in dating stars. To address this problem, most previous work has started with a cluster of stars that are already known to be young, and then searched for planets. Our project tackles the issue in the opposite order: we begin with known planet candidates – specifically the Kepler Objects of Interest (KOIs) – and then constrain the age of the host stars by combining three different dating methods: gyrochronology, isochronal evolution, and lithium absorption. According to our preliminary results, this project has identified over 150 KOIs with rotation periods that indicate their ages are under 730 million years, nearly half of which are confirmed planets.

Exploring the Abiotic–Biotic Gap: A Novel Technique to Measure the Isotopic Composition of Acetate and its Implications for Astrobiology
Juliann Panehal
Mentors: Alex Sessions and Elliott Mueller

Rising interest in potential life beyond earth has highlighted the importance of using earth analogues to study the abiotic-biotic gap. One such site, Kidd Creek Mine, shows evidence of abiological origin of organics in its 2.7-billion-year-old fracture water. To investigate further, this study tests a novel technique to measure the δ^2H composition of acetate in the water while aiming to improve this technique for future use. Acetate was isolated and collected using ion chromatography and analyzed using (ESI)-Quadrupole Orbitrap mass spectrometry. Isotopic compositions of both carbon and hydrogen were analyzed, with δ^{13}C values also compared to previous works. To test for method accuracy, results from synthetic samples with known isotopic composition were compared to Kidd Creek samples. δ^{13}C and δ^2H values were reproducible, with δ^{13}C values comparable to previous findings. This study supports the use of this methodology to precisely measure isotopic composition and its broad applications for future research.

High Throughput Structure-based Drug Design for TAS2R40
Abigail Park
Mentors: William A. Goddard, III, and Soo-Kyung Kim

Bitter taste receptors (TAS2Rs) are not only responsible for bitter taste perception, but also have been found to be expressed throughout the body. TAS2R40 has been associated with hypogeusia, or the loss of taste, and inflammatory obstructive lung disease. However, the lack of a crystal structure has hindered the development of selective ligands as new therapeutic targets. In this study, the 3D structure of the TAS2R40 bitter taste receptor was predicted using the GEnSeMBLE complete sampling method with TAS2R4 and TAS2R5 used as homology templates. Then, the binding mechanism of cohumulone, adhumulone, humulone, and isoxanthohumol to TAS2R40 was predicted using the DarwinDock complete sampling method. The predicted binding results correlate well with experimentally determined effective concentration of ligands to TAS2R40. Further, this study identifies potential drug targets to treat hypogeusia and inflammatory obstructive lung disease. These results will be experimentally validated by collaborators at the University of Arizona and University of Southern Florida and future studies will optimize the binding to enable investigation into TAS2R40s role in hypogeusia and inflammatory obstructive lung disease.

Transitioning Bias Tee in Superconducting Qubit Z-Control to Printed Circuit Board
Emily Parnell
Mentors: Oskar Painter, Eunjong Kim, and Xueyue Zhang

Quantum computers have the potential to exhibit exponential speedup for certain calculations. One quantum computing platform is superconducting qubits. The qubits are controlled by coupling them to microwave waveguides (XY control) and by applying a magnetic flux, also driven by a microwave signal (Z control). A bias tee is used to combine RF pulses and a DC voltage into the Z control signal. The RF and DC inputs are passed through low pass filters prior to the bias tee to minimize noise. Presently in the Painter lab, cables connect separate bias tees and LP filters, occupying valuable space in the dilution fridge. A printed circuit board (PCB) using surface mount LP filters and bias tees offers a more compact Z control setup. The PCB was designed and fabricated, and the available parts were soldered. Once remaining parts arrive, they can be soldered as well and the PCB will be tested.

Expression of Live Cell Reporters in Macrophages
Ekta Patel
Mentors: David Van Valen and Emily Laubscher

One method to improve antiviral therapies is through mechanisms that cause the host to be less susceptible to viral infection. To find targets of host directed antiviral therapies, signaling pathways need to be studied. Antiviral signaling pathways are complex and to clearly map them out, signaling dynamics of proteins in these pathways need to be observed. To study such proteins, a methodology for the expression of live cell reports in macrophages needs to be determined. Macrophages are hard to transfect with DNA due to their nonproliferative nature and activation in response to foreign DNA and so we propose to express reporters in macrophages via mRNA transfections. The mRNA is composed of less immunogenic nucleotides to decrease activation of macrophages. Preliminary transfections of EGFP mRNA composed of these special nucleotides into HeLa cells have been successful, and we are now trying to determine a working transfection protocol for macrophages.

Structural Effects of Bisphosphine Copper(I) Complexes in Photo-Induced Ullmann-Goldberg Reactions
Malik Paulino
Mentors: Greg Fu and Hyungdo Cho

Ullmann-Goldberg condensation, a cross-coupling reaction which forms carbon-nitrogen bonds between anilines or aryl amides with aryl halides, has been extensively developed due to the value of organic products that it could form. Copper salts catalyze this reaction but frequently require high temperatures to undergo its catalytic cycle. Applying these reactions to more general organohalide compounds, such as secondary or tertiary alkyl halides, are not very successful because the high temperatures also yield undesired elimination products. Copper chelated to certain BINAP-derived bisphosphine ligands can undergo photoexcitation at low temperatures upon exposure to blue or UV light and reduce an alkyl halide to an alkyl radical, via a single electron transfer. DTBM-SEGPHOS, a particularly bulky bisphsphine ligand, is one in a class of bisphosphine ligands that is known to endow this unique photochemical reactivity when coordinated to copper. It has been empirically driven that ligand bulkiness is positively correlated to the reactivity of the copper species. The goal of our study is to rationalize this behavior by observing the electrochemical and structural properties of similar bisphosphine-copper complexes with varying structures.

LATTICE: Autonomous Multi-Robot Control for Exploration in Extreme Lunar Conditions
Winter Pearson
Mentor: Soon-Jo Chung

NASA has identified the resources found in the permanently-shadowed craters on the Southern pole of the Moon as essential for the Artemis missions and associated goals of semi-permanent Lunar habitation. Yet, these craters pose extraordinary traversal challenges due to their low lighting, extreme angles (up to 40°) and depth, frigid cold (30 K), and highly abrasive lunar dust. We propose entering the crater only once to lay a Lunar Architecture for Tree Traversal In service of Cabled Exploration (LATTICE), a light-weight, modular series of stakes and cables, which can then subsequently be traversed by specialized shuttles. This cable-car-like design avoids subsequent contact with the ground, thereby mitigating the terrain concerns. Our research reveals the unique control theory challenges of cabled locomotion, stake placement and driving, and inter-robot coordination in these extreme conditions. After systematic experimentation, modeling, and simulation, we present preliminary solutions for optimizing the efficiency of LATTICE and similar systems when tackling these questions.

Genetic Research on the Newly Discovered Nematode, *Steinernema hermaphroditum*
Jackeline Peraza
Mentors: Paul W. Sternberg, Hillel T. Schwartz, and Chieh-Hsiang Tan

The free-living nematode worm *Caenorhabditis elegans,* has been widely used as a research system to study how genes are able to specify the development and function of animal structures and behaviors. While appreciating the many advantages of *C. elegans* for such research, we recognize its disadvantages, in particular its unsuitability for the study of selected biological processes. For this reason we are developing the entomopathogenic nematode *Steinernema hermaphroditum* as a model system, to use similar approaches to pursue research opportunities unavailable in *C. elegans*. *S. hermaphroditum* has a distinct lifestyle in the wild from that of *C. elegans*: where *C. elegans* is found in rotting fruit, entomopathogens such as *S. hermaphroditum* hunt insect prey, that they then invade and kill by exploiting a a mutualistic symbiotic relationship with a lethally toxic bacteria, *Xenorhabdus griffiniae.* This allows us to ask biological questions that have never before been accessible to investigation. In order to study the genetics of this newly discovered nematode, our lab team conducted several ethyl methanesulfonate (EMS) mutageneses that allowed us to perform genetic screens for the first time in this organism. These genetic screens allowed us to collect a number of mutants that will help us start exploring the unique biology of this newly discovered nematode. We have also embarked on a sequencing project that we hope will result in the first ever molecular identification of the gene responsible for a mutant phenotype in an entomopathogenic nematode.

Narrowband Metastable Helium Observations Detect an Atmospheric Outflow at TOI-1268b
Jorge Pérez González
Mentors: Heather Knutson and Michael Greklek-McKeon

The Neptune Desert delimits the regions close to a star where few Neptune-like exoplanets have been found. Processes like photoevaporation, where the planet's atmosphere is blown away by radiation from the host star, could potentially shape the boundaries of the Neptune Desert. Using a narrowband filter centered in the 1083 nm helium triplet absorption feature mounted on the 200-inch Hale telescope at Palomar Observatory, we observed the planet TOI-1268b, which is near the upper edge of the Neptune desert, to determine if there is excess absorption in the helium triplet indicative of atmospheric outflow. Having measured a lower transit depth in the helium bandpass than in the optica, obtained from TESS observations, we detect active photoevaporation in TOI-1268b.

Development of a Microfluidics System for Next-Generation Sequencing
Matthew Petillo
Mentor: Axel Scherer

Sequencing a strand of DNA on a large parallel scale remains a hard and expensive task. Using microfluidics presents an innovative new way to quickly move DNA and RNA for next generation sequencing without the cost of current instrumentation and methods. Presently, there is no routine method to use microfluidics to direct nucleic acids to parallel, high-speed sequencers. To develop a method to do this, a custom-fitted microscope was built to create an environment where DNA and RNA could easily be viewed through a microfluidics chip. DNA and RNA can automatically be channeled using solenoid valves with real-time control via a digital I/O board. Future development recommendations include building a machine learning algorithm that is able to detect when a piece of DNA is going through the microfluidics chip and the dimensions of the strand.

Characterization of the Role of Microbiome Members on the Chemistry of Natural Fly Food
Juni Polansky
Mentors: Nichole Broderick and Julia Kornfield

Drosophila melanogaster is a model host commonly used to study gut-microbe interactions. Such interactions play a crucial role in many processes such as host development, immunity, and maintaining homeostasis. However, in the general field of fly research, there is no standardized fly diet. Flies are often fed artificial diets that do not mimic what is found in nature, which calls into question the validity of applying lab results to characterizing flies in the wild. This project aimed to utilize a natural fruit-based diet to study the effect of different microbiome members on the chemical environment of fly food. Results validated previous findings in the lab that the presence of *Lactobacillus plantarum (Lp)* resulted in an acidification of fly food, while the presence of *Acetobacter tropicalis (At)* had minimal effect on acidity. A cocktail of both bacteria enabled *At* to buffer the acidification of diet by *Lp.* Interestingly, the acidic nature of the food itself also played an effect on these interactions by limiting the bacteria's ability to cause drastic pH changes. Cross-streaking experiments between *Lp, At, and Pseudomonas entomophila (Pe)* indicated that *Lp* inhibited the growth of *Pe*, and *At* was able to modulate this change. This pH data can be important in understanding the human microbiome and dealing with pathogens.

Genetically Encoded Ultrasonic Kinase Activity Biosensors
Sophie Polidoro
Mentors: Mikhail Shapiro and Jee Won Yang

Atypical kinase signaling is associated with various pathologies. But, because the poor penetration depth associated with optical biomolecular tools hinders their use for *in vivo* imaging, understanding complex mechanisms behind such signal transduction pathways requires new tools. Overcoming that limitation requires more penetrant energy sources like ultrasonic sound waves. Building on the properties of Gas Vesicles, which allow the use of ultrasonic waves for imaging, this study develops a genetically encodable biosensor for ultrasonic activity of Protein Kinase A (PKA). To identify promising biosensor candidates, we incubated variants with and without PKA to observe their differential collapse pressure based on the presence of PKA. We are currently optimizing the reaction kinetics of these candidates and characterizing attributes such as sensitivity to varying ATP concentrations and incubation time. Successively, because phosphatase specificity is not well studied, we expect to test multiple types of phosphatases in order to successfully accomplish dephosphorylation. We will also determine the tunability of the differential signal by designing gene constructs with multiple phosphorylation target sites to further exaggerate the confirmational collapse pressure change. Further work would involve expression in mammalian cells to study endogenous cellular mechanisms and develop biosensors for other cellular signals related to cancer immunology.

Machine Learning Guided Investigation of Polymers for Carbon Capture
Dylan R. Pollard
Mentors: Zhen-Gang Wang and Yasemin Basdogan

Membrane separation is the most efficient and environmentally friendly carbon capture method but nevertheless has its limitations. Polymer properties often cannot surpass a certain upper bound, and investigating the polymer property space past this upper bound is of great interest. To discover novel polymer compositions efficiently without random experimental trials, a machine learning (ML) method is used. Polymer properties are predicted via regression analysis on data from literature and are then fed into a genetic algorithm (GA) as a property prediction function (PPF). The GA cycles through the following: 1) fragmented polymer strings are converted to fingerprints and fed to the PPF, 2) fragments are scored based on a fitness function, and 3) the fragments are combined, crossed over, and mutated. The GA is functional, and promising polymers have been predicted past the upper bound with realistic predicted property values. The most common functional groups discovered among the best-fitted polymers are pyridine-3,5-diyl and the combinations of arenes and azaarenes. Current work involves algorithm tweaking and data collection optimization, and in the future we hope to experimentally test and/or simulate the properties of the most promising predicted polymers.

Modeling the Effects of Dark Matter Decays on Halos and Subhalos
Juan Quiroz
Mentors: Andrew Benson, Ethan Nadler, and Philip Hopkins

Dark matter makes up a significant portion of the universe, but its nature remains unknown. In the decaying dark matter model, a massive dark matter particle decays into less massive daughter particles in lifetimes comparable to the age of the universe. Decaying dark matter can potentially maintain some of the large-scale successes of cold dark matter, while fixing some of its issues on small, non-linear scales. In this project we aim to model dark matter decays in GALACTICUS, a semi analytic model for galaxy formation and evolution. GALACTICUS is computationally inexpensive compared to N-body simulations, allowing for larger samples and exploration of the parameter space. New heating and dark matter profile classes were added to GALACTICUS in order to model the effects of momentum injection and mass loss due to dark matter decays on the structure of dark matter halos. We studied the effects of the decays on an isolated halo, finding that they flatten and reduce the amplitude of dark matter halos' inner density profiles. The results of the combination of dark matter decays and tidal heating on subhalos were also studied in order to test whether the combined effects of decays and tidal heating can completely disrupt subhalos.

Modeling Magnetic Field Structures in Low-Energy Plasmas
Rasool I. Ray
Mentors: Morteza Gharib and Sean Mendoza

To better understand the mechanics of atmospheric micro-plasmas, advancing the fundamental research of varying categories of toroidal magneto-plasmas is essential. Especially with the case of cold-type plasmas generated via electrostatic charge from mechanical and shear forces. In this work, a magnetic resonance device based on continuous-wave optical detection (CW-ODMR) was constructed to probe magnetic fluxes emanating from self-confined micro-plasmas in air. An ensemble of nitrogen-vacancy (NV) centers in diamond nanoparticles was employed as a sensor, resulting in a scalar magnetometer with 1.7μTesla/√Hz sensitivity. Additionally, a novel generalized formula for the 3D symmetric magnetic field structure was developed, and allowed us to generate robust theoretical models of our plasma using programs developed in Mathematica. This enabled us to achieve a universal theoretical model of our toroidal plasma. This universal theoretical model was also combined with our experimental model, derived from our magnetometer measurements, to further derive an accurate mathematical model of the geometric structure of the symmetric plasma torus itself. These robust models and formalisms will serve to advance the study of this phenomena, and will also lead to further advancements of potential industrial applications, such as improvements in microelectronics deposition techniques, plasma medicine, energy-storing plasmoids, and many more.

Better Understanding the Working Parameters of a Flextensional Energy Harvester
Juan Renteria
Mentors: Tim Colonius, Martin Saravia, and Luis Phillipe C. Tosi

In-situ power generation in mechanical systems is an attractive alternative to cabled power, potentially offering lower operational and maintenance costs for poorly accessible sites. Previous work at Caltech showed that harvesting energy through fluid-induced vibrations of a piezoelectric material mounted to a flextensional structure and an oscillating, cantilever beam offered substantially longer longevity than similarily-sized turbines. Recent theoretical analyses suggest, however, that an electromagnet would provide higher power output than a piezoelectric element. The harvester was redesigned to characterize the effect of the transducer's increased mass on the oscillation of the beam. After assembly, the oscillation frequency and pressure were measured for various masses as a function of flow rate. High-speed videos of the cantilever beam during oscillatory motion were recorded for future analysis. The results provide a map of the flow-rate bifurcation point as a function of mass, which will be used to measure the efficacy of the new design.

Implementing Molecular Dynamics Simulations to Predict Critical Residues in a Dalotia Gland Specific Laccase
Milan Robinson
Mentors: Joseph Parker and Jean Badroos

Protein systems do not stay in their respective ground states and it has historically presented a challenge to predict which configurations these proteins can achieve as well as which ones they are currently in at any given time. Using molecular dynamics (MD) software combined with machine learning, predicting the future movements and orientations of these proteins is now possible. The aim of this project is to computationally predict which residues in Decommissioned (Dmd), a Dalotia laccase specific for gland function, are of critical importance to the system. This is done by implementing a Predictive Information Bottleneck (PIB) and deep neural network to predict aspects of the biomolecular trajectory. The kinetic information from the PIB will help advise what mutants will be produced with reconstituted DNA *in vitro.* Conclusions from these simulations can better inform design principles and give information about Dmd's metastable states and the pathways used to move between them. The resulting mutants will give more information about the natural thermodynamic inclinations of the Decommissioned laccase and how these properties can be altered.

Spectroscopic Measurements of Protoplanetary Disks With Keck NIRSPEC-AO
Clara Ross
Mentor: Geoffrey Blake

Upcoming JWST programs promise to revolutionize our understanding of planetary formation by enabling us to trace the molecular structure of the terrestrial planet-forming regions around young stars. However, ground-based observations are needed to constrain the spectral and spatial components of the emission features. To this end, we used the NIRSPEC-AO spectrograph on the Keck II telescope at Mauna Kea Observatory to measure CO emission across the 4.5 to 5.5-μm orders for a selection of protoplanetary disks. Multiple sources were targeted over different nights, with the spectrograph's slit positioned at different angles to extract spectra across the major and minor axis of each disk. We prepared an open-source data reduction pipeline to extract 1D calibrated spectra, and processed data from a selection of stars that have upcoming JWST MIRI time. The reduced Keck data will be added to a public repository of protoplanetary disk spectra, and we will be able to analyze the CO line profiles to map the molecule within the near-IR emitting inner regions of the protoplanetary disks.

To Develop a Synthetic Platform to Support Embryogenesis in Vitro
Silas Ruhrberg
Mentor: Magdalena Zernicka-Goetz

Abstract withheld from publication at mentor's request.

Nonlinear Model Predictive Control of a 3D Hopping Robot
Igor Sadalski
Mentors: Aaron Ames and Noel Csomay-Shanklin

Model based control has demonstrated broad success on a variety of robotic platforms. Most if not all demonstrations rely on the use of simplified models, due to computation challenges with using the full order dynamics. The use of these reduced order models limits theoretical justification. We explore the extent to which a formally justified dimension reduction (outputs and zero dynamics) can be used to enable online model predictive control on the full order dynamics. Our approach aims at using the actuated coordinates to control the underactuated coordinates. Observing that for the hopping robot, the orientation of the robot does not impact the center of mass trajectory while in the flight phase and that the orientation is completely controllable, we do not need to optimize MPC while in the flight phase. Therefore, when executing MPC, the flight phase can be ignored in a theoretically justifiable way. We demonstrate success in simulation and on custom developed robotic hardware.

UAV Navigation in the Dark With Thermal Cameras
Varun Saketharam
Mentors: Soon-Jo Chung, Matthew Anderson, and Michael O'Connell

Visual-Inertial Odometry is becoming increasingly common in autonomous navigation due to its ability to provide state estimates to vehicles. The project aims to achieve robust autonomous navigation by improving visual-based navigation in case Global Positioning System (GPS) based navigation fails. The thermal sensor has the potential to outperform the tracking camera due to its capability to detect objects based on temperature and uninterrupted detection in darkness. To incorporate a thermal camera into the system, an appropriate Visual Inertial Odometry (VIO) algorithm must be integrated with the camera. In this work, the T265 tracking camera is used to provide ground truth for data comparison. In this paper, we compare several VIO algorithms and demonstrate why VINS-fusion is the most optimal algorithm for vision-based navigation. The algorithm and camera interface takes place through Robot Operating System (ROS). As a continuation of this work, thermal and tracking cameras will be attached to the vehicle and tested in the dark. The resulting position data from camera tests will be used to generate a position graph. This data should inform differences in detection performance between the T265 and thermal cameras.

Magnetic Susceptibility Response of Neodymium Based Quasicrystals
Omar Salas
Mentors: Thomas Rosenbaum and Daniel Silevitch

Quasicrystals are a group of materials with semi-periodic translational order on a molecular level. These materials show rotational symmetries forbidden by the crystallographic restriction theorem. We perform ac magnetic susceptibility measurements on Neodymium-based quasicrystals using a Physical Property Measurement System and a sample holder we designed to probe the magnetic response of the material. We measure the magnetic susceptibility as a function of frequency (1 Hz to 1 kHz) and temperature (1.7 K to 300 K) using a differential magnetic susceptometer involving two sets of coils to reduce background contributions. The data is analyzed to differentiate between long-range ferromagnetic or antiferromagnetic order, short-range spin glass order, and possibly superconductivity.

Atomic Layer Etching (ALE) for Superconducting Microresonators
Ciro Salcedo
Mentors: Austin Minnich and David Catherall

Superconducting microresonators are essential components for superconducting qubits and MKIDs, but suffer from noise due to two-level systems caused by physical defects in the amorphous dielectrics on their surface, pattern impurities, and stray polar molecules. ALE's single atomic-layer control enhances the uniformity of etching processes minimizing these defects, however it is more often performed on metal oxides than metals as the latter's higher electron mobility impedes bonding between the surface and reactant. Using SF_6 to modify the surface of alumina and an argon plasma to remove said layer in an ICP-RIE, an etch of alumina was confirmed by ellipsometry. Further testing will confirm the self-limiting nature of the observed reactions to prove the process is ALE. Should this ALE recipe be achieved on alumina, the method could be applied for a directional etch of aluminum using controlled oxygenation of the metallic surface followed by an alumina etch process.

Nano-Architected Composite: Energy Absorption and Mechanical Response of Various Composited Nano-structured Sheet Configurations at Various Strain Rates
Yahriel Salinas-Reyes
Mentors: Julia Greer and Kevin Nakahara

Nano-architected sheets can manifest unique combinations of mechanical properties at low densities, namely, energy absorption, high load tolerance, and impact resilience. Herein we demonstrate the creation of composite nano-structured layers (outer dimensions 2.5cm x 2.5 cm and 30um thickness) made of periodic Su-8 nano-pillars (internal features 500nm in diameter) that are shown to exhibit load redistribution and high specific energy absorption capacity. These Su-8 photoresist nano-architected sheets are fabricated using a 3D laser interference lithography process enabled by meta surface mask (Nano-patterning). Next, we composited several secondary reinforcement phase systems into the nano-architected sheets (i.e. Diluted 2k-E Resin, Diluted 635-E Resin, PDMS, MPEC) to investigate varying mechanical responses from different nano-architected composite system configurations (interpenetrated and non-interpenetrated). Compression experiments of the varied nano-architected composites were done on a DMA at various strain rates (10^{-3}-10^{-1}), observing…_(*Work still to be done*)_. Results from depositing a secondary matrix phase thus provides insights into promoting ductile-like deformations and recoverability in the constituent material system (_enter what we use to verify results_). This study provides supporting evidence of material-phase interactions between nano-pillar structures and a secondary supporting matrix which may cultivate unique abilities (i.e. Energy absorption, impact resilience, load redistribution, etc.) in ultra-light material systems.

Extending Ensemble Kalman Methods for Climate Parameter Learning
Anagha Satish
Mentors: Tapio Schneider, Oliver Dunbar, and Eviatar Bach

In current climate models, most uncertainty comes from approximations of physical processes. Parameter learning at the Climate Modeling Alliance (CliMA) is done using Ensemble Kalman Inversion (EKI). EKI is a recently proposed inversion methodology based on the Ensemble Kalman Filter (EnKF) that provides a derivative-free optimization method for solving inverse problems. It is non-intrusive and works well with noisy models, making it ideal for climate modeling. However, there are limitations to basic implementations of the EKI, often caused by a large ensemble size and the assumption of Gaussianity. We studied inflation and localization extensions used to optimize the EnKF algorithm and replicated similar extensions with EKI. We then tested them on several examples: a harmonic oscillator, a sinusoidal curve, and the Lorenz96 dynamical system. Once transferred to CliMA's codebase, these simple examples, along with extensions to the methodology, will provide much needed accessible tutorials for future users of CliMA's EKI.

Natural Language Processing for Sequence Prediction to Build KTR Live Cell Reporter Library
Pranay Satya
Mentors: David Van Valen and Emily Laubscher

Previous studies have shown that single-cell behaviors are heterogeneous and can vary from what is considered as the overall state or dynamics of the broader system. Furthermore, there is a need for new live-cell reporters - current methods like fluorescence resonance energy transfer (FRET) have low signal-noise ratios (SNR) and are unideal for studying sensitive signaling mechanisms and kinetics. Kinase Translocation Reporters (KTRs) are a live-cell reporter system that utilize nuclear import and export as a marker for protein activity; they have a higher SNR making them a good alternative to FRET. We aim to use natural language processing methods, specifically the ESM transformer model, to design a computational library of kinase reporters that can be used to study a much larger range of kinases than is currently possible. We investigate the use of evotuning, where a model is trained on a more directed set of evolutionarily and statistically related sequences to guide its predictive abilities towards a certain class or family of protein. We will use an evotuned transformer to represent both kinase and phosphosite sequences and generate new candidates for the construction of new KTRs to study understudied kinases.

Resonant Amplification of Graphene Sheet Plasmons
Jason Schibler
Mentors: Harry Atwater and Arun Nagpal

The Dirac cones in monolayer graphene support a number of unique and interesting photonic phenomenon through the presence of unique interband relaxation channels. Two properties of graphene that are of great interest to the optics community are its high absorptivity to light in the monolayer limit and its ability to support highly confined surface plasmons in the infrared and terahertz. . It has been shown previously that exposing the graphene to a pulsed laser can induce photoluminescence which leads to a plasmonic emission pathway from 4 – 8 μm, a crucial window for molecular spectroscopy. By fabricating a variety of structures on the surface of the graphene that are resonant to the sheet plasmons, the plasmons can be amplified to ensure brighter emission. Plasmonic resonators with diameters from 1 – 3 μm were fabricated, in resonance with the sheet plasmons of monolayer CVD-grown graphene. Graphene was transferred to the device using a wet transfer technique before measurements were conducted in an FTIR with the graphene exposed to a Ti-Sapphire pulsed laser to bring about the emission pathway of interest.

Optimizing Size and Function of Magnetically Actuated Insulin Pump
Shelby Scott
Mentors: Ruike Renee Zhao and Guillaume Blanquart

Insulin pumps are a great way to reduce injections for managing type 1 diabetes. However, existing pumps are bulky and relatively imprecise. The objective of this project is to develop a pumping mechanism for reduced pump size with increased delivery accuracy. We propose a magnetically actuated pump that is ½ the size of the smallest available insulin pump and can deliver 0.02 units. This design utilizes the magnetic field from a sinusoidal coil to move magnetized, soft material to deliver insulin. In previous versions, flowmeter testing revealed backflow after extrusions, and coil overheating limited successful deliveries. Creating a model that repressurizes the insulin reservoirs after actuations significantly decreases the backflow. Increasing the area of soft material moved by the magnetic field allows for lower current deliveries, which reduces coil heating. Integrating these modifications allows for a functional insulin pump that is one step closer to becoming user ready.

Robustness in Bacterial Dosage Control
Aditi Seetharaman
Mentor: Richard Murray

Through the development of robust population level controllers, microbial consortia—multiple interacting microbial populations—can be engineered to perform coordinated bioprocesses beyond the behavioral limitations of single cells. Robustness, or the persistence of characteristics in a system despite perturbations, is a key component of complex evolvable systems; components of robust circuits exhibit limited variability under changing environmental conditions. Because the vertebrate gut is known to host microbial consortia that affect bioprocesses, microbial populations can be engineered to colonize the vertebrate gut and affect vertebrate bioprocesses. This project repurposes the *Vibrio fischeri* LuxI/LuxR quorum sensing system in a genetic circuit implemented in *Escherichia coli*, allowing communication between individual cells, in an effort to engineer microbes that can exhibit robust behavior in the zebrafish gut. We computationally evaluate the robustness of N-acyl homoserine lactone (AHL) production in six circuit architectures. After confirming the functionality of each circuit component, we determine the efficiency of one circuit architecture in an *E. coli* population by detecting AHL levels across varying external conditions.

Predicting Nitrogen Isotope Fractionation in Nitrate Deposition on Early Mars
Jaylen Shawcross
Mentors: Yuk L. Yung, Danica Adams, and Michael L. Wong

The habitability of early Mars was likely majorly impacted by nitrogen, which has undergone significant loss to space in the past 4 Ga after the shutoff of Mars' global magnetic field. ^{15}N, due to its heavier weight, escapes Mars at a different rate than ^{14}N and can be used as a constraint for ^{14}N's escape (Fox et al., 1993, Kurokawa et al., 2018). Before the transition from ancient Mars (likely warm and wet) to a modern, cold, dry Mars, nitrates were deposited on the surface and record the nitrogen fractionation imparted by planetary processes at the time of their formation. Processes influenced by the loss of Mars' magnetic field, including photochemistry, are responsible for the loss of the atmospheric nitrogen reservoir to space. Nitrogen escapes primarily through photochemical loss. High-energy photons from the sun collide with ambient chemicals in the atmosphere, splitting them and transferring enough energy to reach escape velocity. In a warm, wet early Mars climate, lightning may have split N_2 in the lower atmosphere, allowing atomic N to bond with other ambient species, forming NO_X. Nitrogen oxides (NO_X) may have implications for the origin of life by acting as a high-potential electron acceptor and source of fixed nitrogen for protometabolisms (Ducluzeau et al., 2009, Nitschke & Russell, 2013). This NO_X reacts with HO_X in the atmosphere to form HNO_X, which dissolves and precipitates out in rain. Eventually, the water component of HNO_X evaporates, leaving NO_X deposits on the surface (Adams et al., 2021a). Meanwhile, nitrate depositions could still form in a cold and dry climate by relying on SEP events for nitrogen fixation and ice particles for precipitation (Adams et al., 2021b). We use the Caltech/NASA JPL 1D photochemical model, KINETICS, to conduct simulations of early Mars in the Nochian epoch with various initial conditions and a primordial $^{15}N/^{14}N$ ratio of 1/270 Knowledge of the amount of nitrates and nitriles in Mars' early history will help put future astrobiological investigations in the context of Mars' atmospheric evolution and potential habitability.

Remote Administration of a Visual Matching Interhemispheric Transfer Test to Capture Individual Variation in DCC Adults
Bre' Anna Sherman
Mentors: Ralph Adolphs and Lynn Paul

The corpus callosum is the main bundle of nerve fibers responsible for communication between the hemispheres of the brain. For those with dysgenesis of the corpus callosum (DCC), that bundle develops abnormally, if at all. The symptoms of DCC may include developmental delays, physical impairments, and social processing deficits.

However, the core consequence of DCC is restricted information transfer between the brain hemispheres. We have constructed an online visual-matching task to measure interhemispheric transfer. In each trial, two stimuli are presented, unilaterally or bilaterally, around a central fixation point and the participant must indicate if the stimuli match. The stimuli pairs will vary in complexity (e.g. letters of same or opposite case; symbols with or without a clear meaning). Accuracy and reaction time measurements represent the effectiveness of information transfer within or between hemispheres. For neurotypical participants, we expect a bilateral field advantage (BFA)—that is, an increase in accuracy and reaction time when symbols are presented bilaterally. For DCC participants, however, a BFA is not expected due reduced or absent callosal connections. The aim of this project is to create an accessible and wide-reaching platform for studying variability in interhemispheric transfer of visual information among individuals with DCC.

GA Ansatz Optimization on a QAE for HEP Anomaly Detection
Thomas Sievert
Mentors: Maria Spiropulu, Jean-Roch Vlimant, S. Davis, and N. Lauk

The Standard Model (SM) of High Energy Physics (HEP) has proven itself to be one of the most accurate scientific theories ever formulated. It is no surprise that current HEP research progresses slowly to find the correct Beyond Standard Model (BSM) extension. While experiments like the Large Hadron Collider (LHC) can directly probe exotic phenomena, such experiments produce an overwhelming amount of data. Therefore, it becomes imperative to develop techniques to easily sift through the background, SM processes and identify the new, BSM physics. Furthermore, because the BSM deviations could be caused by any number of theoretical BSM processes, current HEP anomaly detection should be as model-agnostic as possible, while remaining highly-sensitive. We propose to further develop anomaly detection algorithms using breakthrough quantum machine learning techniques. To go beyond fixed-ansatz quantum circuits models, we propose a meta-optimization of ansatz using a Genetic Algorithm (GA). The models and optimization are benchmarked on the LHC Olympics 2020 dataset, an already well adopted dataset when it comes to evaluating anomaly detection performance.

Realisation of Chiral Interfaces for Superconducting Qubits
Štěpán Šmíd
Mentors: Mohammad Mirhosseini and Chaitali Joshi

Quantum computing and information processing is an immensely prospective subject due to its ability to carry out calculations infeasible for any present or future classical computer which presents unimaginable applications throughout a variety of fields. But despite steady experimental progress, the physical implementation of such quantum systems presents many challenges till this day, most of which come from scaling the complexity needed for real applications. One of the leading modern approaches to overcome this comes from creating a modular quantum network of superconducting qubits coupled to a microwave photon waveguide. To prevent information back-flow, chirality can be built into the network using unidirectional photon emitters and absorbers. This non-reciprocal behaviour would have immediate applications for deterministic state transfer. To carry out calculations using the qubits, it is important for them to have low relaxation rate; this can be achieved using a bandpass filter, which decreases the relaxation rate while maintaining the measurement rate.

The primary objective of this project was to design and further analyse a metamaterial which, when coupled to the waveguide, would act as a bandpass filter. Such a behaviour can be achieved using an array of capacitively coupled resonant cavities, with tapering region on both ends tuned to match the impedance of the waveguide to maximise the transmission. The design process was mainly carried out in high-frequency ideal circuit simulator Microwave Office and electromagnetic field simulator Sonnet.

Direct Measurements of the Transport Properties of Sediment Aggregates in a River Delta
Isaac Smith
Mentors: Michael Lamb and Justin Nghiem

In water, the fine particles composing mud aggregate into clumps called flocs in a process called flocculation. Flocculation in rivers controls sediment transport, affecting erosion, sedimentation, and pollutant residence time in riverbeds because flocs settle much faster than the particles composing them. Most prior research studied flocculation in saline environments, but recent work shows flocculation is common in freshwater rivers and deltas and might regulate the transport and deposition of fine sediment in those environments. To test this, we analyzed several time series of images of settling flocs from different environments in Wax Lake Delta, an actively accreting freshwater river delta in Louisiana, to determine settling velocities and sizes of the flocs. We developed particle tracking velocimetry and particle image velocimetry methods to determine the motion of the flocs and the water, respectively. We extracted sizes and settling velocities of the flocs and compared them at different locations in the delta – distributary channels, secondary channels, and shallow wetlands. We expect floc size and settling velocity to be greatest in distributary channels, smaller in secondary channels, and smaller still in shallow wetlands. Areas where flocs settle faster will have faster sedimentation and be more resilient to erosion and rising sea levels.

Solving the Mystery of Life on Mars Using Sulfuric Isotopic Fractionation and Impact of Novel H_2O Cross Sections on Abiotic Anoxic Carbon Dioxide Nitrogen Rich Atmospheres
Kayla Smith
Mentors: Yuk L. Yung, Danica Adams, and Christopher Blaszczak-Boxe

The search for if there is or once was life on Mars has been an ongoing phenomenon for decades. Terrestrial sulfur isotopes are fractionated by atmosphere processes, geology principles, and microbial life. Measurements of non-zero S isotopic fractionation were made from analyses of Mars rock aged 1.3 Ga (billion years ago). I adapted the Caltech/JPL 1D Photochemical/transport one-dimensional model from Venus to Mars. I added in about 20 new sulfur species into the Venus model. In doing this, one of the main tasks that I had was to I was given was to merge the reactions between the KINETGEN and kindata files and make sure that all of the reaction numbers were corrected and changed within the code to match the new database brought over from Venus. I have worked to make the Venus source code run smoother in application to Mars, and eventually eliminate all of the code errors. More recently, I added species into the fully adapted Mars model which allowed the model to incorporate more sulfur abundances. The four main stable sulfur isotopes are ^{32}S, ^{33}S, ^{34}S, and ^{36}S. Adding all of these isotopes into the code is essential for analyzing the full spectrum of sulfur in the Martian atmosphere. We will be able to analyze the fractionation of each isotope and how that shifts when more sulfur is added to the code. Finding life on planets other than Earth has been an ongoing investigation for decades, especially at Mars. Earlier in its history, Mars likely had a thicker atmosphere enriched with greenhouse gases, which would explain its inferred large amounts of surface liquid water in its past. In this work, we implement two H2O(v) absorption cross section datasets to quantify the effects that they have on the photochemistry and atmospheric escape in abiotic anoxic atmospheres, considering Mars as an example. I have created mixing ratios for NOy, COy, and Oy species. I quantified the difference of the chemical loss timescale, reaction contribution to species formation and destruction rates, reaction rates, production and loss rates, generalized scale height, generalized diffusion coefficient, effective wind velocity, and flux. As of right now, I am analyzing the water vapor at a range of latitude from 2km-92km. Utilizing a photolytic chemical algorithm to verify our output files and the photolytic reactions active in our code.

Safe Exploration Methods in High Dimensional Spaces
Saraswati Soedarmadji
Mentors: Yanan Sui, Yunyue Wei, and Yisong Yue

Bayesian optimization (BO) is a well-established approach for sequentially optimizing black-box functions, i.e functions without closed form expressions or gradient information. This sample-efficient method for optimization has been effective in a number of real-life applications, including hyper-parameter tuning and robotics. In addition, many recent works have successfully extended BO to safety-critical applications, such as medical therapies and machinery applications. In such applications, safety guarantees are critical, as a single failure can lead to costly consequences. However, despite its great success in various applications, BO is often limited to the optimization of low dimensional objective functions, as the global optimization of high-dimensional functions can be forbiddingly expensive and is often infeasible. Already, problems with 10 and more dimensions can be challenging for general BO if they need to be optimized with high accuracy. Of course, for many problems such as robotics 10 parameters is all that is needed. However, to advance the state of the art, it is necessary to scale the methodology to higher dimensional parameter spaces. Thus, in this project, we study important characteristics of high dimensional objective functions and their safe regions, and use these results to develop safe optimization methods in high dimensional spaces.

Mapping Arctic Permafrost and Floodplain Evolution Using LiDAR
Vincent Soldano
Mentors: Mike Lamb, Kieran Dunne, and Madison Douglas

To better understand how permafrost affects geomorphic processes in cold environments, it is important to know the extent of the underlying permafrost. However, mapping permafrost is difficult because it is buried, and existing permafrost maps are generalized over broad areas. LiDAR is used to map the topography of the land surface beneath the vegetation layer, offering insight about the evolution of the Yukon River floodplain near Beaver, Alaska. The LiDAR imagery was used to create a relative age map that provides insight into the evolution of the floodplain. Previous studies have shown how certain types of vegetation can indicate permafrost extent. Using geographic information systems, I have created a map of the region including layers that show bare-Earth deposits (LiDAR imagery), the relative age of these floodplain deposits, Landsat surface imagery of floodplain features that indicate permafrost, and the USGS National Land Cover Database that differentiates vegetation that can imply whether permafrost is present at a given location. Together these layers may help to create a permafrost map with a much higher resolution than is currently available. The map will be used and tested by the Lamb group during the 2022 Alaska field campaign.

[2+2] Cycloadditions of Vinyl Cations and Olefins
Alex Solivan
Mentors: Hosea Nelson and Zhenqi Zhao

The [2+2] cycloaddition is a reaction which produces four membered rings through addition of double or triple bonds. According to the Woodward-Hoffmann rules, the [2+2] cycloaddition is forbidden under thermal conditions but photochemically allowed. A [2+2] cycloaddition between a vinyl cation and alkyne can also occur according to the Woodward-Hoffmann rules; further research into these sort of ring-forming reactions would allow access to a larger number of complex molecules including natural products and small molecule therapeutics. Substrates containing both olefin and triflate moieties were synthesized. The triflate group was then abstracted to form vinyl cations formed using weakly coordinating anions. These substrates then underwent a [2+2] cycloaddition reaction to form more complex ring structures.

Extending Polytopic Matrix Factorization to the Underdetermined Case
Leyla Sozen-Kohl
Mentors: Deniz Yuret, Alper T. Erdogan, and Chris Umans

Matrix factorization is a well-established tool in various machine learning algorithms. Polytopic Matrix Factorization is a generative model which takes some samples drawn from a particular polytope and represents input data as linear transformations. Because there is an infinite choice of polytopes, we have flexibility in generating latent vectors with certain properties that boost the performance. In our semi-structured approach, the input matrix is modeled as a product of two factors, each unknown. We can utilize assumptions on either factor to perform the decomposition. The (over)determined case where the columns of the right-factor are latent vectors and the left factor is a full column rank matrix representing the linear transformation taking latent vector to inputs has been studied extensively. In this paper, we investigate the (under)determined case in which the left matrix has more columns than rows and study the class of polytopes for PMF under this constraint.

Intervening Galaxy Analysis of Localized Fast Radio Bursts
Reynier Squillace
Mentor: Vikram Ravi

Fast Radio Bursts (FRBs) are millisecond-range pulses of extragalactic radio emission with uncertain origin. The propagation of FRBs can be used to derive properties of the optically thin matter through which they pass. Thus, with the high resolution of the Deep Synoptic Array-110 (DSA-110), there exist an increasing number of localized FRBs such that specific, identified galaxies may be analyzed through FRB dispersion. In this project, we used catalogues to search for intervening galaxies and approximated their magnitudes via aperture photometry. With these magnitudes, we modeled the Spectral Energy Distributions (SEDs) of candidate intervening galaxies and fitted them using statistical software to estimate redshift, mass, and Virial Radius. The results from this project will be used to characterize the baryonic halo mass of the galaxies in question and to constrain the dispersive effects of the FRB host galaxies.

Wearable Biosensors for Continuous Health Monitoring
Chrystalen Stambaugh
Mentors: Wei Gao, Canran Wang, *Juliane Sempionatto, Changhao Xu, and Minqiang Wang*

Wearable sensors, unlike blood testing, can provide real-time quantitative information on patients' health through the measurements of analytes in biofluids (such as sweat and wound fluid). Enzymatic sensors, by analyzing glucose levels, can give insight into a patient's blood glucose levels when sampling sweat. Electrolyte sensors, through the analysis of sodium, potassium, ammonium, etc. can inform on patient hydration levels. Integrated together in an array, these sensors can provide information on patient stress levels, allowing more personalized stress management. Sampling wound fluid, nitric oxide sensing chemical sensors can inform on patients' wound status in real time, providing key information for wound assessment in patients with chronic wounds caused by conditions like diabetes. Here, we discuss three types of sensors for continuous health monitoring, presenting preliminary findings.

Effects of Water Temperature on the Evolution of Permafrost River Channels
Mavis Stone
Mentors: Michael Lamb and Kieran Dunne

The Arctic is one of the fastest warming places on the planet, raising concerns about the effects of climate change on its permafrost environments. About a quarter of Arctic terrain is underlain by permafrost, a substrate characterized by sand, rock, soil, or organic matter that has been frozen for at least two or more years, often containing high concentrations of heavy metals and organic carbon. Many fluvial systems throughout the Arctic incise through permafrost, creating what are known as permafrost river channels. Permafrost river channels are hypothesized to be controlled by seasonal water temperatures and flow regime, but the onset of climate change could lead to higher permafrost thaw and erosion rates, consequently displacing local communities and affecting regional water quality and the global carbon cycle. As such, a mechanistic understanding of permafrost morphology and evolution is vital to understand how fluvial systems in the Arctic may be responding to rapidly warming temperatures. In this study, we simulate a small-scale permafrost river channel to quantify the effects of rising water temperatures on two mechanisms: permafrost thaw and erosion. We allow our rivers to self-channelize within an experimental flume, replicating permafrost river channel formation for a range of imposed water temperatures. Using infrared and LiDAR imaging to measure the thaw rate, erosion rate, and river channel geometry, we thus explore how permafrost river channels respond to changes in water temperature, providing insight into how Arctic river migration will behave under a warming climate. (243 words)

Maintaining Gene Silence: Interacting Domains Between HP1α and SETDB1
Michael Sullivan
Mentors: Alexei Aravin and Qing Tang

Heterochromatin is a unique aspect of a cell's life cycle. It stays in the nucleus of eukaryotic cells and remains condensed throughout the entire cell cycle. Heterochromatin is responsible for the silencing of genes that come into close contact with it. In humans, this can prevent certain diseases such as cancers, schizophrenia, and gastrointestinal diseases. To function properly, heterochromatin must have a higher-order structure that is signaled by the methylation of lysine 9 on histone 3. This epigenetic mark, made by SET Domain Bifurcated Histone Lysine Methyltransferase 1 (SETDB1), acts as a binding site for Heterochromatin Protein 1 (HP1) to organize the heterochromatin. HP1 and SETDB1 have been found to interact with each other, although the domains and mechanisms of this interaction remain a mystery. In this experiment, plasmids for truncated forms of HP1 alpha are produced using transformation in e. coli cells. These plasmids are used to synthesize truncated proteins via transfection in HEK293T cells. Protein-protein interaction is then identified using co-immunoprecipitation and western blotting to determine which domain of HP1 is responsible for the interaction with SETDB1 and therefore heterochromatin structure. Preliminary Results show that the chromodomain on HP1 is responsible for interacting with SETDB1.

Approximating the von Neumann Entropy of Unknown Quantum States via Classical Shadow Tomography
Bharathan Sundar
Mentors: John Preskill and Andreas Elben

In quantum information theory, randomized measurements (RMs) are used to understand unknown systems by measuring randomly rotated versions of a quantum state. We rely on the classical shadow formalism, which allows us to use RMs to store a "shadow" of our state efficiently in classical memory. From these, we can obtain approximations to polynomial functions of the density matrix directly. We wish to estimate the von Neumann entropy (vNE), the quantum mechanical analogue to the classical Shannon entropy. The vNE characterizes the amount of information in a quantum system, and can also be used to derive entanglement measures. Since vNE is non-polynomial, we first obtain a general-form polynomial approximation to the vNE to arbitrary degree. Drawing on the theory of U-statistics, we construct unbiased estimators for these polynomials, from our classical shadow. We then analytically obtain bounds on the variance of our estimators, and the number of randomized measurements required for an ε-accurate approximation. We also present a method for determining an optimal truncation (polynomial degree) for our estimator a priori.

Light Output and Single Photoelectron Studies of LYSO Crystals for the Barrel Timing Layer at the Compact Muon Solenoid
Kai Svenson
Mentors: Maria Spiropulu and Anthony LaTorre

The Large Hadron Collider is undergoing major renovations to increase its beam intensity. Consequently, the Compact Muon Solenoid (CMS) will require an improved temporal resolution in order to statistically accommodate the increased frequency of particle collisions. A Barrel Timing Layer (BTL) composed of LYSO scintillation crystals is being added to CMS with a goal to achieve a temporal resolution of 30ps. The resolution strongly depends on having a high scintillation light output. We construct a modular testing device that takes light output measurements from 16 different LYSO crystals at a time. The light output is measured by taking the ratio of a 511keV signal from sodium-22, and the signal from single photoelectrons (SPEs). In the BTL production stage, the SPE signal will need to be measured with randomly occurring (dark) SPEs. However, a 407nm picosecond pulse laser can be used to induce SPE generation, yielding a more accurate signal measurement. I have written software that aims to robustly take SPE and light output measurements using both methods, and found only a 2.48% error in the dark method. The software will be used by several institutions around the world to measure the light output of thousands of LYSO detector modules.

Resilience of the Surface Code to Error Bursts
Shi Jie Samuel Tan
Mentors: John Preskill and Christopher Pattison

The standard circuit-level noise model in quantum error correction is typically used to model the noise experienced by the qubits in quantum computation. However, error bursts - noise during a single timestep that occurs with high probability - can occur when qubits are exposed to cosmic rays or during the transduction process required for transmission over a quantum network. In this work, we use Stim and PyMatching's Minimum Weight Perfect Matching (MWPM) decoder to simulate and analyze the performance of the surface code against error bursts. We describe a model of the logical error rate that accounts for error bursts and demonstrate the effect of an error burst on the logical error rate. We also estimate the accuracy threshold for error bursts and produce a phase diagram for the accuracy threshold with respect to the error burst rate and physical error rate. Moreover, we consider the case where the MWPM decoder does not know at what time the error burst occurred and study how the logical error rate of the surface code varies with error burst densities.

Reaction Kinetics of the Chlorination of CeO_2 With $ZrCl_4$
Asmat Kaur Taunque
Mentors: Michael Simpson and Richard Flagan

It has been proposed to convert spent nuclear fuel from current commercial nuclear reactors into new fuel for future advanced reactors via a chlorination process. In this project, chlorination of rare earth fission products found in the spent fuel was studied using cerium oxide. By reacting pre-vaporized zirconium chloride with cerium oxide pellets in a eutectic LiCl-KCl molten salt, the cerium oxide was chlorinated to cerium chloride. Once in the molten salt, cerium can be either immobilized in waste forms or recovered on a cathode after electrolysis in the molten salt. It is hypothesized that the chlorination reaction is governed by a diffusion limited shrinking core mechanism due to the formation of a ZrO_2 ash layer around the cerium particles. This research focuses on understanding the kinetics of this reaction by analyzing cross-sections of the cerium pellets after chlorination and by analyzing the time dependence of cerium concentration in the molten salt. Cerium has been identified in the salt by observing peaks through CV (cyclic voltammetry) and data from ICP-MS (inductively coupled plasma mass spectroscopy) tests. The obtained data is useful for fitting a kinetic model to fractional conversion of cerium oxide into cerium chloride versus time. Once the model is completed, it can be used to optimize process parameters for scale-up and commercialization.

Synthesis and Printability Analysis of 3D Printed Kevlar Nanocomposite Materials
Janet Teng
Mentors: Chiara Daraio, Israel Kellersztein, and Joong Hwan Bahng

To synthesize new materials that exhibit enhanced physical characteristics (e.g. increased strength and toughness), understanding the connection between a material's composition, structure, and property is essential. In this project, we explore the relationship between aramid nanofibers (ANF) to the nanocomposite properties fabricated via two-photon lithography (TPL) by analyzing the structures' shrinkage under varying ANF concentrations in a custom thiol-acrylic photoresist, where the writing conditions are determined through dosage tests. Following the dispersion of ANF in the final resin containing thiol, acrylate, and photoinitiator, cylinder and woodpiles structures are fabricated using TPL. Then, the dimensions and shrinkage of these structures are analyzed through the scanning electron microscope. In our results, we expect to observe decreasing percentage of structural shrinkage as the concentration of ANF increases. By investigating the connection between ANF thiol-acrylic resin and its printability capabilities for TPL, future nanocomposite materials research will benefit from this fundamental understanding.

Examining the Role of Grain Size in River Sediment Aggregation With Lab Experiments
Kenny Thai
Mentors: Michael P. Lamb and Justin A. Ngheim

During transport in rivers, small particles, particularly in the fine silt and clay range (smaller than 60 μm) naturally tend to flocculate, or form composite structures known as "flocs." These flocs settle to the bottom of river channels faster than unflocculated particles. This effect makes understanding the conditions under and the extent to which flocculation occurs essential for accurately modeling sediment transport in rivers. Clay's impact on flocculation has been studied in previous experiments, but the flocculation of sediment with little to no clay is largely unexplored. This research examines whether flocculation can occur when nearly all suspended sediment is silt or fine sand. We repurpose an abrasion mill to simulate conditions of a river. We suspend silt in this 8-inch diameter pipe using a rotating paddle to observe sediment particles and flocs in situ. We vary sediment concentration, concentration of known organic matter flocculating agents, and sediment mineral composition. The resulting flocs (or lack thereof) are studied through imaging and concentration vertical profiles, in which we measure light obscuration at various heights as a proxy for sediment concentration. Understanding the conditions in which silt-based sediment flocculates will greatly improve our ability to model deposition rates in silty rivers.

Using Data Augmentation to Learn Heading Invariant Dynamics
Jacob Thompson
Mentors: Soon-Jo Chung, Matthew Anderson, and Michael O'Connell

The Neural-Fly deep-learning-based adaptive tracking controller has been demonstrated to robustly adapt to rapidly changing wind conditions, significantly outperforming state-of-the-art quadcopter tracking controller performance by dividing the prediction of unmodeled aerodynamic effects into an online wind-condition-dependent adaptive control component and an offline domain-invariant deep neural network (DNN)-generated component. The current DNN implementation is dependent on yaw angle, forcing the UAV to maintain constant eastward attitude, and is independent of altitude, preventing robust prediction of both near-ground and far-ground aerodynamic effects. We first rebuilt the DNN, removing dependence on yaw angle and adding dependence on ground altitude. We then built, tested, and used a modular trajectory-plotting software to generate random spline trajectories at various heights above the ground to train the DNN outdoors. After training, we will determine what DNN architecture provides optimal tracking performance, and how this depends on training data used. In addition, we will cross-validate indoor data and outdoor augmented data to determine if imitating windy conditions and artificial vehicle states provides comparable performance to actual data. Together, these changes will confirm whether modern data augmentation techniques enable better training and generalization of Neural-Fly, further improving the performance and utility of the controller across domains.

Historical Narratives of Water in the San Joaquin Valley
Oliver Tom
Mentors: Hillary Mushkin and Brian Jacobson

California is currently facing an unprecedented water crisis. The San Joaquin Valley is the heart of the state's agriculture, feeding people throughout the U.S. and around the world. Yet, many of its residents are facing severe water shortages and water stored in its underground aquifers is being extracted faster than it can be replenished, causing the land's surface to drop dramatically.

The Valley's hydrology has been fundamentally altered by various infrastructural projects constructed throughout the 19th and 20th centuries. Discussions of the water crisis, however, have often been dominated by solely scientific and economic explanations for current conditions. Through a humanistic analysis of textual and visual archival materials, this project focuses on the various ways water has been perceived and communicated. By disentangling the interwoven narrative histories of water, the human decisions and socio-political contexts that underlie the history of the Valley's hydrology are made visible.

Measuring α-Synuclein Aggregates to Determine the Impact of Parkinson's Disease on the Enteric Nervous System in the Gut of Model Mice
Matthew Torres
Mentors: Sarkis Mazmanian and Matheus de Castro Fonseca

Parkinson's disease is linked with the overexpression of a gene which codes for the protein α-Synuclein (αSyn), which then aggregates in clumps called Lewy bodies and causes neurons to malfunction. Besides the characteristic motor impairment, patients with Parkinson's disease are also known to suffer from gastrointestinal symptoms. Despite this established link, further work is required to determine how enteric neurons are affected. Using the Thy1-hSNCA mouse model, which presents αSyn overexpression, we performed dot blots and confocal fluorescence microscopy to locate and quantify αSyn aggregates in the gastrointestinal tract. Through the dot blot technique, we found that αSyn aggregates are present in higher amounts than the wild-type in stomach lysates of animals at 2 and 5 months of age, but not in significantly higher amounts in other gastrointestinal tissues. In addition, at 2 and 5 months of age, animals already present brain αSyn inclusions even though no motor or gastrointestinal impairments are found. The results of this study result in a baseline to then compare against further experiments that hope to reduce αSyn levels in the gastrointestinal tract.

Water Absorption in the Dayside Emission Spectrum of WASP-19b
Abigail Tumborang
Mentors: Heather Knutson and Jessica Spake

Here, we present a detailed analysis of the atmospheric properties of WASP-19b, a large hot Jupiter exoplanet (~ 1.17 M_{Jup}, ~ 1.39 R_{Jup}) orbiting a 5,568 K host star (~ 0.97 M_{sun}, ~ 0.885 R_{Sun}) every 0.789 days. A secondary eclipse of WASP-19b was observed with the *Hubble Space Telescope'*s Wide Field Camera 3 spectrograph with a wavelength coverage of 1.1 – 1.7 μm. Our analysis of the observations has shown a slight water absorption feature on the planet's dayside hemisphere at around 1.36 – 1.48 μm. We fit our measured eclipse spectrum with an atmospheric retrieval model and found a dayside temperature of 2,452 K. By comparing the model to a best-fitting blackbody spectrum, we obtained a relative water feature strength of 0.136 ± 0.039, consistent with other exoplanets with similar properties. These results appear to indicate that despite being a hot Jupiter close to its star, there may be some internal heating processes within WASP-19b that result in an absorption feature at temperatures above 2,000 K.

Optimizing GPU-Accelerated Monitoring of High-Rise Building Motions and Deformation
Maria Vazhaeparambil
Mentor: Monica Kohler

A real-time method to ensure building safety after an earthquake is being developed by applying accelerometer data to complex physics models to determine how frequency variations, and the displacement and drift experienced by each floor can be used to detect building damage. However, as the Community Seismic Network (CSN) expands and intakes more data, the current processing method implemented on the CPU will not be efficient enough to ensure a real-time output, since it does not have a high throughput or the ability to process in parallel. Using Java bindings for CUDA and an NVIDIA RTX A6000, it is now possible to implement large-scale data processing calculations that are more time-consuming on the GPU rather than the CPU. The aim of this project is to convert two heavy computations to the GPU: a recursive low-order low-pass filter and the Fast Fourier Transform. By gathering and processing data faster, the computational models and machine learning training can be done more efficiently, and it will be easier to create and visualize digital twin models of buildings. These results will help accurately keep track of zones of structural damage in buildings and provide a measure of safety.

Post-printing Bonding and Multi-material Assembly of 3D-architected Metallopolymer
Alejandra Vazquez Yanez
Mentors: Julia Greer and Seola Lee

There is a growing interest in creating multi-material structures in additive manufacturing due to new opportunities for fabricating multi-functional materials. For example, programmed mechanical gradients and extreme strain delocalization are exploiting different mechanical properties of a multi-material structure. In this project, we fabricated 3D-architected Metallo-polyelectrolyte Complexes (MPECs) with divalent and trivalent metal ions such as Ni(II) and Al(III) via projection-micro-stereolithography and demonstrated post-print bonding mechanisms to create a homogenous multi-material structure without any interface or detachment problems. Due to the reversible formation and dissociation of dynamic bonds of metal cations, strong bonding on the interface of prefabricated components was observed, and most samples exhibited cohesive failures during debonding experiments. To quantitatively study the strength of the bonding interface between different metal ions, we conducted the 180-degree peel test (ASTM D1876) and the standard shear test (ASTM 2255) using Dynamic Mechanical Analyzer (DMA). The interface toughness and shear strength varies from 0.4 to 0.55 MPa depending on the type of metal ions used. To show the applicability of this method for constructing a complicated architecture of multi-material assembly of 3D-MPEC, different interlocking structures and pattern transformation structures with the dimensions of millimeter to centimeter were constructed.

3D Mapping of the Neutral X-Ray Absorption in the Local ISM: The Gaia and Chandra Synergy
Mayra Velazquez
Mentors: Javier García and Efraín Gatuzz

The interstellar medium (ISM) is the material between stars composed of primarily hydrogen. Numerous studies have researched the distribution of hydrogen in the ISM, particularly in the radio wavelength. However, they utilize telescopes with large angular resolutions (~36 arcmin), limiting views of the finer structure of the ISM. X-rays provide a useful way of studying the ISM since they can probe larger distances than radio telescopes and have smaller angular resolutions. Chandra, an X-ray telescope, has a small angular resolution of 0.5 arcsec. Using the hydrogen column densities from Chandra and distance measurements from Gaia, we present a 3D map of the hydrogen distribution in the ISM. We perform a crossmatch between Chandra and Gaia DR3 to obtain geometric distances to sources. Following the procedure outlined in Rezaei Kh. et al. (2016), we predict the hydrogen distribution along a given line of sight. We show that that the synergy between two telescopes allows us to map the finer structure of the ISM, helping us better understand its role in star and galaxy formation.

Crack Nucleation in Lithium Ion Battery Particles Utilizing a Phase Field Approach
Tristan Villanueva
Mentors: Kaushik Bhattacharya and Jean-Michel Scherer

Lithium ion batteries have important uses on many electronic devices that are frequently used. Conventional materials used in batteries suffer from swelling and shrinking of particles. These swelling and shrinking phenomena lead to cracks in particles and limiting the (dis-) charging rate that can be applied to batteries. For this reason, it is important to model and predict the onset of crack nucleation and the resulting crack paths. In this project we utilize a phase field approach to model fracture under the case of linear elasticity and incorporate the effects of diffusion of ions in the particle. We solve a set of one-dimensional problems analytically followed by two dimensional circular problems with isotropic conditions utilizing finite element methods. We are able to extract the damage, concentration of ions, and displacement fields. Afterwards we will analyze the effects of anisotropy in the stiffness tensor and in the fluid mobility. Our final problem is to apply our model onto scans of anode particles; starting with one particle and then a system of particles to analyze the crack nucleation with these systems.

Investigating the Composition of HSF1 Complexes via Single-molecule Pull-down
Amy-Doan Vo
Mentors: Ankur Jain, Cameron Schmitz, and William Clemons, Jr.

Heat shock factor 1 (HSF1) is the main transcription factor of the heat shock response pathway. Upon cell stress, activated HSF1 trimerizes and relocalizes to nuclear stress bodies (nSBs) to bind repetitive sequences known as satellite III DNA. We perform the first single-molecule experiments involving HSF1, utilizing single-molecule pull-down (SiMPull) to test the specificity of HSF1 for its binding partners in both normal and heat shock conditions. We also present tools for the automated analysis of single molecule images. Our results provide insight on the details of nSB formation.

Heat Transfer in Microfluidic Devices
Kodie Vondra
Mentors: Stephanie McCalla and Justin Bois

Advancing microfluidics "lab on a chip" devices promise to bring about a new standard for point of care applications due to the decreased sample size required and high throughput data generated. "Lab on a chip" devices typically consist of a glass and polymer layer such as PDMS (polydimethylsiloxane), amounting to about the size of a microscope slide. However, many microfluidic operations that "lab on a chip" devices perform involve thermocycling, such as Polymerase Chain Reaction. We look to measure the efficiency of heat transfer within the device, using models of varying dimensions, to determine if the device reaches the desired heating and cooling temperatures employed in many processes. We further compare that with the resulting data of changing the temperature of processes using a commercial microfluidic device- OpenSPR. We created multiple models of "lab on a chip" devices with varying PDMS thickness and used type T thermocouples with different locations within the device to measure the temperatures. While thermocycling the models, we found that there is a difference in internal device temperature and the desired temperature, as well as a delay in temperature acquisition.

Quantitative Analysis of *Pseudomonas aeruginosa* Growth in Agar Block Biofilm Assays (ABBAs) to Assess Antibiotic Resistance and Tolerance
Gia Han Vuong
Mentors: Dianne K. Newman and Avi I. Flamholz

Cystic fibrosis (CF) is a common disease that causes the buildup of thick mucus in patients' airways. Opportunistic pathogens like *Pseudomonas aeruginosa* (PA) colonize this mucus layer and are often recalcitrant to antibiotic treatment. As the mucus impedes O_2 diffusion and both host and bacteria consume O_2 through their metabolism, PA is found to grow heterogeneously in the O_2 gradients that emerge. Generally, metabolically active bacteria are more susceptible to antibiotics (unless they carry a resistance gene), so I expect that the efficacy of antibiotic treatment depends on growth and O_2 gradients. I aim to understand how O_2 gradients affect growth and antibiotic tolerance in the model bacteria PA and *E. coli*. Agar block biofilm assay (ABBA) is a CF sputum model in which the growth of PA colonies inside a 3D agar environment leads to dynamic oxygen gradients. Calibrating a confocal microscope (measuring the point spread function) will enable me to quantify the size of fluorescent PA aggregates over time and, thereby, calculate their growth rates. To support measurements with fluorescent proteins, I compare them to colony volume measurements using standard cell-labeling chemical dyes. Ultimately, drug treatment at various time points will uncover the relationship between growth, O_2 gradients, and antibiotic tolerance.

Ice Crystal Growth Near the Melting Point: A Kinetic Model for Vanishing Facets
James Walkling
Mentors: Kenneth Libbrecht

When ice crystals are heated to a temperature near -2°C in vacuo, the prism facets of the crystal become circular. While this is commonly attributed to a roughening transition, recent measurements of the nucleation barrier on ice prism facets suggest this is not possible. In this paper, an alternate kinetic growth model is proposed. The Hertz-Knudsen equations are used to describe the lowest order growth of a hexagonal crystal via the velocity of its facets and vertices. Several characteristic timescales of the problem are established which vary from minutes to years for a micrometer scale ice crystal. Within a range of reasonable parameters, the kinetic model can reproduce the observed rounding of the prism facets around -2°C.

Development of Hyperspectral Data Processing and Visualization Tools
Yifan Amy Wang
Mentors: Rebecca Greenberger and Bethany Ehlmann

Hyperspectral imaging, also known as imaging spectroscopy, is a method used in multiple disciplines such as geology and planetary sciences to analyze and interpret data from surfaces. Current software packages used for analyzing imaging spectroscopy are expensive, not user-friendly, and have difficulty interpreting three-dimensional datasets. The Workbench for Imaging Spectroscopy Exploration and Research (WISER), a software program, was developed to combat these problems. Plugins were developed for WISER in order to enhance its purpose and abilities. To develop these plugins, it is necessary to understand the mathematical algorithm behind each imaging spectroscopy analysis method. From there, the source code is developed and tested on personal laptops. The source code is then translated into a WISER plugin and interfaced with WISER. Plugins developed include: continuum removal, decorrelation stretch, layer stacking, and 2D scatter plot. These plugins have been thoroughly tested and compared against similar software programs. Additionally, these plugins also contain the ability to perform analysis techniques unavailable on competitive software programs (ENVI) such as continuum removing an entire image. Not only are these plugins capable of performing necessary imaging spectrometry analyses, they also serve as a template for future users to develop their own plugins as needed.

Integration of Ultra High Vacuum Cryostat in Ultrafast XUV Spectroscopy for Charge-carrier Dynamics Analysis
Audrey Washington
Mentors: Scott Cushing, Jocelyn Mendes, and Jonathan Michelsen

Through transient extreme ultraviolet (XUV) spectroscopy we can study photoexcited charge-carrier dynamics of solids. However, within these solid materials the periodicity of the lattice allows quantized collective vibrational modes that can be excited in the unit of phonons. These phonon modes can interact with charge carriers in the material, complicating the signal that we receive from the sample. A cryostat cools samples to temperatures as low as -196^{o}C. These extremely low temperatures mitigate phonon interactions with the charge-carriers while avoiding the long-lived effects like triplet states. Such low temperatures also allow for studies on materials that have different magnetic and conducting characteristics at these conditions, such as Mott Insulators and Superconductors. Developing a cryostat design optimal for the complex arrangement of the XUV spectrometer will expand the classes of materials capable of being studied by the XUV spectrometer.

Internal Tandem Catalysis in Nanoporous Au/Cu Gas Diffusion Electrodes for Enhanced CO_2 Reduction
William Wei
Mentors: Harry Atwater and Aidan Fenwick

The electrochemical reduction of carbon dioxide (CO_2) into value-added chemical feedstocks is an increasingly attractive technology that incentivizes industries to adopt carbon neutral processes. Bifunctional tandem gas diffusion electrodes have been found to facilitate CO_2 reduction for C_{2+} products better than traditional liquid systems, but limited progress has been made to examine the morphological effects of internalizing nanoporous (np) catalyst layers for enhanced catalytic function. In this study, copper (Cu) is selectively deposited onto a nanoporous gold (Au) substrate along the electrode length and orthogonal to the electrode plane using underpotential deposition. In order to deposit Cu onto Au consistently, it is first necessary to understand how np-Au morphology changes as a function of the experimental procedure. Future research will determine if internal np-Au/Cu catalysts achieve higher C_{2+} current densities, increased faradaic efficiencies of C_{2+} products, and larger electrochemically active surface area compared to previous external tandem catalysis studies.

Structural and Functional Characterization of Cryptochrome 1 and 2
Ryan West
Mentors: André Hoelz and Sema Ejder

Delayed sleep phase syndrome (DSPS) is the most common circadian rhythm disruption among sleep-wake disorders. DSPS is the product of the atypical molecular regulation of specific proteins and their interactions found in mammals, resulting in delayed sleep cycles of up to several hours. The interactions between the proteins clock, aryl hydrocarbon receptor nuclear translocator-like protein 1 (Bmal1), cryptochrome 1 and 2 (Cry 1 and 2), and period 2 (Per2) serve as the cycle's mediator. The Cry1 C-terminal tail is associated with extended circadian rhythms of 26h, frequently observed in delayed sleep phase syndrome (DSPS). Exon 11 skipping, which resulted in in-frame deletions in the Cry1 terminal region, is predominantly responsible for this expansion. Together with Per2, Cry1 is transported to the nucleus via the bipartite Nuclear Localization Sequence (NLS) on the Cry1/2 tail. As a result, nuclear import and export of these critical components are essential for preserving the circadian rhythm's standard functionality. To better understand these interactions, this project focused on determining the transport factor responsible for nuclear transport of the protein complex, as well as the specific sequence on the Cry1 C-terminal tail responsible for binding the transport factor.

Data-Driven Dominant Balance Analysis of Wall-Bounded Turbulent Flows
Tomás Wexler
Mentors: Jane Bae and Eric Ballouz

Despite its prevalence in our everyday lives, a true understanding of turbulent flow remains an unsolved mystery. Experiments and direct numerical simulations are very expensive and time-consuming to run, adding to the challenge in accurately studying turbulence. In wall-bounded turbulent flow, coherent structures like streaks and vortices are present, and while their existence has been known for a long time, their physics and some characteristics still are difficult to study. This project aims to use data-driven dominant balance analysis to reveal some of the underlying physics of these structures. Dominant balance analysis clusters sections of the flow based on the individual terms of the Navier-Stokes equation using various different models and methods, including a Gaussian mixture model and sparse principal component analysis, allowing for different flow clusters to be compared to various definitions of coherent structures in wall bounded flows. The clusters with the best correlation to the structures in the flow are then analyzed to gain a better understanding of the physics driving the creation of these structures, and of the flow as a whole.

Using Spitzer Phase Curve Analysis to Detect an Atmosphere on the Super-Earth HD 213885b
Kate Wienke
Mentor: Jessie Christiansen

In its lifetime, the Spitzer Space Telescope was able to study not only Saturn's rings and distant galaxies, but also exoplanets. We can learn about exoplanets, which are planets outside of the Solar System, by looking at their phase curves. A phase curve shows the brightness of the planet as it orbits around its star and provides insight into the temperature, reflectivity, and even the atmosphere of the planet. Super-Earth HD 213885b is a hot, rocky exoplanet that completes one full orbit of its G-type star in a day. By using Lisa Dang's Spitzer Phase Curve Analysis (SPCA) code, HD 213885b's raw Spitzer data will be used to create a phase curve that can then be studied to determine if the planet has an atmosphere or not. Prior to examining HD 213885b's data, SPCA was first debugged and edited until it was able to reproduce the published results for the exoplanet CoRoT-2b. With this confirmation that SPCA is performing correctly, the code can then be run with HD 213885b's data to produce a phase curve. Values like the phase curve offset, the dayside temperature, and the nightside temperature can be acquired from the phase curve and used to discover if heat is being dispersed across the planet. Therefore, since heat redistribution is indicative of an atmosphere, HD 213885b's phase curve could tell us if the irradiated planet has an atmosphere.

Flat Field Estimation for SPHEREx
Abby E. Williams
Mentors: James J. Bock and Howard Hui

We optimize the flat field estimation algorithm for SPHEREx, an upcoming near-infrared all-sky survey. Due to the full sky coverage and the usage of Linear Variable Filters (LVFs), the calculation of the detector flat field warrants the development of a novel approach in an effort to maximize accuracy and minimize computational expense. In this work, we estimate the relative flat field matrix using an iterative procedure from an ensemble of simulated sky exposures, and we quantify and constrain the error in this recovery process.

First, we stack images generated with a sky simulator module and apply selection criteria to discard any images with exceptionally high signal variance. Then, we use the LVF spectral information to flatten each image according to the zodiacal light spectral response in each pixel.
Finally, we apply a fitting algorithm to the images to estimate the flat field. We find that using 120 simulated sky exposures containing zodiacal light, diffuse galactic light (DGL), photon and read noise, and detector flat field, we can recover the relative input flat field in detector Array 1 with 1.32% mean pixel error, and a standard deviation in error of 2.00% across the array. Spatial variation in the calculated flat field error primarily results from the DGL component of the total image signal.

Allosteric Leak Reduction in Catalytic Strand-Displacement Circuits
Spencer H. Winter
Mentors: Lulu Qian and Samuel Davidson

DNA-based computers have become increasingly complex in recent years, able to carry out information processing tasks such as Boolean logic computation and neural network functionality. Catalytic strand-displacement circuits, such as those using the seesaw motif, are capable of robust information processing via signal amplification. However, the signal restoration process means that spurious signals from leak, unintended chemical reactions, can be amplified and lead to incorrect outputs. Several leak reduction mechanisms have been proposed, but none so far that reduce leak in a seesaw gate. Here, a novel design of the gate complex is explored that exploits the conformation change of the gate after output displacement, preventing the fuel strand from unintended interaction. Five variations of the design are tested both for leak and for functionality via a fluorescent output. Leak, indicated by premature fluorescence, is expected to be significantly reduced compared to standard seesaw complexes with maintained catalytic functionality.

Targeted Mutagenesis of Endogenous Loci Using TRACE
George Wythes
Mentors: Fei Chen and Kaihang Wang

Being able to continuously introduce mutations into targeted regions of the genome can mimic natural mutagenesis and help our understanding of cancer, drug resistance, and protein function. Many techniques allow local editing of the genome but these approaches often lack range to cover full exons or are ineffective in human cells. The recently developed T7 polymerase-driven continuous editing (TRACE) mutagenesis system fixes many of these limitations but has yet shown on endogenous loci. Here, we show elevated mutation rates of human genomic loci by introducing an intronic T7 promoter and subsequently expressing the TRACE editor. We used endogenous TRACE in vitro to mutate key genes involved in cancer drug resistance to explore the sequence landscape that allows for resistance.

Specificity in Interaction of Intrinsically Disordered Proteins
Michael Xiong
Mentors: Shasha Chong and Qinyu Han

Not every protein has a well-defined structure that can be used to interpret its function. Yet, these intrinsically disordered proteins perform highly specific functions. Measuring the interaction behaviors of intrinsically disordered proteins is crucial for constructing a foundation for understanding these proteins. One important class of intrinsically disordered regions are the transactivation domains of transcription factors. Exchanging these domains within transcription factors can have dramatic effects on biology, such as the fusion of the intrinsically disordered region of the RNA-binding protein EWSR1 with the DNA-binding domain of transcription factor FLI1, which results in Ewing's sarcoma. Here, we demonstrate how fusion of other transactivation domains with the DNA binding domain of FLI1 alters behavior of the fusion protein within the nucleus—such as its propensity for phase separation—and efficiency in promoter activation. In addition, we demonstrate a method of measuring the interactome of any intrinsically disordered region with a potential to undergo liquid-liquid phase separation within the cytosol, using NPM1c for proof of concept. With some improvements, this method can be used to map the interactome of many other intrinsically disordered proteins.

Malnutrition and Nutrient Context for Peri-implantation Embryo Development
Peyton Yee
Mentor: Magdalena Zernicka-Goetz

Embryonic development can be studied through in vitro culture platforms that rely on a media with non-physiological nutrient levels. Work on models of mammalian embryonic development, such as pluripotent stem cells, have identified seven nutrients (pyruvate, glutamine, glucose, ascorbic acid, lipids, proline, and methionine) that influence developmental outcomes. How these affect in vitro embryo culture remains unknown. We focused on pyruvate and glutamine due to their significance as energy substrates in early development and aimed to determine how variations in concentration affect peri-implantation embryo progression. We collected E4.5 mouse embryos and cultured them for three days with altered nutrient levels. Then, we performed immunostaining to characterize correct morphogenesis and lineage allocation, linking embryo changes with altered pyruvate and glutamine concentrations. In the future, this work will improve the culture systems for peri-implantation development and define how changes in the extracellular environment, such as maternal malnutrition, can affect embryo progression.

Stray Light Analysis of GS 1826-24: A Sudden Spectral State Transition of a Clocked Burster
Sol Bin (Hazel) Yun
Mentor: Brian Grefenstette

The *Nuclear Spectroscopic Telescope Array (NuSTAR)* is NASA Small explorer mission and a focusing telescope covering the hard X-Ray bandpass (3-79 keV). *NuSTAR* observations of targets near the galactic plane can be contaminated by stray light from other sources. However, stray light can be valuable as they can give long term pictures of sources at a finer spectral resolution than other all-sky X-ray monitors. Using Stray Light, we conducted an X-ray analysis of GS 1826-24, a neutron star X-Ray binary. GS 1826-24 had been in a persistent hard spectral state and was observed to transition into a soft spectral state recently from other observations. We present Hardness Ratio-Intensity diagrams and spectral fittings to confirm the transition between spectral states. The neutron star in GS 1826-24 accretes material from its companion star and releases the material through regular Type 1 X-Ray bursts, giving its nickname: the Clocked Burster. We modelled the Type 1 X-Ray bursts and characterized the differences between bursts from the hard and soft states. The stray light analysis of GS 1816-24 hope to reveal explanations for long term behaviors of neutron star X-Ray binaries, and to set a stepping stone for long term X-ray analysis of other sources.

Regulation of Neuronal Physiology by the Electromechanical Effects of the Action Potential
Inés Zaragozá Llatas
Mentor: Carlos Lois

Voltage fluctuations across cellular membranes have recently been found to cause wave-like membrane motion. To date, it remains unknown the influence of these electromechanical waves in cellular physiological processes, which were traditionally associated with biochemical regulation. We thus investigate whether action potentials can generate sufficient mechanical force to control cell signaling pathways, such as Delta-Notch.

Using lentiviral vectors carrying dominant-negative dynamin, we inhibit endocytosis in epithelial cells and vary their confluency to evaluate the effect of pulling forces on engineered Notch mechanoreceptors *in vitro*. Moreover, in Drosophila we block endocytosis with temperature sensitive shibire and/or block action potentials with kir2.1 to study Notch mechanotransduction in neuronal cells.

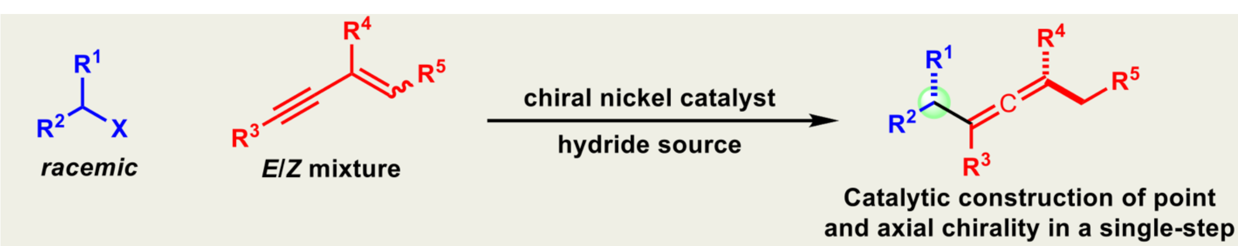
Previous results showed that inhibiting endocytosis in neurons does not interrupt neuronal signaling. Therefore, we additionally blocked mechanical forces from electromechanical waves and observed a decrease in the downstream induction of this mechanosensitive engineered Notch system. This suggests that neuronal membrane oscillations can regulate cellular signaling events. This would then open the door to a new field of study on the role of electromechanical waves associated with action potentials in the regulation of brain function.

Investigating the Effects of Pressure and Molecular Films on Copper-Mediated Electrochemical CO_2 Reduction
Pierre Zeineddin
Mentors: Jonas Peters, Matthew Salazar, and Nick Watkins

Aqueous electrochemical CO_2 reduction on copper has the potential to reverse the process of combustion, taking CO_2 released into the atmosphere and reconverting it into fuels. However, this process has struggled with selectivity for multi-carbon products due to the low water solubility of CO_2 and the kinetically favored hydrogen evolution reaction (HER). To address the issue of low CO_2 concentration, higher system pressures serve as a feasible and intriguing base of study. Electrochemical CO_2 reduction on polycrystalline copper was conducted under pressures ranging from 1 to 3 atm. As the pressure increased, the partial current density increased for multi-carbon products and decreased for hydrogen gas, showing the ability for pressure to suppress HER and increase CO_2 solubility. To resolve the issue of low selectivity, investigation into combining pressurized systems with additive films has shown promise in facilitating boosted multi-carbon product generation.

Nickel-Catalyzed Enantioconvergent and Diastereoselective Allenation of Alkyl Electrophiles: Concurrent Generation of Point and Axial Chirality
Claudia Zhang
Mentors: Gregory C. Fu and Asik Hossain

Carbon-carbon bonds such as those between sp^3-hybridized carbons (alkyl-alkyl bonds) form a majority of organic molecules and thus, being able to form these bonds and control their stereochemistry has major implications for organic synthesis. Past work using metal complexes has been able to control a single stereocenter during alkyl-alkyl bond formation. More recently, methods that control the point chirality of two vicinal stereocenters have been developed by the Fu group. To further probe the depth of doubly enantioconvergent alkyl-alkyl coupling reactions, this study aims to concurrently generate point and axial chirality from racemic starting materials. The desired reaction will use a chiral nickel catalyst to cross-couple an enyne and a secondary or tertiary electrophile to produce an allene that contains distal point chirality. The stereoselectvity of the desired products are measured using nuclear magnetic spectroscopy and supercritical fluid gas chromatography.



Towards End-User Tool for Auditing Social Bias in Deep Language Models
Vivian Zhang
Mentors: Anima Anandkumar and Rafal Kocielnik

Deep language models suffer from learned human-like implicit social biases due to media and texts they are exposed to in training. Bias detection and quantification understandable to non AI-experts is essential to interpreting nuanced and evolving biases that require specific domain expertise (e.g., social science, gender studies experts). Existing methods for auditing deep LMs, such as association testing, which evaluates model's propensity towards producing stereotypical social group terms in different contexts, are limited in real-world scenarios, as they are not flexible or robust against natural domain expert input and rely on handcrafted templates and keywords. This project aimed to address these limitations and extend association testing methods to enable domain expert input, by making the method more flexible and robust. We concluded that using approximate perplexity to calculate fill probability in BERT-like models can be used to extend association testing methods to handle multi-word inputs. We also propose a few-shot controllable generation method which replaces hand-crafted and artificial templates used in prior work, with natural contextual sentences more representative of real-world use. Lastly, we are in the process of adapting our method to an end-user tool which allows non AI-experts to examine the language model’s bias across different fields.

Biochemical Characterization of Nuclear Pore Complex Mutations Associated with Triple A Syndrome
Wentao Zhang
Mentors: André Hoelz and George Mobbs

Within eukaryotic cells, massive ~110-MDa transport complexes called nuclear pore complexes (NPCs) facilitate the transport of macromolecules across the nuclear envelope. Protein constituents of the NPC, called nucleoporins (nups), are essential in the assembly of the mitotic spindle during cell division. Mutations in nups can cause erroneous spindle morphology, leading to defects in the biogenesis of various human tissues and resulting in uncurable congenital diseases such as achalasia, Addison disease, and alacrima autosomal disorder, collectively symptoms of triple A syndrome. The disease mechanisms of Triple A syndrome have remained elusive, with no clear correlation between mutations and disease phenotype.
We will use pull-down biochemical assays to identify the binding partners of nups implicated in Triple A syndrome. We will solve high-resolution crystal structures to inform our biochemical analysis of mutations associated with Triple A syndrome. Our findings will facilitate development of targeted therapies for those suffering from Triple A syndrome.

Systematic Mitigation on Overlapping Large Scale Structure Surveys
Zhuoqi Zhang
Mentors: James Bock and Ami Choi

Large scale structure (LSS) maps are often contaminated by observational systematics. Correctly removing the systematics and recovering the underlying galaxy density is crucial to cosmological analyses. As LSS surveys accumulate data that spatially overlap on the sky, one can potentially use the overlapping regions to assess and improve systematic mitigation. In this work, we develop and verify a novel method for checking if the cleaned LSS maps from two overlapping surveys are consistent and assigning error bars on them. In addition, we also propose methods to use both surveys to jointly recover the cleaned LSS maps. We test these methods on realistic simulations based on the Legacy Survey and the Dark Energy Survey. We demonstrate that the new methods can more effectively remove systematics, reducing the mean squared error by up to 50% compared to single-survey methods, and are more robust against overfitting.

Using a Neural Network Framework for Quantitative Analysis of Transcriptomic Data
Lian Zhu
Mentors: Rob Phillips and Tom Roeschinger

Although genomes can be readily sequenced, understanding how genes interact or where transcription factors bind still stands as a challenge. Even for *E. coli*, one of the most well studied organisms in biology, more than 65% of its genes have unknown regulatory architectures. The Phillips Lab has previously investigated 100 promoters by generating variants, sequencing RNA and DNA to get counts per variant, and inferring regulatory information by generating energy matrices from this data. We are scaling up the project to 1000 promoters and hoping to improve the computational analysis. Thus, the aim of this project is to replace the analysis method with a neural-network based Python package called MAVE-NN, which is expected to decrease computational time by a factor of 100. We have adopted MAVE-NN to analyze some existing datasets and generate energy matrices. Continued work involves using MAVE-NN to identify binding sites for promoters with unknown regulatory information.

Manufacturing 3-D Lithium-Ion Batteries With Interpenetrating Lattice Electrodes

Fangyu Nathan Zou
Mentors: Julia Greer and Yingjin Wang

A 3-D lithium-ion battery backbone was created using a 2-step process, in which the first step 3-D printed the overall structure as a polymer, and the second step sputtered gold onto the polymer for conductive properties. The 3-D printed backbone consisted of two interpenetrating lattices made of post-cured PR48 resin that would serve as the anode and cathode, while the electrolyte would fill the space between the two electrodes. During the sputtering process, the polymer structure was rotated 6 times to guarantee that the sputtering will be conformal throughout the lattice. Electrodeposition was used to generate a $LiCoO_2$ anode and a Li cathode. Gold was discovered to be etched by KOH during the electrodeposition process due to the disappearance of the metal coating around the polymer. A new conductive metal that is unreactive with Lithium and in high pH must be used to successfully electrodeposit the anode and cathode material onto the 3-D battery backbone. This work demonstrates that PR48 can be successfully used as the backbone material for the manufacturing of a 3-D battery, although a new metal needs to be chosen to coat the polymer for the electrodeposition process.