Generative Feedback and Memory Replay for Few-Shot Learning
Nico Adamo
Mentors: Anima Anandkumar and Yujia Huang

Over recent decades, deep neural networks have proven themselves highly capable in modelling a variety of classification tasks. However, neural networks show massive weaknesses compared to humans in "few-shot" settings, where very little labeled data is available to learn from. This becomes especially apparent in deploying ML models to real world data, which usually consists of many classes with very few samples. In our project, we introduce a method for few-shot learning that pulls inspiration from the structures for learning in the human brain, and incorporates both generative feedback and memory replay to bolster the robustness of the model's internal representations. We show that these methods outperform current state-of-the-art models for few-shot learning on standard benchmarks, including MiniImageNet and CIFAR-FS.

Disruption of Axion Miniclusters in the Milky Way Environment
Gabriel Aguiar
Mentor: Kathryn Zurek

We seek to better understand the evolution of small-scale dark matter (DM) structures in the Milky Way galaxy, and to use our studies of the disruption effect to determine the detectability of these small-scale structures by techniques such as Pulsar Timing Arrays (PTAs). We chose axion miniclusters with an NFW density profile as the basis for our studies, motivated by the possibility of the axion serving as both a component of dark matter and a solution to the strong CP problem in quantum chromodynamics (QCD). In collaboration with the Hopkins group, we created n-body simulations with the GIZMO simulation code to observe the effect of changes to various parameters, which we then compare to our analytical model. The result will be an improvement on previous models, with a full-scale galaxy simulation that will build on the results of our observations.

CRISPR Screen Reveals Genes Related to the Enteric Nervous System Development in Zebrafish
Gerardo Ivan Aguirre
Mentors: Marianne Bronner and Can Li

The Enteric Nervous System (ENS) is the largest division of the autonomic nervous system that controls and coordinates gut movement, water and electrolyte balance, gastrointestinal enzyme secretion and local blood flow to ensure food digestion and nutrient absorption. External development of zebrafish embryos, well-established genetic approaches and high genetic similarity between human and zebrafish make this organism a suitable model to study ENS development. With single cell RNA-sequencing technique, we have identified genes expressing in ENS progenitors, such as anxa4, foxp4, zeb2a, and expressing in subtypes of ENS neurons, such as tcf7l2 and satb2. To reveal the functions of these genes, we used CRISPR/Cas9 system to knockout the genes in zebrafish genome at 1-cell stage. We synthesized gRNAs targeting these genes, performed microinjection to deliver gRNA/Cas9 complex into zebrafish embryos, and used immunohistochemistry and in situ hybridization methods to visualize the number of ENS progenitors and neurons. With this CRISPR-based screen, we could understand the roles of these genes in ENS development.

Analysis of iDQ Glitch Detection Statistics During LIGO's Standard Veto Flags
Nezir Alic
Mentors: Erik Katsavounidis and Alan Weinstein

To optimize gravitational wave searches, it is necessary for LIGO and other interferometric gravitational-wave detectors to accurately distinguish between true astrophysical signals, and non-Gaussian noise, or "glitches." This can be difficult at times due to the similarity between these two types of signals. However, algorithms exist that address this problem, including iDQ, which provides low-latency, probabilistic information such as the likelihood of a glitch. Statistical comparisons between the conclusions of iDQ and those of human-made veto definers are presented. Segments of active detector time from both LIGO detectors that are flagged by such veto definers as vetoes of various categories, as well as segments that are not flagged, are selected. The iDQ values of these times are then analyzed in order to establish whether the probability of a glitch, as determined by iDQ, differs in a statistically significant way during veto times. Preliminary results suggest that there may indeed be a particularly high p(glitch) for those times corresponding to veto flags, but this requires more review and verification; the project is only halfway complete.

Predictive Models for the Reduced Partition Function Ratio (RPFR) of Clumped Organic Isotopologues
Simon Andren
Mentor: John Eiler

The clumping of heavier isotopes is a strong predictor of paleoclimate due to its strong correlation with the temperature of the chemical reactions. Theoretical predictions of the clumped isotopologues enrichment of a chemical reaction in equilibrium are computed using the Reduced Partition Function Ratio (RPFR) for the involved reactants and products. The UBM (Urey-Bigeleisen-Mayer Model) model expresses the RPFR as a function of the vibrational frequencies for a molecule before and after isotopic substitutions. In this project, we compute the RPFR for all singly and doubly-substituted isotopologues for several organic molecules, such as including C1-C9 Alkanes and three amino acids, using DFT/b3lyp/6-31G* level of theory. We built an exponential regression model and a gaussian processes regression model using the computed RPFR and features of the singly and doubly substituted isotopologues. We found that our models accurately predicted the RPFR for doubly substituted organic isotopologues. With the substantial number of possible clumped isotopologues for even the smaller molecules, theoretical predictions reliant on the computation of vibrational frequencies aren't feasible with today's computational power. Our predictive models can thus be used to provide an initial hypothesis about the enrichment in clumped isotopologues for geochemical relevant reactions.

Single Particle cryoEM Studies of a Turnover-Modified Form of the Nitrogenase MoFe-Protein
Rita Anoh
Mentors: Douglas Rees and Rebeccah Warmack

Bioavailable nitrogen in forms such as ammonia can be produced both biologically and industrially. Nearly 50% of fixed nitrogen used by the global population is produced industrially, however, naturally fixed nitrogen produced by the enzyme nitrogenase requires significantly less energy and thus contributes less to global warming. To gain some insight on the enzymatic mechanism of biological nitrogen fixation, I am working to characterize an inactivated, modified form of the Molybdenum-Iron (MoFe)-protein, a component of the nitrogenase complex under turnover conditions. The purified and high pH turnover-inactivated MoFe-protein will be characterized using cryoEM single particle analysis. The project aims to obtain information about nitrogenase from the structural differences between resting state and high pH turnover inactive forms of the MoFe-protein.

HOMES Lunar Dust Mitigation Through Electrodynamic Shielding: Implementation and Testing of Modular Electronics Systems
Hope Arnett
Mentor: Soon-Jo Chung

Lunar dust has posed issues to astronauts and scientific instruments in previous lunar missions due to its electric charge and abrasive properties. Electrodynamic shielding--using a four-phase high-voltage switching pattern--has been successful in generating non-uniform electric fields to electrically move dust in a given direction. As a finalist and recipient of funding from the NASA 2021 Big Idea Challenge, the Habitat Orientable and Modular Electrodynamic Shielding (HOMES) team at Caltech seeks to implement this technology in modular and scalable panel arrays for dust mitigation in future missions. We strive to demonstrate modularity in the panel's electronics circuitry through constructing and connecting two panels and the control box. Within this system, a microcontroller in the control box generates the four low-voltage square wave signals, and a series of gate drivers and n-type MOSFETs each panel switches and steps up the signals to upwards of 3.8 kV. While we have not yet fabricated the two-panel system, extensive tests of these isolated parts of the electronics indicate the possibility of functionality in panel modularity. Given HOMES's potential for creating new opportunities in planetary exploration, we will continue to refine and construct an operational two-panel HOMES system throughout the fall.

Structure-Based Protein Fitness Prediction and Landscape Navigation Using Graph Neural Networks
Marianne Arriola
Mentors: Frances Arnold and Kadina Johnston

Informative protein representations are essential to enable machine learning tasks for accurate protein fitness prediction as they determine how models learn sequence-fitness mappings. Recent work demonstrates that graphs can efficiently represent protein structure at the residue level and provide higher accuracy in classifying structure-function relationships than standard sequence-based encodings. However, there has been no attempt to use graphs to represent protein structure for predicting fitness of specific protein variants. Therefore, we leverage such graph representations for fitness prediction by implementing a graph convolutional network that learns structure-fitness mappings. We then explore the single-mutant fitness landscapes of the aliphatic amide hydrolase from *Pseudomonas aeruginosa* (amiE) across three different substrates. This work investigates both the variation in fitness landscapes due to substrate identity as well as how well our model performs based on the substrate upon which it is trained. We also show that this model outperforms standard approaches that use sequence for fitness prediction. We further extend this model to automate fitness landscape navigation by training the protein graph representation to maximize fitness.

Evolution of Phytohormone Signaling Pathways and Implications on Agriculture and Metagenomics
Scarlet Au
Mentors: Elliot Meyerowitz and Paul Tarr

Studies in plant development provide broad research applications from agriculture to metagenomics. The cytokinin phytohormone signaling pathway is a crucial mechanism that affects the ability of plants to utilize nutrients/maximize growth and is hypothesized to be critical in the vascularization of plants. The pathway is also a molecular mechanism of interest as its two-component Histidine-Aspartate phosphorelay signal transduction is widely found in prokaryotes and plants present one of the few occurrences of this type of signal transduction pathway among eukaryotes. How the cytokinin signaling pathway was acquired by plants is still an open question, as current models suggest plants obtained this signaling system through a cyanobacteria from the symbiotic event that gave rise to plastids in plants. Our recent results suggest an alternative to this hypothesis in that horizontal gene transfer may have likely been involved in the transfer of this signaling system into plants. Addressing nutrient regulation and the acquisition of this signaling pathway will impact our understanding of developmental processes and plant interactions with soil bacteria. Through confocal microscopy, bioinformatics and phylogenetic analyses, this study presents 1) evidence that the biosynthesis of the hormone in the cytokinin pathway is related to the nutrient status of the environment and coupled with growth regulation, and 2) an evolutionary history of the components of the signaling pathway with a focus on its potential transfer from bacteria into plants.

Semi-Automatic Identification and Quantification of Point Defects on Quantum Materials From Atomic-Resolution Electron Microscopy Data
Beatriz Avila-Rimer
Mentors: Lena Kourkoutis, Noah Schnitzer, and Katherine Faber

Quantum materials have the potential to revolutionize the world of electronics, however, much is still unknown about the phenomena that induce their exotic properties. Understanding how a material's structure impacts the properties of interest requires close analysis of its nanoscale structure. Here, we use scanning transmission electron microscopy data to characterize the low symmetry C2/m atomic scale structure of La3Cd2As6, which exhibits a vacancy ordering in the cadmium sites. This system is of special interest because it was found to be a narrow-gap semiconductor with a band width of 105 meV. Disorder-free narrow-gap semiconductors are of interest because of their potential in fields such as thermoelectricity and dark matter detection. Furthermore, the La3Cd2As6 system showed a thirteen order of magnitude increase in electrical resistivity upon cooling which suggests that the system has a remarkably clean insulating ground state. In this work, a semi-automated analysis procedure is presented consisting of identifying the cadmium vacancy sites, measuring their image intensity to identify whether there are atoms occupying these sites, and then comparing the intensities in the vacancy sites with the neighboring cadmium sites to quantify the degree of partial occupancy. Identifying these point defects may help understand the origin of the material's remarkable electronic properties.

Quantifying the Effects of Canted Motor Positioning on Quadrotor Dynamics and Controllability
Nelson Badillo
Mentor: Soon-Jo Chung

In recent years the development of unmanned aerial vehicles has increased exponentially due to their broad range of applications. One important application is photography, which due to its precise nature requires the use aircraft with high degree of yaw authority. Through previous works it has been determined that modifying the angle direction or "cant" of a motor significantly increases yaw control. This project focuses on modeling and experimentally testing the effects of modifying motor cant configuration on a quadrotor's dynamics and controllability. The work done looks to expand on previous research done on the topic and provide real-world validation for these results by conducting flight tests at Caltech's Center for Autonomous Systems and Technologies. The resultant models represent the optimal arrangement of motor positions in 3-dimensional space and subsequently increase aircraft controllability. These results can be implemented into future controllers and experimental autonomous aircraft.

Is Democracy Fair? An Observation of Congressional Elections Over Time
Adinan Banse
Mentors: Jonathan Katz and Danny Ebanks

It is without a doubt that congressional elections are a pivotal asset to our democracy. It is also evident that within these elections, incumbents prospectively tend to win a sustained majority. This is often referred to as the incumbency factor, which describes the emergence of a more candidate centered electoral process that favors one class of congressional candidates to prosper: the incumbent office holders. In this study, we examine a large dataset for congressional elections dated to late 1960s - 2016 to compare elections for all state legislatures in the U.S. Using Andrew Gilman and Cary King's unified theoretical method of evaluating electoral systems, we build upon existing literature by augmenting the scope of this thesis. We particularly ask: Is Democracy fair? We use this framework to generalize factors such as: the incumbency advantage and competitiveness over time.

Shedding Light on the Electronic Phases of Strongly Driven Calcium Ruthenate
Cora Barrett
Mentors: David Hsieh and Xinwei Li

The fundamental physics underlying the electronic phase transitions and non-equilibrium electronic states of complex crystals are far from well-understood. Manipulating the electronic phases of complex crystals with light can enable harnessing large responses from small external stimuli, and this new physics can lead to applications in high-speed electronics. The Mott-insulating calcium ruthenate (CRO) has a strong insulator-to-metal switching response in the presence of a weak DC electric field, prompting the question: how will CRO respond under light-field? In this project, we attempt to uncover a novel electronic phase transition by pumping CRO with high-intensity, low-energy laser pulses and looking for symmetry breaking using an optical probe with femtosecond time-resolution. Additionally, we performed density-functional theory simulations on CRO using QuantumESPRESSO to guide our experimental approach. The hope is to map out a phase diagram dependent on pump fluence and temperature for CRO.

Possible Disk Obscuration in the Black Hole X-Ray Binary XTE J1550-564
Eunice Beato
Mentors: Javier Garcia, Riley Connors, and Guglielmo Mastroserio

Black holes (BHs) drive some of the most energetic events in the universe. The accretion of matter onto BHs, which releases large amounts of energy, has been observed in active galactic nuclei (AGN) and X-ray binaries (XRBs). The X-ray spectra of AGN and XRBs are dominated by a thermal component and a power law. Modeling the reflection spectrum allows us to probe the inner workings of the BH and the accretion disk properties. In these models, the most commonly used geometry is a razor-thin disk. The XRB XTE J1550-564 has well-established characteristics, including an inclination of ~75°. Despite this, current reflection models predict a much smaller inclination of ~40°. In this paper, we test the hypothesis that a high inclination accretion disk could be obscuring the blue-shifted line emission, artificially producing a reflected X-ray spectrum akin to that of a much lower inclination. We first reproduce the key results in Connors et al. (2019), which established the low ~40° inclination. We then use Reltrans, a relativistic transfer function model, to add thickness to the XTE-J1550-564 disk instead of assuming a razor-thin disk. We analyze the relationship between the thickness of the accretion disk and the inclination.

Motion2Recon: A Motion-Robust Semi-Supervised Framework for MR Reconstruction
Harris Beg
Mentors: Shreyas Vasanawala, Arjun Desai, Batu Ozturkler, Beliz Gunel, and Adam Blank

Deep learning (DL) approaches have gained attention for accelerated magnetic resonance (MR) reconstruction, surpassing traditional parallel imaging and compressed sensing algorithms in image quality. However, standard supervised DL algorithms often require vast amounts of fully-sampled references, which are difficult or infeasible to collect prospectively at scale, to avoid overfitting to training data. Additionally, these approaches are sensitive to out-of-distribution (OOD) data, making it dangerous to deploy these algorithms in practice. A typical example of OOD data in MR reconstruction is scans corrupted by artifacts such as noise, patient motion, or phase-accrual during the MR acquisition process. Due to acquisition time, discomfort, and other such factors, patient motion in MRI is perhaps the most prominent adversary to obtaining high-quality images through MR reconstruction networks. We hypothesize that MR reconstruction may be made robust to motion artifacts through the use of a semi-supervised, consistency-based reconstructive MR image framework. This DL-based approach utilizes consistency between motion-corrupted *k*-spaces and under sampled *k*-space data in order to attempt to learn to identify motion artifacts and remove them, leaving only the important, uncorrupted scan data, and serves as a viable candidate for the removal of motion artifacts in MRI in the future.

Zebra Classification Using Triplet Loss
Jonathan Beltran
Mentor: Pietro Perona

Accurate population counts are critical for assessing the conservation status of species. The Camera traps set up in the zebra's natural habitat provide a non-invasive way to monitor animal populations. Unfortunately this comes with the cost of obtaining an accurate population count in image data. We need to re-identify the zebras in each image where the camera recorded a zebra sighting. In this project, we present a model for zebra re-identification by segmenting each sighting image and passing the data through a triplet loss network. Given a target zebra, our best segmentation model can correctly pick a match between two options 83.76% of the time. We further examine the effects of data set size, margin parameter, and dataset geodiversity on the performance of segmentation models as compared to models using the entire image or an input cropped to a bounding box.

The Impact of Blue Sky Laws on Financial Development
Halle Blend
Mentor: Michael Ewens

Equity market regulations or changes in securities laws can impact entrepreneurial firms and their finances.
An economy's growth depends on the size of its aggregate production from every business. Regulated at the state level through "Blue Sky Laws," all local jurisdictions govern the offering and sale of securities, impacting small firms that usually must resort to equity financing to raise capital. The purpose of this research project is to create a predictive model for the changes in entrepreneurial activity based on any alterations in securities laws, specifically Blue Sky Laws from 1950-1970. We will investigate the legal and regulatory features of financial

markets through the Blue Sky Laws to understand the role of these local securities regulations and their connection to financial development and economic growth. This predictive model allows for further exploration of the correlation between changes in securities laws and economic outcomes and growth in later time periods, including the present.

Azimuthal Dependence of the Circumgalactic Medium in the FIRE Simulations
Daria Bonds
Mentors: Phil Hopkins and Cameron Hummels

This project concerns the study of outflows of material out of the disks of galaxies, using sophisticated computer simulations of galaxy evolution to determine the direction of those outflows. The circumgalactic medium (CGM) is the cloud of gas and material that surrounds galaxies beyond their main disk structure. Within the CGM, we observe complicated flow and complex ionization states. This medium is the location for material fall-out and recovery, essential to a galaxy's lifetime and evolution. Investigating the halos of the CGM, the volumes just above and below the galactic disk, we will have a better understanding of the factors that shape galactic systems. To carry out this study, we use we use computational simulations that model the formation and evolution in a galaxy in its larger environment. Among the relevant phenomena that we are tracking are gravity, fluid dynamics, star formation, and galaxy evolution. Our project compares results from these computer simulations to observational data. Observations suggest that there is more material ejected in the polar regions as opposed to along the galactic disk. My research analyzes simulations that show the composition and structure of the CGM halo regions.

The Search for Dark Matter
Aldair Bonilla
Mentors: Sunil Golwala and Osmond Wen

Dark Matter has been puzzling physicists for the past 80 years since its discovery in the 1930s. Throughout the late 1900s, there has been lots of evidence pointing towards some missing matter in galaxies' orbital velocity. Keplerian mechanics tells us the orbital speed of a galaxy should decrease as you go further out from the center, whereas observation shows us that it becomes constant in the outer fringes of galaxies. Dark matter would account for this extra mass that is flattening the curve. To solve this mystery, this project aims to build a detector using cryogenically cooled germanium and silicon crystals at temperatures as low as 15mK. This experiment will be in an underground clean room laboratory, where a precise gantry will be using linear translational stages to install detectors into the cryostat chambers. One of the assemblies would couple the Y and Z translational stages together and would need to carry at least 300 pounds without much deflection or stress. After making the mechanical design of the YZ coupler, I found that the stresses are below yield strength and that the deflections are acceptable. I will then integrate the assembly into the full model to apply more realistic loads.

Coordinate-Based Multilayer Perceptrons for Super-Resolution in Medical Resonance Imaging
Charlotte Borcherds
Mentors: Shreyas Vasanawala, Christopher Sandino, and Katherine L. Bouman

Super-resolution is a method used to convert low-resolution images to high-resolution (i.e. deblurring). One issue in medical imaging is the lack of data: datasets will generally carry few images, which makes it difficult to train good models. Coordinate-based Multi-layer perceptrons (MLPs) try to get around this by learning smooth functions mapping coordinates to RGB values for one image, allowing us to infer the missing pixel values. However, this method exhibits 'spectral bias': MLPs are bad at learning high-frequency data, so the inferred images turn out blurry. Two solutions: are to use FFN (Fourier Feature Networks) and SIREN (sinusoidal representation networks). We alter these methods to be suitable for medical resonance (MR) images, and build improvements on them. Our findings are that SIREN produces better quality images, at the cost of time when using downsampling that discards every second pixel. However, sinc interpolation outperforms FFN and SIREN when we use sinc downsampling on the training image. The continuation of this project will examine methods to fix this, as well as applying these methods to image compression.

Studying Differential Isoform Expression in the *Clytia* Jellyfish Using Single-cell RNA Sequencing
Mihir Borkar
Mentor: Lior Pachter

Past research by the Pachter Lab has shown that full-length SMART-Seq single-cell RNA-seq data can be used to measure gene expression at isoform resolution, making possible the identification of isoform markers for cell types and for the development of an isoform atlas. The lab has also developed an organism-wide, transcriptomic cell atlas of the jellyfish *Clytia hemisphaerica*. By combining the ideas from the aforementioned research, we investigate differential isoform expression in *Clytia hemisphaerica* cell types by analyzing the transcript compatibility count matrix, which can be produced by the kallisto/bustools software from jellyfish single-cell RNA-seq data, using logistic regression methods. We find differentially expressed isoforms of genes in jellyfish neural cells. Next, we will investigate the protein sequences of these isoforms and look for features of interest potentially related to neural development. This will allow us to explore how jellyfish nervous system development differs from that in bilateral animals, how alternative splicing plays a role in this development, and how a decentralized nervous system can lead to coordinated behavior in the absence of a centralized brain.

Hyperspectral Thermal Infrared Remote Sensing of the Fish Creek Basin, Imperial County, California
Sarah Bowers
Mentors: Joann Stock and David Tratt

The cumulative offset and geologic slip rate of faults derived from field and other experiments do not always agree. This is often due to the size of the fault and the variation in geological structures along it. Thermal Infrared (TIR) imaging facilitates a greater understanding of a region's large-scale geological properties via the perspective and spectral properties of the geology it provides. Working to mitigate discrepancies, a program utilizing Environment of Visualizing Images (ENVI) software was created to process data collected by The Aerospace Corporation's Mako Airborne TIR imaging spectrometer over the Fish Creek Basin - a region of Southern California containing the Elsinore Fault and other minor faults. The processing significantly reduced the noise present in various bands of the data for a more accurate display of the geology's spectral properties - enabling a more detailed classification of the geological features caused by plate movement. One can now see folds and continuations of faults that were not obvious from ground based geological field work. On a large scale, the research method proposed allows scientists to strengthen the reconstruction of fault history and risk assessments through the mitigation of discrepancy in slip rates and crustal motion.

Knotting Is not for Naught: Effects of Topology, Friction, and Constituent Materials on 2D Woven Lattices
Makyla Boyd
Mentors: Julia R. Greer, Widianto Moestopo, and Seola Lee

The ultimate goal of our summer research project is to create a new form of reconfiguration and energy dissipation in architected materials through friction. We seek to achieve our objective by focusing our study on the woven topology, surface frictional properties, and constituent material. The study on topology will focus on designing embedded knots, specifically how the crossing number and intra-connected fibers affect fiber movement, junction strength, energy dissipation, and deformability of the lattice. The study on constituent materials will utilize PR 48 and a commercial flex resin. Our work will take place on the macroscale, where we will create a 2D sheet of tesselated woven unit cells using a commercial 3D printer. This 2D sheet will utilize a knotted lattice structure where three fibers form an effective beam with each fiber creating an overhand knot with itself in each unit cell. We will then use the same design and synthesis framework to make materials for specific applications and develop a model that can predict how our knotted woven lattices would perform given a specific constituent material under the same physical parameters (geometry, coefficient of friction, etc.).

Crystal Structures of MurG With Park's Nucleotide and Murgocil
Helen Brackney
Mentors: William M. Clemons Jr. and Anna K. Orta

The peptidoglycan layers in bacterial cells is a popular target for antibiotic development. Essential membrane and peripheral membrane proteins MraY and MurG are part of a critical step in the synthesis of peptidoglycan. The product of MraY, Lipid I, is thought to be recognized by MurG through its soluble domain. Currently, there is no structure of MurG with its lipid substrate, Lipid I. Crystallographic methods were applied to study the interactions between MurG and the soluble domain of Lipid I through the substrate mimic Park's Nucleotide. By adding this substrate-mimic and an inhibitor, Murgocil, to concentrated MurG, crystals formed under optimized conditions. The crystals were diffracted using the Stanford Synchrotron and electron-density maps were then used to model the structure of MurG.

The Influence of Prosthetic Aortic Valve Size on Downstream Residence Time
Amelia Burns
Mentors: Morteza Gharib and Alexandros Rosakis

Polymer prosthetic heart valves are one potential option for aortic heart valve replacements. The size of the prosthetic valve used for this procedure is suspected to affect the dynamics of blood flow in the aortic sinuses; a larger than necessary valve may restrict blood movement behind the valve's leaflets. One measure of hemodynamics is residence time, the amount of time a particle of fluid spends in a specific region. A high residence time can lead to an increase in clot formation, potentially relating valve size to clotting in the aortic sinuses. We compared the residence time of fluid downstream of polymer aortic valves of two different sizes (inner diameters 27 and 23 mm) by using a pulsatile heart pump to pump water through a chamber modeling the aorta. Tracking the presence of UV fluorescent dye injected both above and below the valves over several cardiac cycles revealed the rate at which particles are washed away from these regions of interest. We also used particle image velocimetry (PIV) to compare the velocities and vorticities of particles in these regions, as well as simulated particle tracking to model the movement of said particles and determine their residence time.

Protocol Optimization for Drug Localization of a Retinopathy-Treating Peptide in Mouse Retina Using Peptide-Fluorescent Dye Conjugate
Connor Call
Mentors: Julia Kornfield and Jin Mo Koo

Age-related macular degeneration (AMD) is a leading cause of vision loss in the industrial world. Risuteganib (RSG) is peptide drug that has been shown efficacious in treating AMD in clinical trials without adverse effects. However, the mechanism of action (MoA) of RSG remains unknown, and the binding target is unclear. The aim of this work was to optimize a method to reliably determine RSG-dye conjugate localization in mouse retinal sections in hopes to progress towards a MoA. Several variables in sample preparation were investigated including tissue preservation, type of fluorescent dye tag, drug-dye conjugate solvent, and age of the eye sample. Trials were performed using confocal microscopy on treated BALB/c mice retinal sections using various conditions and DAPI staining to visualize retinal anatomy. It was found that staining is best performed on samples that were preserved for 5-10 minutes in a 4 w/v% paraformaldehyde solution following tissue sectioning to minimize tissue damage. Additionally, it was concluding that sulfonated-Cy5 fluorophore showed the least specific labeling in retinal tissue sections among four fluorophores compared. Lastly, homogenized vitreous humor was shown to be the best solvent due to the additional peptides and salts present to simulate endogenous conditions.

Evaluating the Exhumation History of the Central Aleutian Arc Using Geobarometry
Odalys Callejas
Mentors: Claire Bucholz and Emma Sosa

Exhumation is a process by which rocks deeply buried or crystalized at depth are brought to the surface in response to erosion of overriding material or tectonic processes. The Aleutian Arc is an ideal location to study the dynamics of exhumation and arc systems in general because (1) it displays an extensive exposure of plutonic rocks and (2) it lacks back-arc spreading, thus simplifying its exhumation history. In this project, we will obtain a regional data set of exhumation timing, rates, and trends from samples spanning >1400 km of the Central Aleutian arc. We will be studying plutons (predominantly composed of diorites and granodiorites, which are rocks primarily made of plagioclase, amphibole, and quartz). This will allow us to assess various hypotheses for exhumation mechanisms that have been proposed in the literature but have not been directly tested. I will perform petrographic analyses to constrain the mineral assemblage of samples and microprobe analyses to obtain mineral compositions. I will conduct geobarometry calculations (Al-in-hornblende geobarometer) to quantitatively calculate the depth (pressure) of pluton emplacement. This study will provide insights into arc system dynamics and may help constrain whether magmatic, tectonic, and/or climatic forces drive plutonic exhumation.

A p-adic Analogue of the Quantum Error-Correction Picture of AdS/CFT
Ali Cataltepe
Mentor: Sarthak Parihk

The Anti-de Sitter Space/Conformal Field Theory correspondence (AdS/CFT) conjectures a duality between a theory of quantum gravity and a conformal field theory. Several models have been proposed to analyze AdS/CFT by discretizing the space using methods inspired by number theory. The correspondence provides a dictionary between quantum operators defined in the bulk and boundary of a bounded manifold. An operator in the bulk can be reconstructed on multiple different subsets of the boundary, and this redundancy invites a quantum error-correction interpretation of AdS/CFT. This can be achieved by placing a tensor network forming a code or state in the space and deriving a connection between its algebraic and spatial properties.

Methods for Single-Cell eQTL Analysis
Isha Chakraborty
Mentors: Lior Pachter and Ingileif Hallgrímsdóttir

The complete sequence of the human genome has enabled the undertaking of numerous association studies that link genetic variants with traits. Among the many traits whose genetic basis have been explored, the molecular trait of gene expression, which is fundamental to biological processes, is of particular interest. Association of genetics with gene expression is known as expression quantitative trait loci (eQTL) analysis, and eQTL studies have revealed thousands of sites throughout the genome whose variants associate with the gene expression of nearby genes [1]. These have served to pinpoint functional regions of interest in the genome that play key roles in the molecular biology of the cell.

Single-cell eQTL (sc-eQTL) analysis is a recently developed refinement of eQTL analysis that leverages new technologies for simultaneously measuring gene expression in large numbers of individual cells. Whereas eQTL analysis has traditionally been based on bulk gene expression measurements (i.e. whole tissue samples), single-cell gene expression assays allow for comparing and contrasting gene expression between different cell types within tissues. In particular, single-cell RNA-seq (scRNA-seq) assays, which are an amalgamation of methods that utilize novel microfluidics and/or novel biochemistry to extract gene expression measurements from single-cells, have been shown to be scalable and cost-effective in experiments that produce gene expression measurements in up to hundreds of thousands of cells. Thus, single-cell eQTL analyses are now tractable, and they can allow for identifying variants associating with gene expression in specific cell types.

To facilitate sc-eQTL studies, we developed a workflow to perform eQTL analysis on clusters of cells from single-cell RNA-seq. We leveraged a novel suite of bioinformatics tools called kallisto - bustools, that facilitate rapid pre-processing of single-cell RNA-seq data and we integrated this pre-processing with downstream eQTL analysis methods, focusing on the single-cell aspect and producing reliable eQTL annotations for cell types.
The p-adics are a number field obtained by the Cauchy completion of the rationals with respect to a different norm (determined by a fixed prime p) from the absolute value, and the set of all finite truncations of the p-adics has the structure of an infinite p+1-regular tree, the Bruhat-Tits tree. Replacing real-hyperbolic space with this tree (or a finite radial truncation) when using tensor networks eliminates discrete artifacts that emerge during similar analysis of real AdS/CFT, since the underlying space itself is now discrete. However, as of yet work has mostly been done on formulating the behavior of states composed of perfect tensors situated in p-adic space. We characterize a class of tensor networks that implement quantum error-correcting codes with properties modeled by p-adic AdS/CFT, such as complementary recovery and a Ryu-Takayanagi formula relating the length of a geodesic dividing two regions in the tensor network to the entropy of their individual output states.

Structural and Electrical Properties of Dysprosium Barium Copper Oxide Thin Films
Sean Chang
Mentors: Y. Eren Suyolcu and Joseph Falson

Dysprosium Barium Copper Oxide ($DyBa_2Cu_3O_{7-x}$, DBCO) is a high–temperature superconductor exhibiting similar characteristics with $YBa_2Cu_3O_{7-x}$ (YBCO). Herewith, we revisit DBCO to determine whether we can exceed the previously reported physical properties of DBCO films with our recent precise calibration and temperature ramping methods. In particular, our samples will be superconducting DBCO thin films precisely synthesized in co-deposition regime by ozone-assisted molecular-beam epitaxy (MBE). To make precise growth, we will perform routine calibrations providing the information of the specific source fluxes (*e.g*. Dy source flux), where X-ray reflectivity (XRR) will be utilized for measuring the thickness. Moreover, we will also be looking at the structural properties of our DBCO thin films by inspecting the peaks obtained by X-ray diffraction (XRD) scans. In the last stage, by measuring temperature dependent resistivity, we will test the superconducting properties of the samples when brought to its critical temperature, if any, by liquid helium. All data including optimum source, substrate, and growth temperatures will be recorded so that the MBE system can produce similar -or better- quality samples in the future. These samples may be useful to future growth like heterostructure thin films.

Analyzation and Visualization of Mitochondrial DNA via In-Situ Third Generation Hybridization Chain Reaction
Simon Chau
Mentor: Bruce Hay

Mitochondria have a separate and distinct genome that encodes rRNA's, tRNA's, and proteins essential for oxidative phosphorylation and energy production within the cell. Mutations of mitochondrial DNA (mtDNA) can lead to sustaining populations of deleterious mtDNA that give rise to maternally inherited disease, and diseases of aging such as cancer and neurodegeneration. In-situ third generation HCR is typically used to visualize mRNA; however, once adapted properly this technique can in principle allow for the multi-target visualization of mitochondrial DNA and individual mitochondrial genotypes, as well as mitochondrially encoded RNA. Here, we show that using third-generation HCR, it is possible to detect and localize both strands of mitochondrial DNA in HeLa cells. Advanced visualization and analysis techniques are necessary for development of therapies aimed at reducing the frequency of mutant genomes and increasing cellular health. We hope that adapting this technique for mtDNA analysis will provide a straightforward method for visualization of mtDNA of different genotypes and RNA in cells and organisms. Such a technology will enable high throughput screens for molecules that can promote the selective removal of mutant mtDNA.

Development of a Bioinspired Fin Propulsion System for Maneuverable Autonomous Underwater Vehicles
James Chen
Mentors: Morteza Gharib, Peter Renn, Noel Esparza-Duran, and Cecilia Huertas-Cerdeira

In recent years, Autonomous Underwater Vehicles (AUVs) have been brought into the spotlight due to their range of applications from industry and defense to space exploration. Two major considerations in AUV design are propulsion and maneuverability. Interestingly, fish are able to achieve higher propulsion efficiency than man-made propellers and can also change orientation more easily. In an effort to achieve this level of performance, a novel underwater robot was created that combines a biomimetic fish fin with a traditional propeller; the fin can perform complex trajectories in a thirty degree cone using a parallel manipulator, and can also spin around its axis like a conventional propeller to generate additional thrust. The software controlling the fin was updated so that the actual trajectory performed closely follows the intended trajectory. In addition, communication systems were set up between the fin, control electronics, sensors, and MATLAB so that the entire pipeline can be run with a single click.

As a continuation of this work, the completed robot will be tested in a water tank and various fin trajectories will be performed to determine how to best generate both forward thrust and torque.

Simultaneous Integration of a Genetic Circuit Into Multiple Genome Loci in *E. coli* Using Integrase-Mediated Cassette Exchange
Victoria Chen
Mentors: Richard M. Murray and John Marken

Synthetic biology relies heavily on the usage of synthetic circuits in order to understand biological design principles and to implement and test new cellular functions. However, such synthetic constructs impose an unnatural load on the host. Thus, cells that randomly mutate to inactivate the synthetic circuit propagate more successfully than engineered cells. Since plasmids can segregate upon cell division to concentrate broken plasmids into fewer daughter cells (random plasmid partitioning), circuits programmed on plasmids face the problem of the population quickly losing circuit function. Previous work has shown that the most stable expression system requires multiple copies of the circuit integrated onto the genome. The goal of this project is to develop a platform for single-step integration into multiple genome locations simultaneously. Unlike previous methods, the resulting genome contains only the synthetic circuit and no extraneous material (e.g. plasmid origins, resistance markers). Our method takes advantage of recombinase-mediated cassette exchange. Two integrase *attP* sites with a spacer sequence between them are made into the genome, resulting in a "landing pad." A donor plasmid is also constructed in which the gene of interest is flanked by *attB* sites. When induced, the spacer should be swapped with the gene of interest. We anticipate that a modified genome which contains multiple "landing pads" will ease testing of synthetic circuits in the future by providing a quick way to perform multiple genome integrations for various applications, including increasing circuit stability.

A Laser-Engraved Carbon Biofuel Cell for Powering Wearable Devices From Human Sweat
Seunghee Cho
Mentor: Wei Gao

The wearable sensor, such as the electronic skin, has novel robotic functionalities suitable for various medical uses including personalized healthcare. Sweat biofuel cells are applicable to wearable devices because they provide a continuous energy source that it needs to operate wirelessly and be self-powered. We propose a laser-engraved carbon biofuel cell for powering wearable devices from human sweat for efficient and low-cost mass production. We fabricated and optimized the laser engraved carbon electrodes by using our CO2 laser cutter and tuning the laser parameters to maximize thickness of the carbon, which increases current response. The bioanode was prepared by drop casting the lactic oxidase (an abundant enzyme in human sweat) and hydrothermally applying mediators, Mendola's blue (to optimize on-set potential) and either Tetrathiafulvalene 7,7,8,8-tetracyanoquinodimethane salt or tetrathiafulvalene (to optimize current response). We also chose the optimal cathode for the biofuel cell to catalyze the reaction, where the candidates were Prussian blue analogs and platinum. We prepared the Prussian blue cathode through electrodeposition, and the platinum cathode through a hydrothermal method. Then, we test and evaluate the biofuel cells in body fluids such as sweat for powering electronics.

Optimized Eddy-Viscosity Models for Coherent Structures in Turbulent Jets
Haeyoung Chloe Choi
Mentors: Tim Colonius and Ethan Pickering

The inclusion of eddy-viscosity models in resolvent analyses of turbulent jets gives dominant modes that compare favorably to observed structures. In previous studies only a limited region of the flow parameter space has been examined. In this study, we investigate the effects of different azimuthal modes and regions of the jet that had not been considered previously. We determine an optimal eddy-viscosity field by applying a Lagrangian optimization framework that maximizes the projection between resolvent analysis and spectral proper orthogonal decomposition (SPOD) modes determined from a large-eddy simulation database for a round Mach 0.4 jet. We find that while the optimal eddy viscosity substantially improves the agreement between the resolvent and SPOD modes for all frequencies investigated (i.e., low to moderate frequencies), the improvements are inferior to those of the axisymmetric modes. As the first and second helical modes contain the most energetic structures at these frequencies, determination of a more effective turbulence model is important for predictive models. We investigate some alternatives suggested by the data.

CytoSPRITE: A Split-Pool Barcoding Technique to Capture Cytoplasmic RNA-RNA Interactions Involved in Co-Translational Regulation and Protein Synthesis
Bryson Choy
Mentors: Mitchell Guttman and Jamie Wangen

A fundamental part of the central dogma of molecular biology is the process of translating messenger RNA (mRNA) into proteins. As such, protein synthesis is a highly regulated mechanism that is modulated by various types of RNA, which work in conjunction with ribosomes to ensure translational fidelity. Molecular biology research has increasingly turned its attention to characterizing the function of non-coding RNAs due to their multifaceted role in cellular processes such as protein trafficking and regulation of mRNA translation. To explore how these regulatory RNAs interact during protein synthesis, we have developed a new experimental method to study multiway cytoplasmic RNA-RNA interactions that can provide a deeper understanding of translational efficiency and RNA-protein complexes in the cytoplasm. Through experimental optimization, we have adapted a split-pool barcoding technique to study these interactions (Cytoplasmic Split-Pool Recognition of Interactions by Tag Extension, "CytoSPRITE"), taking advantage of its scalability and combinatorial nature to achieve a comprehensive overview of translation. We demonstrate that our technique is an efficient method to capture clusters of cytoplasmic RNAs and proteins within the same complex *in vivo* and, in the future, plan to scale up our sequencing efforts to explore the molecular mechanisms underpinning RNA virus activity.

Modelling Meningioma in Zebrafish
Katelyn Chu
Mentors: Marianne Bronner and Ayyappa Raja

Meninges are the protective covering of the central nervous system originating from neural crest and mesodermal cells. Mutations in tumor suppressor genes lead to meningiomas, the tumors of meninges. Interestingly, 60% of meningiomas across different grades and subtypes display genetic alterations in the NF2 (Neurofibromin 2) gene. NF2 is a membrane-cytoskeleton linker that inhibits cellular proliferation via contact-dependent regulation of various signalling pathways, including Notch, Hedgehog, TGF-Beta, Hippo, and receptor tyrosine kinase. To understand the effect of NF2 mutations on meningioma-genesis, we propose to generate a zebrafish meningioma model by targeted knockout of Neurofibromatosis 2 (NF2) gene in neural crest and mesoderm derived meninges. To test this, we used a CRISPR-Cas9 based mutagenesis system to knock out, or cause complete loss of function of, NF2 in zebrafish. We performed a preliminary screen to identify competent gRNAs that generate INDELS (insertions or deletions of bases) in the NF2 gene. The INDELS were verified by T7 endonuclease-Heteroduplex assay and validated by sanger sequencing. We observed developmental delay and hyper-pigmentation upon NF2 knockout. Since mutations in NF2 lead to early embryonic defects and affect the survival of the mutants we propose to utilize conditional mutagenesis to generate mosaics and perform prolonged analysis.

Analysis of the Acoustic Properties of Helical-Structured Metamaterials With Variable Centrosymmetry
Kaila Coimbra
Mentors: Chiara Daraio and Gunho Kim

Acoustic metamaterials are uniquely architectured structures that exhibit acoustic properties that are not found in nature. In this project, we explore the acoustic properties of helical-structured metamaterials with variable centrosymmetry through numerical simulations and experimental validation. Using the commercial finite element analysis software COMSOL Multiphysics®, we first analyze the acoustic properties, such as wave speed and hybridization of normal modes, of helical-type acoustic metamaterials with various geometrical parameters. From this study, we optimize the geometrical parameters of the helical structure so that they meet the constraints of a physical experimental study. Furthermore, we break the centrosymmetry of the helical structures by incorporating added mass into the base structure. Inducing non-centrosymmetry in the structure allows us to control the degree of mode coupling at low frequencies and the size of the longitudinal band gap. Subsequent work will include controlling the centrosymmetry of helical metamaterials with a tunable mechanism and eventually validating the numerically predicted acoustic characteristics through experimental analysis.

Local Information Scrambling in Random Quantum Circuits
Laura Cui
Mentors: John Preskill and Alexander Dalzell

Random quantum circuits are an effective model for the behavior of chaotic quantum systems, including the phenomena of information scrambling. While it is known that local random circuits scramble information in a time linear in system size, for applications in condensed matter, it is often impractical to allow evolution time to scale with the size of a physical system. We define local forms of scrambling, in which information in the system appears scrambled when only a region of fixed size can be accessed, and characterize the conditions for which it is achieved by a local random circuit. We find that a weaker form of local scrambling is achieved with circuit depth linear in the size of the subregion, independent of the size of the entire system; this result generalizes to a stronger form of scrambling in the limit of large local qudit dimension. We also describe applications to classifying topological phases and characterizing the entanglement structure of quantum matter.

Analysis of Turbulent Channel Flow Simulations With Wall Transpiration
Daniela Davalos
Mentors: Beverley J. McKeon and Yuting Huang

Heterogeneous rough-wall turbulent flows have been of interest in recent years. The effect of spanwise-varying surface heterogeneity on turbulent channel flow is analyzed using direct numerical simulation (DNS) at a friction Reynolds number $Re_\tau = 657$. In this study, we investigate whether wall transpiration can be utilized to approximate surface roughness. Heterogeneously distributed roughness is simulated by imposing non-zero streamwise and wall-normal velocities at the wall. A triple decomposition of the velocity field was computed to determine the 2D mean profile, turbulent fluctuation, and mean spanwise variation. Turbulent profiles of the 2D mean velocity are used to compare the profiles between the DNS data and experimentally observed behavior of a real rough wall. Reynolds stresses as a function of the channel height were plotted using the turbulent fluctuations of the stream-wise and wall-normal velocities. The 2D mean profile and streamwise vorticity turbulent profiles reveal that secondary flows are apparent near the transition between the rough and smooth surfaces, similar to the experimental results. This study showed that transpiration boundary conditions can mimic the behavior of rough surfaces, enabling more efficient simulations in the future.

Synthesis of Brain Permeable Na^+/K^+ ATPase Inhibitors
Isabel de la Torre Roehl
Mentors: Brian Stoltz and Veronica Hubble

Researchers at the Huntington Medical Research Institutes (HMRI) have detected an increase in sodium concentrations in cerebrospinal fluid (CSF) during migraine. Na^+/K^+ ATPase is a transmembrane protein channel found in a variety of human organs (i.e., kidney, heart, brain) responsible for regulating and maintaining sodium and potassium levels in the blood and CSF. This makes it a potential drug target for the treatment of migraine. There are several known molecules (i.e., cardenolides, bufadienolides) that inhibit the activity of Na^+/K^+ ATPase, but their lack of brain specificity and known cardiotoxicity warrant structural modification in order to be used. Based on what we know about the activities and binding of these inhibitors, we worked to synthesize novel compounds with enhanced blood-CSF permeability that could specifically target Na^+/K^+ ATPase within the brain. We explored various methods for modification including methyl protection, TBS protection, Stille coupling, and Suzuki coupling.

An Organism Wide Survey of piRNA Activity in *Drosophila melanogaster*
Carlos Del Angel Aguilar
Mentors: Alexei Aravin and Yicheng Luo

Piwi-interacting RNAs (piRNAs) and their associated mechanisms are a recently discovered method of epigenetic regulation. piRNAs are primarily believed to control transposon activity. Although piRNA activity has only been well characterized in the reproductive organs, recent research shows both transposon and Piwi protein activity outside these organs. We hypothesize that piRNA systems are therefore active outside the reproductive organs as well. To this end, we have created a line of *Drosophila melanogaster* that contains a reporter gene that is silenced when the piRNA system is active. We have conducted dissections of multiple organs in both the new line and a positive control line to identify the location of possible piRNA activity outside the reproductive system. To this end, we have so far identified activity in the R5 region of the midgut as well as at the distal tip of the VNC in the larval brain. piRNA activity was not observed in the salivary glands. piRNA activity seems to occur only in small cell types in the gut and brain, although this matches what is observed in the reproductive systems.

The Role of Overconfidence in Susceptibility to Conspiracy Theory Belief
Dasani DelRosario
Mentors: John O'Doherty, Caroline Charpentier, and Lisa Kluen

Conspiracy theories have gained traction in the media due to beliefs surrounding COVID-19 and recent presidential elections. Common associations are made between traits such as illusory pattern perception and political extremism and belief in conspiracy theories. While confirmatory studies have been conducted involving visual pattern perception and belief superiority in relation to conspiracy endorsement, there is not yet an account that fully investigates the role that overconfidence plays in susceptibility to these beliefs. This study aims to measure whether conspiracy theory belief is related more strongly to illusory pattern perception or overconfidence, specifically looking at participants who have a high number of false alarms in a visual pattern perception task (seeing images in granular patterns where there are none) by using regression analysis and generalized linear models. Pilot data shows a correlation between political extremism and confidence levels, which helped to select the target demographics of the study, Americans on opposite ends of the political spectrum. The visual pattern perception task also collects confidence data from participants and is followed by questionnaires gauging the extremism of the political, spiritual, and conspiracy beliefs from the two groups of American subjects (self-reported conservatives and self-reported liberals). The goal of this study is to analyse the predictive value of these factors in estimating how subjects will rate their conspiracy belief in the questionnaires and to gauge the significance of the role that overconfidence plays in the endorsement of conspiracy theory belief.

Examining the Effects of N-Aryl Pyridinium Additives on Copper-Mediated CO_2 Reduction via Hammett Analysis
Matthew Demer
Mentors: Jonas C. Peters, Nick Watkins, and Madeline Hicks

Industrial electrochemical conversion of CO_2 provides an attractive method for sequestering carbon dioxide and providing alternative chemical feedstocks. The use of copper electrodes in aqueous CO_2 reduction gives high yields of carbon-coupled products such as ethylene and ethanol. Previous studies have shown thin films of electrodeposited N-aryl pyridinium molecules onto the cathode improves the catalyst selectivity for these value-added products. In this project, we probed the relationship between electronic properties of the molecular additives, described by Hammett analysis, with the observed product partial current densities. Varying the functional group at the *para*-position of the aryl ring yielded no clear relationship. This result suggests that there may be other variables that better explain the differences in selectivity between additives, such as steric bulk or film morphology.

Understanding the Physical Properties of the Kilauea Volcano by Analyzing Long-Period Events
Monica Diaz
Mentors: Zachary Ross and John Wilding

Understanding long-period (LP) or low-frequency events are a vital source in volcanic seismology. It is associated with physical changes that lead to predictions of seismic hazard events. This project demonstrates an analysis of low-frequency events that trigger the caldera collapse and magma propagation near the East Rift Zone in 2018. To study these events, we interpolated a seismic velocity model that later was analyzed to build an earthquake catalog that contains over 76,324 events across 100 stations to obtain a ray trace. Using obspy to examine the data waveform traces by selecting a range frequency bandpass between 2.0-16.0Hz to have a close estimation of the arrival times. To obtain better quality for the seismic data, we have calculated the signal-to-noise ratio (SNR) to eliminate the noise and calculated the frequency index (FI) to measure the ground energy. The continuation of this project will allow us to use FI as a reference to distinguish low-frequency events from other different types of volcanic seismic events, and it will also contribute to building a relation between the physical characteristics and phases at Kilauea.

From Human Locomotion to Robot Locomotion
Christina Dong
Mentors: Soon-Jo Chung and Sorina Lupu

By advancing robot robustness, robots will be able to better carry out tasks that might be dangerous or ill suitable for humans, such as space exploration. We wish to create a biped robot with robust gait planning, autonomous navigation, and efficient locomotion. Our proposed robot will learn how to navigate complex terrains (such as elevated or uneven surfaces) by utilizing a locomotion model based on human locomotion data. The first step of the project is to construct a wearable costume to collect human hiking data with 13 IMUs, 3D depth and RGB camera, and a foot sensor. An Extended Kalman Filter will process the IMU data to obtain orientation information of human limbs in movement. After that, a self-supervised learning model will create the robot locomotion model. Then we will use this model to train a biped robot in simulation and in real life. We will compare our locomotion model performance to Reinforcement Learning and Model Predictive Control. If successful, our robot will be able to explore terrains previously not possible on Mars.

An Analysis of Column Specialization, Time Invariance, and the Effects of Depth on Self Organizing Spiking Neural Networks
Zack Dugue
Mentors: Matthew Thomson and Guru Raghavan

The Type of Spiking Neural Network worked on by the Thomson Lab is unique in its ability to self-organize. This means that, given unlabeled training data, the network will alter its structure to form ‘regions’ in the 2d neuron space that make up layers in this type of Spiking Neural Network, that fire in response to a given class of inputs. This kind of self-organization is driven by the Hebbian learning rule, simply ‘Neurons that fire together, wire together”, and this self organizing behavior i This paper covers my work furthering our understanding of this type of Spiking Neural Network. Including investigating whether columns (‘separate sets of layers with slightly different properties) specialize to classify certain types of data, whether the network’s ability to properly classify a class of data is time invariant, and finally how the network operates as the layer depth of the network is changed.

Mannequin Test of Particle Filtration Efficiency and Pressure Drop of Face Masks Used to Curb the Airborne Transmission of COVID-19
Roulince Dukuly Jr
Mentors: Richard Flagan and Buddhi Pushpawela

Since the beginning of the COVID-19 pandemic, mask usage has been increasingly recommended and often mandated to prevent virus transmission. The difficulty of breathing through face masks is important for their use. I investigated the particle penetration of, and pressure drop across four different face masks: N95, KN95, Procedure, and Cloth masks. For the particle penetration testing, we fastened a mask on the mannequin head and simulated breathing during light exercise as it was exposed to a dry polydisperse salt aerosol. The fraction of particles transported through the mask, particle penetration, was determined from the size distributions (30-800 nm) of upstream and downstream particle counts. When the mask was held only by ear loops (normal fit), the particle penetration was higher and pressure drop was lower than when the mask was sealed tightly to the mannequin with tape (tight fit). This result indicates that proper sealing and fitting of the face mask by users can increase the protection of the user against airborne transmission. The pressure difference and particle penetration measurements indicate a substantial leakage across the different face masks, especially for normal fit. This study further examined why particle penetration is higher than expected, even for the N95 mask.

Lewis Acid and Charge Effects on Lehn-Type CO_2 Electroreduction Complexes Supported by Extended π System Ligand Architectures
David Dumas
Mentors: Theodor Agapie and Gavin Heim

Although electrocatalysis of CO2 Reduction Reactions (CO2RR) has been well-studied for decades, the emerging climate crisis has placed urgency on the need for advancements to circumvent fossil fuel reliance. Lehn-type rhenium catalysts are highly selective CO2 reduction electrocatalysts that convert carbon dioxide to carbon monoxide but suffer from large overpotentials. Developing more energy efficient Lehn-type catalysts would be beneficial given that carbon monoxide is a synthesis gas component used to prepare carbon-rich materials via Fischer-Tropsch. The introduction of electron withdrawing groups, extended pi systems and dicationic Lewis acids can lower the overpotential of CO2RR, which could provide new avenues for the development of homogeneous electrocatalytic systems. We are interested in targeting a single-component electrocatalyst that incorporates redox-innocent Lewis acids with metal centers capable of reducing CO2. Attempts to metalate tetrapyridophenazine, salicylsalphene and their respective derivatives with rhenium have been largely unsuccessful due to solubility issues. Cyclic voltammograms of rhenium bipyrimidine complexes do not display an obvious catalytic wave, demonstrating that electrocatalysis for CO2RR is not achieved. Moreover, electron-deficient ligands are burdensome for installing a Lewis acid. Moving forward, bulky substituents will be incorporated where appropriate to increase ligand solubility. Cyclic voltammograms will be performed with exogenous Lewis acids to generate the binuclear complex in-situ.

Altering Immunostaining With Signal Amplification by Exchange Reaction (Immuno-SABER) to Spatially Map Proteins With Stimulated Raman Scattering (SRS) Microscopy
Emily Dunn
Mentors: Lu Wei and Li-En Lin

Immunostaining with signal amplification by exchange reaction (Immuno-SABER) enables the spatial mapping of proteins within tissues but is limited in throughput and quantification due to the quenching or photobleaching of the fluorophores and limited number of distinct signals. Here we focus on altering Immuno-SABER for stimulated Raman scattering (SRS) microscopy because engineered polyynes, imagers created for super-multiplex SRS microscopy, have a higher specificity, sensitivity, photostability, and number of distinct spectral barcodes than fluorescent imagers. We designed three orthogonal probes based on the methods applied in Immuno-SABER for the visualization of alpha-tubulin, fibrillarin, and lamin b. We fabricated the extended primers for the probes utilizing the primer exchange reaction (PER). To confirm the success of the extended primer synthesis we completed the hybridization with fluorescent imagers. We were able to image the immunostained samples with both fluorescence and SRS microscopy. With iterative Immuno-SABER, we anticipate a 23.5-fold signal amplification over traditional secondary antibody staining. Future research will explore the synthesis of DNA tagged engineered polyynes to serve as the imagers for Immuno-SABER SRS microscopy with the hope of achieving single protein visualization.

Characterizing the AC Magnetic Field Gradient for Microscale Biomedical Device Localization
Liliana Edmonds
Mentor: Azita Emami

Present techniques for device localization, such as X-ray fluoroscopy and manometry, have become the primary tools for common medical procedures like capsule endoscopy and orthopedic surgery. Previous research focused on applying a direct current (DC) to thin, planar X, Y, and Z gradient coils to create a static magnetic field gradient that could be measured by wireless microscale devices. These devices encode the magnetic field data to a unique spatial point, then communicate it to an external receiver to determine the real-time location of the device. The first device prototype used to characterize the DC magnetic field within the 20x20x10 cm3 field-of-view (FOV) consisted of a CMOS chip-controller and an externally powered DC magnetic sensor. This externally powered sensor and reliance on a high supplied current to achieve high resolution introduces power inefficiencies to the system, making direct current an ineffective method for creating a magnetic field gradient. This project primarily focuses on the use of an applied alternating current (AC) to create a sinusoidal field at each point in the FOV that can be increased in strength by increasing the current frequency (100-500 Hz), making it a more power-efficient option. The focus of this research is characterizing a 500 Hz AC magnetic field using a commercially available sensor in order to create an AC gradient system at the device level, whereby the previous DC magnetic field gradient can be replicated and improved by supplying the coils with an alternating current and capturing the peak value of the generated sinusoidal field. This will allow the CMOS-controller chip to have a completely integrated 3D AC magnetic sensor that can achieve high resolution through tuning the frequency instead of consuming external power or relying on high supplied direct current.

Creation of a Joint Experimental and Computational Workflow for the Analysis of *in vivo* AAV Gene Therapy Expression Levels
Desmond Edwards
Mentors: Viviana Gradinaru and Acacia Hori

Adeno-associated viral (AAV) vectors are safe and effective vehicles for gene delivery, with vectors being engineered for increased cell type specificity compared to natural serotypes. These features render AAVs the vectors of choice to deliver gene therapies, in which a gene encoding a functional protein supplements low expression or dysfunction of a patient's mutated copy. Unfortunately, systemic AAV administration offers minimal control over the vector genome biodistribution of each cell. For genes which require tight regulation to avoid pathological overexpression, this represents a significant challenge. One such gene is methyl-CpG-binding protein 2 (MeCP2). Sporadic mutations in MeCP2 decrease its expression and target-binding affinity, causing Rett Syndrome (RTT), while overexpression causes MeCP2 Duplication Syndrome. As such, high-throughput analytical methods are needed to evaluate the effectiveness of pre-clinical RTT gene therapy candidates.

Hybridisation chain reaction offers a means by which to quantify AAV-MeCP2 transcripts while maintaining single-cell transcript spatial distribution, but data requires many hours of manual analysis. Coupling this approach with cell membrane immunostaining of murine brain slices, I devised an automated CellProfiler analysis pipeline while maintaining single-cell resolution. These results demonstrate both a proof of concept for a preclinical RTT gene therapy and automated analysis of *in vivo* transgene expression.

Explorations in the Mathematics of Gauge Theories
Frenly Espino
Mentor: Sergei Gukov

Gauge theories are important in describing the physics of elementary particles and have provided the most promising method to unify the four fundamental forces of nature. The mathematical language of these gauge theories is that of Lie groups, Lie algebras, and representation theory. In this project, we familiarize ourselves with the topology of Lie groups, how Lie algebras are the set of left-invariant vector fields over Lie groups, the Jacobson-Morozov theorem, and the coadjoint orbits and representations of Lie groups. In the future, we can leverage this new mathematical background to construct a bijection between the coadjoint orbits of B and C type groups to rank 4 and 5.

Entanglement Distribution Between Two Remote Nodes at Caltech
Gabriel Fabre
Mentors: Maria Spiropulu and Raju Valivarthi

Quantum networks promise a wide variety of applications that include secure communication, enhanced sensing capabilities, scalable quantum computing architecture and fundamental tests of the universe, capabilities that are beyond that of the classical internet. Distributing entanglement between remote nodes of a network is one of the fundamental tasks of these networks. The most suitable method to achieve this over long distances is through distribution of time-bin entangled qubits. We have aimed to establish a system of remote nodes on campus for time-bin entanglement distribution, across 0.7 km of optical fiber cable travelling to a different lab, where other experiments may be conducted, and creating a system much closer to a real-world network. This has involved testing of photonics equipment and analysis of the fiber link with new and previous techniques and systems developed in past experiments by members of the INtelligent Quantum NEtworks & Technologies (INQNET) program. Working with remote nodes increases the complexity of experiments in terms of synchronization and data analysis but is required to create networks. Accomplishing this would allow further research on improving teleportation fidelity, reducing interference and noise, and increasing transmission rates, as well as research on other quantum technologies, such as quantum memories.

Quantifying Carbon Export in the Southern Ocean: Observations From Ocean Gliders
Ellie Flint
Mentors: Andy Thompson and Lily Dove

Oceans are integral to the global carbon cycle, as removing atmospheric carbon from the surface ocean sequesters carbon over long time scales. Carbon sequestration is accomplished through "pumps" that transfer organic carbon to the deep ocean. The strength and persistence of various pumps determine the depth and magnitude of carbon export and therefore, the quantity and duration of carbon storage. Identifying the mechanisms, i.e. "pumps", and their relative contribution to vertical global carbon flux is a fundamental objective of oceanography. Traditionally, ocean carbon export has been attributed to the biological gravitational pump (BGP), where surface carbon is passively transferred to the deep ocean via sinking. However, newly discovered particle-injection pumps, such as the eddy-subduction pump and mixed-layer pump, provide alternative, active mechanisms of carbon export for small-particle particulate organic carbon (POC). Due to the novelty of these pumps, and because they act on small spatial and temporal scales, limited observational data exists that describe their capacity for carbon storage.

Here, we calculate the flux of POC from the eddy-subduction and mixed-layer pumps in a Southern Ocean region using glider and float observational data from the SOLACE (Southern Ocean Large Areal Carbon Export) Voyage. Data was collected between December 2020 and January 2021, during and after the Southern Ocean spring bloom. The glider data identify and characterize mesoscale features via anomalies of temperature, salinity, POC, and oxygen at depths of 100m to 400m. Changes in properties are strongest alongside eddy edges. Overall, we observe a temporal change in the eddy subduction pump strength, where POC flux peaks, reaching values as high as 96 mg m-2 day-1, at the start of the spring deployment, and steadily decreases by a factor of roughly 5 into the summer season. Preliminary results suggest that the mixed layer pump strengthens with the onset of stratification and makes a greater contribution to carbon export at the start of the summer. Quantifying carbon export from BGP-alternate pathways will assist in closing the global ocean carbon budget and improve ocean carbon cycle models.

Optimizing Electrochemical CO_2 Reduction Cell Design for Concentrated Products and Downstream Tandem Catalysis
Alex Fontani Herreros
Mentors: Jonas C. Peters and Nick Watkins

The electrochemical reduction of CO_2 to carbon-neutral fuels and petrochemical feedstocks is a promising strategy to close the anthropogenic carbon cycle. To date, significant efforts in the field have been devoted to improving the activity and selectivity of heterogeneous CO_2 reduction catalysts towards valuable multi-carbon products, with the goal of improving overall energy efficiency and commercial viability. However, many systems still suffer from low CO_2 conversion rates, resulting in diluted product streams that would require costly and energy-intensive downstream purification if deployed. This work focuses on the iterative design of a CO_2 electrolyzer optimized for high single-pass CO_2 conversion, resulting in a more concentrated product stream. The cell employs a Cu-based gas diffusion electrode in a membrane electrode assembly configuration, eliminating the need for an aqueous cathode electrolyte. This approach overcomes the solubility and mass-transport limitations of dissolved aqueous CO_2, while also preventing the dilution of desirable liquid products. Operation at elevated pressures and the use of selectivity-enhancing molecular additives are also being investigated as a means of further increasing CO_2 conversion. Future work will explore the coupling of this system with an ethylene oligomerization catalyst being developed by the Agapie group for the formation of higher-carbon CO_2 reduction products.

Advancing the Power of Affordable Spectroscopy for Education
Ian Fowler
Mentors: Melissa Hovik, Jeff Mendez, and Adam Blank

Spectrometers made for education are expensive and require little input from students, obscuring and mystifying the phenomena of absorbance and diffraction. The act of constructing a spectrometer with household materials is low-cost and pedagogically valuable, yet existing software options to conduct spectrometry are either nonexistent or dysfunctional. To solve this issue, a web application called Spectrala was developed in autumn of 2020. The software analyzes the video feed from a camera placed in a box containing a light bulb and a diffraction grating to collect spectra usable for educational chemistry labs. Spectrala was used with success in the Caltech course Fundamental Techniques of Experimental Chemistry during the remote winter and spring terms. To further increase accessibility to educators, a version of Spectrala was developed to run natively on smartphones and tablets during the summer of 2021. This setup is necessarily more interactive than existing spectrometers for education, requiring users to configure a physical spectrometer and calibrate spectra using the software. Development of a mobile version of Spectrala promises a hands-on and accessible way to learn and perform spectroscopy.

Time Complexity Inference via Static Analysis of Abstract Syntax Trees
Bruno Freeman
Mentor: Adam Blank

Time complexity is a fundamental concept in both practical and theoretical computer science that describes how the runtime of an algorithm scales with the size of its input. Although the problem of universally determining algorithmic time complexity is proven to be undecidable, we have developed software that answers the question for a wide array of algorithms implemented in a carefully selected subset of the Python programming language. The complexity decider achieves this by iteratively updating a dictionary of program variables represented as functions of symbolic inputs while traversing an abstract syntax tree of the implementation. Recurrence relations are employed to resolve runtimes for looping constructs and instances of recursion.

The development of this software has a pedagogical motivation. The complexity decider is to be utilized by a new course offering at the California Institute of Technology intended to ease the transition between the study of practical and theoretical computer science. The course will have students implement algorithms programmatically before attempting formal proofs. With test cases asserting correctness and the complexity decider confirming realization of the required runtime, students will be able to proceed from implementation to formal proof confident in the logic and efficiency of their algorithm.

Porous p-GaN via Photoelectrochemical Etching for Selective Gas-Phase Carbon Dioxide Reduction
Áshildur Friðriksdóttir
Mentors: Harry Atwater and Xueqian (Lucy) Li

Reduction of carbon dioxide (CO_2) into a targeted products holds great potential to close the carbon cycle and meet the rise in energy demand. However, CO_2 is a stable molecule with strong bonds, making it difficult for electrochemical conversion. Utilizing heterogeneous catalysts and power generated from the sun remains the most promising method for CO_2 reduction due to the mild operating conditions required for the conversion process. In this project, nanoporous p-GaN is fabricated with photoelectrochemical etching to increase the surface area for gas-phase CO_2 reduction to CO using Au and Cu catalysts. We investigate the photoelectrochemical response of the structure in terms of increased optical absorption and enhanced reaction rate of the CO_2 reduction. Morphology of porous p-GaN surfaces was characterized with scanning electron microscopy, energy-dispersive X-ray spectroscopy, and atomic force microscopy.

Characterizing the Microbial Ecology of Coastal Seagrass Roots and Associated Sediments
Nicole Garrido
Mentors: Victoria Orphan, Kriti Sharma, and James Mullahoo

Seagrass meadows (e.g. *Zostera marina*) are a type of 'blue carbon' ecosystem as they have net carbon storage and do this by efficiently sequestering carbon underground long-term, contributing upwards of 10% of total carbon capture from the ocean annually. *Z. marina* is an aquatic perennial monocot and has an extensive root system and associated microbiome that may impact plant productivity and ability to store carbon. Cable bacteria, a sulfide-oxidizing chain of filamentous, electrically conductive bacteria, may have a role in detoxifying the root environment by decreasing the sulfidic conditions present in the sediment, which at high concentrations is toxic to root tissue; and also may be able to give the plant nitrogen. We retrieved samples using push cores and injected them with HPG, 15N2, and 15NH4 isotope labels. Our sequencing data characterizes the bacteria localized by sediment depth, bacteria along the root, and compares old and young roots. We also determined if these bacteria can fix nitrogen. To study the relationship between the roots and cable bacteria, we used BONCAT-FISH fluorescent probes to identify where cables are present and active in order to investigate if the plant may be using its roots to enrich the presence of cable bacteria.

Individuals High in Symptoms of Anorexia Nervosa Display Differences in Attention and Learning
Karlton Gaskin
Mentor: Cindy Hagan

Anorexia nervosa is an eating disorder characterized by extreme levels of thinness which is achieved by engaging in restrictive eating practices, purging, or otherwise unhealthy behaviors including excessive exercise, vomiting, laxative, or diuretic abuse. Two prominent theories of anorexia nervosa explain these behavioral manifestations either by heightened underlying levels of anxiety or enhanced proneness for developing habits hindering food consumption. Here we test evidence in support of each of these theories and their influence on attention and learning in individuals high in symptoms of anorexia nervosa.

One thousand participants were recruited using Amazon Mechanical Turk and asked to complete a questionnaire assessing presence and severity of symptoms of anorexia nervosa. Of these 1000, individuals screening positive on at least 2 of the 5 symptom categories were invited to take part in a follow-up on-line longitudinal study where tasks of attention and learning were administered. Individuals screening negative (no symptoms) were also invited, and were matched to the other group on the basis of sex and reported body mass index (BMI). Two hundred and six people with symptoms of anorexia (127 females, 79 males) and 206 symptomless control participants (127 females, 79 males) agreed to take part in the study. To probe the presence of group differences in attention and learning, dot probe and pavlovian association learning tasks were administered to all participants in addition to a variety of questionnaires to characterize the study sample.

Data analyses are still underway, but we anticipate that individuals high in symptoms of anorexia are quicker to respond to targets replacing high calorie food images (i.e., threatening stimuli) relative to targets replacing object images or targets replacing low calorie food images (i.e., nonthreatening stimuli) and that these differences will be exacerbated by the level of arousal induced by the wheel of fortune spin. Furthermore, we anticipate our drift diffusion models will demonstrate that individuals high in symptoms of anorexia will be quicker to learn rewards associated with low calorie food images due to habit proneness and slower to learn rewards associated with high calories food images in comparison to control individuals.

Developing Metrics and Identifying Key Parameters for Prosthetic Foot Design
Jesse George-Akpenyi
Mentors: Aaron Ames and Rachel Gehlhar

Prosthetic foot design is known to have a significant effect on the gait mechanics of active and passive prostheses, yet very little is known of how key parameters of the foot (curvature, shape, flexibility) impact prosthetic functionality. The metrics for the foot design of active prosthetics have also not been widely formalized. This project aims to identify which parameters of foot design have a significant impact on the efficiency and gait symmetry of active prostheses and develop reliable metrics for determining an optimal foot design. To accomplish this, the center of pressure profiles and gait domain duration data will be taken for a series of foot designs and analyzed to determine which parameter changes affected gait mechanics significantly. This project could be continued by utilizing this data to create a "superior" foot and an "inferior", which would then be tested to verify if altering the identified parameters had an impact on gait mechanics and whether the metrics used were accurate in predicting improved or worsened functionality.

Social Learning and the Dynamic Updating of Group Value
Isaias Ghezae
Mentors: Colin Camerer and Sarah Tashjian

In complex social learning environments, simple learning mechanisms, such as associative learning, are used to guide the decision-making processes that facilitate cooperation in novel contexts. However, there is little empirical work showing how social learning occurs when faced with an unfamiliar other who belongs to a group to which there already exists robust value associations. In the intergroup psychology literature, race has been shown to hold powerful group value associations amongst individuals. Thus, in the present behavioral study, we leverage a stimulus generalization framework to examine how racial similarity between known individuals and unfamiliar strangers shapes social learning. Participants will play an iterative trust game with three partners who exhibit behavior varying in trustworthiness. After learning which partners can be trusted, participants will then select new partners for a second game. We expect that for participants who play with an outgroup member that displays untrustworthy behavior, participants will be more averse to prospective partners who share the racial similarity of that outgroup member when selecting new partners. Ultimately, this study hopes to elucidate how group value is updated in response to new moral information and how this updating process is constrained by previously held group value associations.

Characterization of Enteric Nervous System Alterations in the Gut of a Mouse Model of Autism Spectrum Disorder
Allison Glynn
Mentors: Sarkis Mazmanian and Jessica Griffiths

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder which affects approximately one in 59 children in the United States. ASD is characterized by impaired social communication and repetitive stereotyped behaviors; it is often comorbid with chronic gastrointestinal issues such as frequent abdominal pain, diarrhea, and constipation. The *Shank3*$^{\Delta 13\text{-}16}$ mouse model for ASD is representative of the mutations of the *Shank3* gene found in approximately 1% of human ASD cases; these mice exhibit ASD-like behaviors in addition to a marked decrease in gut transit time. Here, we attempt to identify factors contributing to the transit time phenotype by characterizing and comparing aspects of the enteric nervous system (ENS) of wildtype and *Shank3*$^{\Delta 13\text{-}16}$ mice, focusing on neurotransmitter and neuronal subtype quantification via enzyme linked immunosorbent assays and immunohistochemistry, respectively. Interestingly, we have measured relatively lower levels of serotonin in the gut tissues of the *Shank3*$^{\Delta 13\text{-}16}$ mice, indicating a possible role for serotonin in the transit time phenotype. As enteric serotonin levels have been linked with the microbiome, we then analyze 16S sequencing data from both wildtype and *Shank3*$^{\Delta 13\text{-}16}$ mice to determine the microbiome composition of each genotype, and thus if there are differentially abundant microbes related to gut motility and neurotransmitter profiles.

Improving the Modeling Efficiency of Methane Gas Combustion
Joaquín A. Gómez
Mentors: Guillaume Blanquart and Matthew Yao

Over the past decades, natural gas has become an important energy source, particularly in the United States. Given that methane is the principal component of natural gas, we must be capable of modeling its combustion accurately and efficiently for researchers to investigate safer and more efficient combustion methods. As they are less demanding and more repeatable than experimental combustion, physically validated computer simulations have become the method of choice in studying methane combustion. However, methane combustion simulations are prohibitively expensive and insufficiently accurate. The goal of this project was to investigate simplified combustion models to improve the efficiency and accuracy of methane simulations, thus allowing for more accessible investigations of the combustion process while creating a more accurate model. The simulations were performed using the NGA code (developed by Guillaume Blanquart) by pairing the Large Eddy Simulation framework with computationally efficient tabulated chemistry models. The model will be evaluated using the test case of a low swirl burner leading into a combustion chamber as a benchmark. Currently, we have seen promising results from turbulent, non-reactive, low-resolution simulations. Our next steps will be to add a reactive element and raise the resolution of these simulations to validate them against experimental results.

Applying InSAR to Tectonic Deformation in California
Julia Grossman
Mentors: Mark Simons, Oliver Stephenson, and Yuan-Kai Liu

In order to study the geophysical mechanisms associated with natural hazards, obtaining reliable ground motion data is vital. A common geodetic technique for acquiring such data is Interferometric Synthetic Aperture Radar (InSAR). However, InSAR data can be noisy and contain errors, which are commonly caused by high topographic relief, snow cover, and dense vegetation, all of which are present in Eastern California. Therefore, it is important to understand the quality and accuracy of InSAR data when analyzing ground motion and fault slip in California. I analyzed Sentinel-1 interferograms from the European Space Agency and InSAR time-series displacement fields of Long Valley and Little Antelope Valley using the Python package MintPy. I validated the accuracy of the InSAR data by comparing it to Global Navigation Satellite System data for the seismically-active Long Valley region. While some interferograms displayed low coherence, after data quality control, the interferograms and velocity maps are expected to provide valuable, accurate information about regional tectonic and volcanic processes. I also used InSAR data to assess the extent of the deformation caused by the M6.0 Jul. 8, 2021, Antelope Valley earthquake. I will identify potential surface ruptures and understand the earthquake's fault parameters using Okada's model, which will yield more insight into the recent tectonic activity. This work will help to evaluate the efficacy of the ever-increasing archive of SAR data; such validations will be extremely beneficial for future NASA missions that investigate solid-Earth geophysical phenomena.

Action Functionals for Gravitational Theories With Fractal Spatial Hypersurfaces
Pedro Guicardi
Mentor: Matilde Marcolli

Fractal spacetime topologies have become increasingly popular models for describing the early reports of fractal galaxy distributions or modeling the arrangement of compact, closed universes in Euclidean 4-space. Fracticality is known to add corrections to the Einstein-Hilbert action in General Relativity, which depends on the configuration of the fractal spatial hypersurfaces. Here, we derive the action functional for different fractal arrangements using the theory of spectral geometry. We specifically compute the action for a general Sierpinski fractal of a platonic solid, whose isometries are encoded in Γ and used to construct 3-sphere quotients of the form S^3/Γ, which make up the individual building blocks of the spatial fractal, whose growth is modelled by Friedmann–Lemaître–Robertson–Walker metrics. We follow a similar calculation and use the Feynman-Kac formula to compute the heat kernel of the Dirac operator, using known properties of Brownian bridge integrals and Bell polynomials to get an analytic expression for the high energy limit expansion of the spectral action. We also derive an analytic expression for two different Apollonian-like packings of 3-spheres in R^4 with integer curvature using number theoretic properties. Additionally, we consider the intersection of 3-spheres as a boundary for the transmission of gravitational waves and propose a 3-ball of interference modes as a possible prediction of the intersection of positively curved universes. Lastly, we propose a new theory of fractal spaces using the formulation of simplicial complexes from algebraic topology. This paper provides new examples for the study of fractal universes, physical predictions for the perturbation of fractal configurations, and a new description of fractals using category theory and should be useful in the study of fractals as mathematical subject as well as the study of non-commutative geometrical physical models, which not only provide ways to study non-trivial topologies in gravitational theories, but also may provide a bridge between classical and quantum gravity through spectral theory.

Determining if Insulin-Like Peptides (ILPs) Are Involved in the Dauer Exit Decision
Anthony Gutierrez
Mentors: Paul Sternberg and Mark Zhang

Here we use *Caenorhabditis elegans* to study neuropeptide biology in the context of developmental decision-making. During larval development, *C. elegans* will choose between two mutually exclusive developmental pathways: the normal developmental life cycle or a state or dormancy during environmental stress called dauer. There are 40 genes that encode insulin-like peptides (ILPs) that are believed to be involved in the dauer entry and exit decision. To identify which of these are involved in the dauer exit decision, we are utilizing six of several null mutants that have been previously demonstrated to exhibit a dauer entry phenotypes. Dauer entrance and exit assays were performed on three of the six insulin deletion mutants we are interested in; however, compared to the control, we observed phenotypes that contradict results reported in the literature. We suspect that this is because the genetic backgrounds of these strains differ too greatly, we anticipate that dauer assays using strains that had been crossed with a wild-type background will more closely reflect phenotypes previously reported. Dauer assays will be repeated on strains that were crossed three times. After phenotypes of these null mutants have been determined, the endogenous function of the deletion mutants will be restored via genomic rescue.

Probing for Super Fast Transients Using Palomar Gattini-IR
Kylie Yui Hansen
Mentors: Mansi Kasliwal and Kishalay De

Palomar Gattini-IR (PGIR) uses a small, 30-cm telescope with a field of view of 25 square degrees. PGIR has a “Fast Readout Mode” with a short exposure time of about 0.82 seconds, allowing one to study very fast time domain phenomena which change over timescales ranging from a few seconds to even a few tens of milliseconds. As PGIR takes data in the infrared, it can peer into areas of the universe obscured by dust. The Fast Readout Mode was utilized to take data of nova V1674 Her (Nova Her 2021), searching for short timescale structure in the nova’s lightcurve. Both PSF and aperture photometry were performed on the nova; PSF photometry was shown to be unreliable due to variance in sensitivity across individual pixels. Image subtraction was also performed to search for unknown transients, and preliminary results are discussed.

Finding the Bounds on the Quantum Fisher Information in Noisy Dynamics
Luis Hidalgo
Mentors: John Preskill and Tuvia Gefen

The quantum Fisher information bounds the achievable precision of a measurement experiment in quantum metrology. By understanding the maximum achievable precision, an experimentalist can refine their methods to achieve that precision. However, calculating the quantum Fisher information is a difficult task. Although there are several upper bounds to the quantum Fisher information, not all are equally powerful. An ultimate upper bound would optimize the quantum Fisher information over the three degrees of freedom of a quantum metrological experiment: initialization, evolution, and measurement. In this project, we consider the channel extension upper bound for the quantum Fisher information. This bound optimizes over all degrees of freedom but has only been calculated for time-independent quantum systems and noise. We expand it to make it applicable to time-dependent systems and noise. We derive a practical formula using this bound and apply it to a noisy qubit system.

Mechanical Characterization of Cu and Ni Based Metals Produced via Hydrogel Enabled Additive Manufacturing
Richard Isaac Hopwood
Mentors: Julia Greer and Rebecca Gallivan

Copper (Cu) and its alloys have been studied thoroughly due to these material’s exceptionally high malleability and thermal conductivity which makes them of particular interest in a variety of applications. In recent years, the manufacturing of these metals and metal alloys on the micron scale has been expanded from producing 2D materials via planar lithography to producing 3D ones via various forms of additive manufacturing (AM). However, micron-scale AM of Cu and its alloys can be problematic due to Cu’s high thermal conductivity interfering with the methodology of most traditional AM techniques in the form of rapid heat dissipation, high local thermal gradients, and other undesirable effects. In response to these issues, a novel hydrogel infusion AM method has been developed that avoids the undesired effects often seen from other AM methods when producing Cu. However, the mechanical properties of the materials produced via this novel method have not been investigated. This work investigates fundamental characterization of Cu and CuNi, along with pure Ni, via nanoindentation and provides a strong baseline for the engineering characteristics of these materials. Specifically, modulus and hardness were calculated from the data collected, and, through EBSD methods, these characteristics were related to microstructural features (i.e. grain size and twin density) to provide an effective understanding of how these materials compare mechanically to more traditionally additively manufactured Cu and Cu alloys.

Investigating the Inhibition of NF Kappa B and TBK1 to Target CB-5083 Drug-Resistant Colon Cancer Cells
Rauful Hossain
Mentor: Tsui-Fen Chou

Although there have been many developments within targeted therapy, the utilization of certain drugs can lead to drug-resistant mutations in the cancer cell. As a result, cancer cells can continue to proliferate, indicating a reduction in treatment effectiveness. As part of the efforts to develop targeted therapy, p97/VCP, a central regulator of proteostasis, exists as an inhibitory target to induce proteotoxic stress in the cell. Recently, our lab identified resistant colon cancer cell lines induced by an ATP competitive p97 inhibitor, CB-5083, which entered clinical trials. Results from cells exposed to CB-5083 produced five different p97 mutations, correlating to drug resistance. After establishing a CB-5083 resistant cell line, our results indicate that targeting the proteins NF-kappa B and TBK1, which are utilized to rescue the cell from cell death in the drug-resistant cell lines, can lead to cell death—investigating the differences in inhibiting NF-kappa B and TBK1 between the HCT116 parental cancer cell line and the drug-induced mutant cell line can be used to establish a therapeutic approach to overcome drug resistance.

Deep Learning Myocardial Strain From Multiplanar Cardiac Magnetic Resonance Images
Jerry Huang
Mentors: Albert Hsiao, Evan Masutani, and Michelle Effros

Understanding the contractile function of the heart is key for diagnosis and tracking of the progression of cardiovascular diseases. Myocardial strain is a particularly useful metric for quantifying cardiac function. To evaluate myocardial strain, current software approaches include the use of "feature tracking" to track the motion of segments of the myocardial wall, but these methods require significant manual contour editing. We thus propose a deep learning-based approach to automated myocardial segmentation and tracking of wall motion. A dataset of cine 2D cardiac MR image planes in the 2, 3, and 4-chamber long-axis views was annotated with endocardial and epicardial contours and used to train a 2D U-net convolutional neural network to perform myocardial segmentation. Dice similarity coefficient (DSC) was used to evaluate performance. Preliminary results yielded on average a DSC within 0.74 ± 0.22 on an independent test set. Measures such as Lagrangian global longitudinal strain and optical-flow based strain estimation may be computed from the CNN-inferred segmentations. Further work may be necessary to confirm accuracy of this approach relative to standard feature tracking software.

Mechanisms of Conductivity Within Cubic Structure $Li_7La_3Zr_2O_{12}$
Aelin Hunt
Mentor: Scott Cushing

Solid-state electrolytes (SSEs) are a safer and more energy dense alternative than conventional liquid electrolyte lithium-ion batteries, but many do not exceed the ionic conductivity (~10^{-3} S/cm) necessary for commercialization due to higher energy barriers to Li-ion movement. Current design principles for optimizing the ionic conductivity of SSEs, derived from experiments that indirectly probe interactions between the conducting ion and the immobile lattice, have inconsistent results across classes of solid electrolytes. Resonantly driven charge transfer excitation is hypothesized to lead to a change in ionic conductivity by changing the electronic structure and decreasing the energy barrier for Li-ion diffusion. We aim to directly investigate the mechanisms of superionic conductivity (conductivity at or above that of liquid electrolytes) in SSEs by examining the ionic conductivity and ion-electron interactions of garnet structure $Li_7La_3Zr_2O_{12}$ (LLZO) over time scales ranging from seconds to microseconds. To probe this, we will simultaneously excite cubic phase LLZO (c-LLZO) with a 10-20 mW femtosecond pulsed 1KHz laser source and measure the impedance with electrical impedance spectroscopy (EIS). This will give insight on the ion-electronic interactions during ionic conduction and the coupling of ionic hopping with different electronic interactions of the host lattice. We have produced c-LLZO through sol-gel synthesis and confirmed the composition and structure using X-ray powder diffraction. C-LLZO will be further investigated with an EIS scan over a frequency range of 1MHz to 1 Hz to determine the activation energy of the ion hopping pathway, which will serve as a control for how the ionic conduction pathway changes upon resonant excitation with the pulsed femtosecond laser source.

Characterizing the Novel Bacterial Species *Paraburkholderia edwinii* Protecting Against Phenazines
Katie Ann Huy
Mentors: Dianne Newman, Kurt Dahlstrom, and Rei Alcalde

Phenazines are redox active metabolites produced by bacteria that aid in nutrient acquisition, stimulate biofilm development, serve as signaling molecules, and inhibit the growth of other microbes. Despite the toxic presence of phenazines in the rhizosphere, the area around plant roots, susceptible fungi are able to survive by forming mutualistic relationships with protective bacteria. The Newman lab recently isolated such a pairing (*Paraburkholderia edwinii-Aspergillius sp.*) from the soil of a blood orange tree on the Caltech campus. *P. edwinii* was found to be a novel species. We aimed to metabolically, microscopically, and compositionally characterize this bacterium. We utilized confocal microscopy to describe the appearance of the bacterial cells. Using Environmental Scanning Electron Microscopy, we found the fungal mycelium to interact directly with the bacterial aggregates. We also tested growth conditions on diverse carbon sources and alternative electron acceptors under anaerobic conditions. *P. edwinii* can metabolize a limited range of carbon sources, is sensitive to high sodium concentrations, and is unable to reduce nitrate. Lastly, we conducted a fatty acid methyl ester analysis to characterize the lipid composition of its membrane. This study of *P. edwinii* advances our understanding of the physiological needs of a novel bacterial species that protects fungi from phenazine assault, laying a foundation for future studies.

Expression Profile of *Drosophila* Olfactory Coreceptor (Orco) in Non-Olfactory Tissues
Justin Hyon
Mentors: Elizabeth Hong and Ezgi Kunttas

Olfactory receptors (ORs) are an essential group of chemosensory receptors expressed in the cell membrane of olfactory neurons. They are responsible for the detection of specific odorant molecules, which lead to the sense of smell. In insects, ORs are located on the antennae and other chemosensory organs to form complexes on the cell membrane with a co-receptor called Orco. This then leads to a formation of cation channels responsive to particular odors. Interestingly, the expression of ORs and Orco has been reported in various tissues across the body, with limited understanding of their roles. In this work, we sought to confirm the expression of Orco in the reported tissues, with particular focus on gonadic expression in Drosophila. Our results confirmed the expression of Orco in both testes and ovaries using an Orco-driven GFP reporter. Future studies will aim to elucidate the role of Orco during spermatogenesis and oogenesis by characterizing the phenotype of Orco[2] mutants, a null mutant which lacks Orco expression.

Optimization of Spatially Engineered Microbial Consortia in Bacteria Powered Biobatteries
Joshua Ibrahim
Mentor: Richard Murray

A major goal of synthetic biology is to engineer novel behavior of cells in a predictable manner. Pushing this frontier is the development of microbial consortia where selected strains can work together for a specific task. Consortia are engineered for metabolic specialization between strains which creates a division of labor allowing for advantages in performance in complex systems. One of these promising systems is bioelectrochemical systems for sustainable bioelectricity production. Miniaturized biobatteries have been recently developed using microbial fuel cells (MFCs) where maintenance and nutrient replenishment is not needed. MFCs work by leveraging the microbial extracellular electron transfer (EET) mechanism. Respiration acts as a cascade of electron exchanges that interact with mediators to transport electrons to an electrode, generating a current. Although limited MFC mathematical models appear in the literature, the existing models are integrated models that can only capture overall substrate and population dynamics. To explore consortia dynamics further, this project develops and optimizes a novel chemical reaction network (CRN) model that links MFC dynamics to spatial topology in multipopulation synthetic consortia. Through simulation, our model predicts similarly transient dynamics as existing integrated MFC models. This suggests that our CRN model can still accurately represent the dynamics seen in the literature but also incorporate spatial optimization through the formulation of a networked dynamical system.

Evolution of Major Element Chemistry in Protoplanetary Disks and Its Connection to Planetesimal Growth
Rohan Iyer
Mentor: Yoshinori Miyazaki

Chondrites are likely candidates for the building blocks of Earth and understanding the processes that could produce bulk compositions similar to Earth's is crucial in constraining how and where planets formed and grew in the early Solar System. In particular, the chemical composition of chondrites have a puzzling characteristic as chondrites exhibit surprising depletions in refractory elements including Al, Ca, and Mg. However, we still lack an astrophysical model to bridge the gap between the early stage of disk evolution and the formation of planetesimals because the formation of planetesimals within the evolution of the protoplanetary disk still remains unclear. To this end, we built a self-consistent model solving for the disk evolution from the dust condensation to the planetesimal growth stage. The key mechanisms for planetesimal formation considered in the study are pebble accretion and the transition of magnetorotational instability (MRI). In our model, we consider the effects of temperature varying alpha values due to MRI as well as dust to gas ratio thresholds and accretion timescales that onset streaming instability in order to yield planet masses on the same order of magnitude as terrestrial planets like Mercury and Mars. Our results demonstrate that MRI transition doesn't create enough dust enrichment needed for the classical criteria for streaming instability. The theoretical criteria needed for streaming instability is characterized by a dust to gas ratio of 1 whereas in both cases for our model, constant alpha and MRI dependent alpha, the dust to gas ratio failed to surpass 0.01. Thus, we anticipate that our model will be a motivation to consider other mechanisms that can trigger streaming instability.

Enhancing Quantitative MR Image Reconstruction With Unrolled Convolutional Neural Networks
Sahil Jain
Mentors: Shreyas Vasanawala, Zhitao Li, and Julian Tyszka

In the field of Magnetic Resonance Imaging, T1 mapping has been shown to be effective in the diagnosis of various diseases, including Parkinson's disease, liver cirrhosis, and cardiac diseases. However, acquiring the contrast images for T1 parameter maps is costly in terms of both time and resources, creating the need for a data undersampling and subsequent MR image reconstruction approach. In this project, we propose a novel ML pipeline involving a variational network with Norm U-Nets for MRI reconstruction on non-cartesian undersampled MRI data. An initial 40 epoch training demonstrates preliminary efficacy of the model, with an L1 training loss of around 5.92×10^6 and a clear progression in the quality of reconstructions as the training proceeds. However, training with a greater number of epochs and continued optimization of parameters such as number of cascades, channels, and pooling layers is necessary to comprehensively evaluate the model's performance and maximize its efficiency. Ultimately, the hope is that the model could be applied to newly acquired patient data from a 3T data to determine the model's clinical applicability in MRI reconstruction and subsequent disease diagnosis.

Digitalizing Parisian Death Records for Building a Searchable Database
Leo Jenkins
Mentor: Jean-Laurent Rosenthal

The objective of this project is to turn typewritten Parisian death records from 1942 to 1974 into a searchable database in order to enhance future research into the factors that promote sustained economic growth. Due to the scope of this project, there is still outstanding research and analysis yet to be done. However, while there are not yet results available, conclusions can be made on the success of different research methodologies. We have been successful in the automation of the use of Amazon Web Services' Textract feature to digitize the typewritten records. Additionally, we have been able to write language detection algorithms to split the data into its component records, and further splice each act into information about each individual's birth, life, and death. Not only are we confident that these processes will lead to analyzable data, we believe that they can be applied to other data sets for future economic research.

Chemical Oxygen Demand (COD) and Energy Optimization for Portable Primary Effluent Treatment Systems
Nicolas Jimenez-Lozano
Mentor: Michael Hoffmann

ULTRON (Ultra-portable Three-stage Oxidative Nanofiltration) and REM (Reactive Electrochemical Membrane) are prototypes for portable wastewater sanitation units designed to address the current sanitation crisis involving the almost 2 billion people worldwide that do not have access to improved sanitation and thousands of deaths caused by wastewater related illnesses. While the current systems treat completely domestic wastewater to the NSF-350 standard through the use of OH radicals produced by electrodes, this SURF aims at combining both systems in an effort to increase removal of pollutants while keeping energy usage as low as possible. This is necessary since ULTRON has low energy consumption but only reduces COD, while REM reduces nitrogen as well as COD but has high energy consumption. Two series of experiments with alternating treatment order and treatment time were run while tracking energy consumption, COD removal, turbidity, and pH. The trends in each were analyzed. Overall, experiment 2.a (5 minutes of REM followed by 40 minutes of ULTRON) and 2.b (10 minutes of REM followed by 40 of ULTROn) were found to be the most efficient. Experiment 2.a had 22% more COD removal than ULTRON, 29.5% more COD removal than REM, and 33% the energy usage of REM.

Modeling Passive Propulsion in Vortex Wakes
Anfal Jneidi
Mentors: Beverley McKeon and Tanner Harms

Numerous studies have reported the possibility of passive energy generation by naturally occurring fluid dynamics. One of these studies is an experiment performed by Beal at al from the Massachusetts Institute of Technology where a euthanized fish was placed in the path of an oscillating vortex wake, thus generating thrust, and causing the dead fish to swim upstream. Motivated by this experiment, an ongoing experiment in the group studies an airfoil with a fixed chord placed a fixed distance downstream from a cylinder but allowed to move in pitch and in the transverse direction. The aim is to understand fluid structure interactions of the airfoil in a cylinder wake. We develop a mathematical model for simulating and visually representing the system and then compare it to experimental data.

Mixed Observable RRT: Multi-Agent Planning in Partially Observable Environments
Kasper Johansson
Mentors: Aaron Ames, Ugo Rosolia, and Andrew Singletary

Humans are excellent at making observation-based decisions in unexplored environments, for instance when driving a car on a busy road or chasing a target. Decision making based on observations is much more difficult for robots. However, mission planning in partially known environments is of great importance in robotics, and to mimic human behavior we would like mission plans to incorporate observations from the environment.

In this paper, we consider a centralized mission planning problem for multi-agent systems, consisting of agents with capabilities of traversing different regions. The aim of the multi-agent system is to find, and move to, a hidden goal target. We assume a fully observable state-space and model a partially observable environment, consisting of the goal location, using a hidden Markov model. We then leverage rapidly exploring random trees (RRTs) for finding plausible mission plans. Finally, we find the mission plan by minimizing a pre-defined cost function over all RRT trajectories.

Our findings show multi-agent systems making intelligent decisions, based on environment observations and communication with each other. However, results vary depending on parameter settings, so parameter tuning could be an area of future research.

Light-Guided Generation of Ordered Mesostructures With Defined Wetting Anisotropy Using Artificial and Natural Insolation
Sarah Kabboul
Mentors: Nathan S. Lewis and Madeline Meier

Many photosynthetic plants, notably palm trees and sunflowers, exhibit phototropism whereby new growth is directed to optimize solar harvesting. An analogous phenomenon has been demonstrated via the light-mediated electroplating of semiconductor films. Such inorganic phototropism can affect the spontaneous, template-free generation of highly ordered mesostructures consisting of anisotropic nanoscale features wherein the exact nature of the morphology is a function of the illumination inputs utilized during growth. Solar insolation was investigated as an input to direct inorganic phototropic growth and ordered arrays of anisotropic lamellar features were generated using polarized insolation. Depositions were performed in a fixed orientation at different times during the day to examine the effect of the varying solar position and spectral distribution and correlations with the out-of-plane feature orientation and feature pitch were observed. Similar structures were generated using illumination from narrowband light-emitting diode sources. The lamellar structures generated were similar to a series of naturally occurring biological interfaces, such as at the surfaces of rice leaves and butterfly wings, that define wetting interactions. The structures exhibited anisotropic wetting which resulted in anisotropic spreading of liquid droplets along the long axis of the nanostructured features.

Implementing the Aerosol Activation Parameterization in the New Earth System Model
Shevali Kadakia
Mentors: Tapio Schneider and Anna Jaruga

In the aerosol activation process, aerosol particles suspended in the air act as nucleation points on which water vapor condenses to form cloud particles. Aerosol activation influences the cloud albedo and precipitation efficiency. It also is an important source of uncertainty in climate change predictions. The Climate Modelling Alliance (CliMA) at Caltech develops the atmosphere component of the next generation Earth System Model. It is an open-source model that combines machine learning techniques with state-of-the-art parameterizations. Most recently, we added a parametrization of aerosol activation to the codebase. The implemented aerosol activation parameterization is available as standalone open-source package written in Julia. It comes with an extensive test suite, documentation, and usage examples. The free parameters used by the parameterization are calibrated using methods based on Ensemble Kalman Filters, to match results from previous publications. This poster introduces the aerosol activation theory, describes the code structure of implemented aerosol activation parameterization, and shows the results from the calibration experiments.

Electroanalytical Mechanistic Interrogation of Nickel Promoted Oxidative Addition in the Nozaki-Hiyama-Kishi Reaction
Elya Kandahari
Mentors: Sarah E. Reisman and David E. Hill

MRecently, the use of electrochemistry to drive reductive processes such as the Nozaki-Hiyama-Kishi reaction (NHK) has emerged as a more sustainable and scalable alternative to metal powder reductants. While pioneering, applications of the electrochemically driven NHK (e-NHK) remain limited due to the lack of mechanistic knowledge of the transformation. A recent electroanalytical study has speculated Ni-Cr interactions as relevant to NHK reactivity. To interrogate the validity of this multimetallic hypothesis, we aim to synthesize monometallic and heterobimetallic ligand scaffolds for subsequent mechanistic e-NHK studies. Through a combination of spectroscopic and electroanalytical experiments, we observed significant changes in catalytic activity of low valent Ni in the presence and absence of the chromium(III) co-catalyst. On-going work aims to provide detailed mechanistic evidence and characterization of a Ni-Cr interaction, and a fundamental basis for heterobimetallic catalysis in NHK chemistry.

Star Formation Environments: Clump Properties in Sprial Galaxy NGC 4501 - WISDOM Project X
Ishaan Kannan
Mentors: Lijie Liu and Charles L. Steinhardt

Variations in star formation properties across different types of galaxies have puzzled astronomers for some time. Giant Molecular Clouds (GMCs) are mysterious gaseous objects in which most stars are formed, but their study in external galaxies was limited by their small size. As part of the WISDOM project, which utilizes unprecedented spatial resolution ($\approx 4.9 \times 2.9$ pc^2) to analyze cloud properties in a wide survey of galaxies, we present a comparative analysis of molecular gas structure in low-redshift (nearby) spiral galaxy NGC 4501 by performing a "dendrogram analysis" that simultaneously identifies gaseous structures on several spatial scales. We hypothesize that molecular clump collisions are a dominant mechanism in regulating clump properties and creating turbulence that supports the galaxy's gravitationally unstable outer gas disc. Our model successfully predicted several clump properties including collision radius, mass distribution, collision timescale, velocity distribution and turbulent energy injection rate. We note that there exists a discrepancy in the energy passed down from collisions at the turbulence driving scale, as predicted by the model, and the energy that cascades to smaller scales. This interesting phenomenon occurs outside the scale covered by our model but provides a potentially interesting avenue for investigation. Our work in NGC 4501 furthers the results from dwarf lenticular galaxy NGC 404 and holds promise for our ability to understand gas and star formation properties in faraway galaxies.

An Environmental Sensing System for the High Contrast Spectroscopy Testbed for Segmented Telescopes (HCST)
Cole Kappel
Mentors: Dimitri Mawet and Jorge Llop Sayson

The Caltech Exoplanet Technology lab utilizes the HCST to enhance their starlight suppression techniques in an effort to characterize planets that are earthlike. The testbed is used to test different technologies to determine the best way to filter out unwanted starlight to obtain the best signal from planets. Though, the HCST is kept in a rectangular enclosure in the lab where environmental factors such as temperature, humidity, and vibrations could alter the data being recorded with it.

To ensure that the data being recorded with the HCST is valid, I have been working on an environmental sensing system that measures and records the environmental data inside the testbed. This work has involved reading coding documentation and discussion forums, upgrading the current hardware parts, writing documentation for the project and writing and testing code to create the best possible setup that can be used long after I leave Caltech.

The environmental sensing system includes a program that shows the live readings of the environmental data inside the HCST, a program that allows the user to look at the environmental data from any desired span of time, and another program that saves all of the data to an SD card.

The Study of Rotating Shrouded Propellers
Seenara S. Khan
Mentors: Morteza Gharib and Emile Oshima

Shrouds can improve propeller efficiency by reducing thrust losses and decreasing energy consumption. In the past, there has always been a focus on stationary shrouds that act as a shell to protect the propeller from the environment as well as protecting ground crews in real world applications. The aim of this project is to compare the hover performance of stationary shrouded propellers, rotating shrouded propellers, and unshrouded propellers. The cross section of the propellers used standard NACA airfoils for the shroud and blade. The designs of the shrouded propellers were 3D printed, tested, and recorded. MATLAB graphs the data and gives the coefficient of thrust and torque which was quantified through dimensional analysis. Broader applications would consist of comparing the flow of the stationary shroud and rotating shrouded propellers using a water tunnel as a visualization to further understand the flow physics.

Design of Hull and Heating Systems for Lighter-than-Air UAV
Maisha Khanum
Mentors: Morteza Gharib, Cecilia Huertas-Cerdeira, and Peter Renn

Unmanned Aerial Vehicles (UAVs) have been developed extensively over the last few decades and are increasingly used in cargo transportation, medical delivery, and surveillance. One major limitation in UAV flight is the short mission duration due to expending energy for vertical propulsion. One possible solution is to utilize lighter-than-air gases to assist the lift of the drone. This project aims to design a balloon system that can generate lift by relying primarily on hot air to control altitude. To demonstrate the feasibility of such a drone, we developed and tested the heating system and hull of a balloon with simple controls. Our experimental results show that heatsinks attached to PTC heaters oriented perpendicular to fans generates sufficient convective heat to lift at least its own weight. From the different fabrics tested with this setup, polyethylene film was the most efficient for the weight and scale of the balloon. Two layers of polyethylene were used to fabricate a 1.75-meter diameter ellipsoid balloon to contain the heating system.

Determining Consensus Mutations' Capability and Generality to Stabilize Cytochromes P411 With Novel Evolved Catalytic Activities
Catherine Ko
Mentors: Frances Arnold and Ravi Lal

Biocatalysts are an attractive alternative to traditional catalysts due to their inherent selectivity as well as their increasing tunability as high-throughput protein engineering techniques become more facile. Over the past decade, cytochromes P450, in particular $P450_{BM3}$, have been engineered toward numerous carbene transfer activities. However, the accumulation of activity-enhancing mutations in $P450_{BM3}$ has led to a decrease in the stability of this protein scaffold. Lack of protein stability places constraints on these enzymes' applicability in industry and hinders further activity-enhancing evolution. We set out to find a set of mutations that are generally stabilizing to enzyme variants derived from $P450_{BM3}$. This was accomplished using computational consensus design methods and FireProt, a software package for predicting thermostable multiple-point mutants. Both consensus methods and FireProt converged on several of the same mutations which we have been testing in the laboratory for desirable activity and stability. Ultimately, my investigation for stabilizing mutations will increase the potential of these catalysts for discovering new-to-nature carbene transfer chemistries.

Atmospheric Characterization of the Transiting Exoplanet WASP-44b
Amelia Konomos
Mentors: Heather Knutson and Jessica Spake

The detection of helium in planetary systems can provide new insight into the evolution and loss of primordial atmospheres. We used the NIRSPEC near-infrared spectrograph on the Keck II telescope at Mauna Kea Observatory, Hawai'i, to measure the transmission spectrum of the transiting exoplanet WASP-44b. WASP-44b is a hot Jupiter on a short orbit around a G8 type star in the constellation Cetus. Our project used the NIRSPEC Data Reduction Pipeline to reduce the raw data and extract 32 spectra of the WASP-44 system, taken over 3 hours. By comparing the spectra during transit and out-of-transit, wavelength dependent changes in the amount of light blocked by the planet can be detected. Spectra are extracted from raw data frames and then converted into a transmission spectrum. Excess absorption in the 10830 Angstrom line during the planet's transit would indicate the presence of helium in WASP-44b's atmosphere. This discovery would be significant due to the fact that there are currently only seven exoplanets with published helium detections and such confirmation can provide insight into the evolution of planetary systems and may allude to atmospheric escape.

Engineering Bench Scale Accelerated Limestone Weathering Reactor for Carbon Sequestration
Albert Kyi
Mentors: Jess Adkins and Sijia Dong

Limestone weathering, the ocean's natural process to buffer against ocean acidification, can be accelerated in reactors as a method of carbon sequestration. Carbon dioxide from point sources, container ships specifically, is reacted with seawater and calcium carbonate to produce an effluent that impacts neither ocean pH or pCO_2. Models estimated greater than 75% capture efficiency of maritime carbon emissions, in line with new maritime regulations, however lab scale fluidized bed reactors do not perform as well as models predict. Therefore, after isolating solid dissolution as restricting reaction progress, gas and solid dissolution reactions were separated in newly constructed, modular bench-scale column reactors. Efficiency data collected after changing the directions and magnitudes of water and gas fluxes will allow us to best plan a demonstration plant.

Compiling Radial Velocity Datasets for Exoplanet Discovery
Sarah Lange
Mentors: Andrew Howard and Fei Dai

Radial Velocity (RV) datasets, used to discover exoplanets, are scattered in the literature and throughout various platforms and databases. There is no uniform way that this data is organized, thus the datasets come in different formats and standards. Due to the lack of uniformity, there is a need to collect and standardize RV datasets. We have compiled RV data to create a uniform and cohesive dataset structure. In addition, we have written a package that can be used to convert additional RV data to our dataset structure and contains our database of existing files. Our database and dataset structure will aid in the long term curation of data of this type and aid in exoplanet discoveries through their integration into various databases, including the California Planetary Search's, Jump. Our effort to create a uniform, cohesive dataset structure and installable package will make the most of the existing and future RV data and will benefit the wider exoplanet community.

Development and Optimization of a Wearable Sodium-Selective Sensor With Improved Analytic Performance for Continuous Health Monitoring
Alison Lao
Mentors: Wei Gao and Changhao Xu

Wearable sensor technology is a step forward in the advancement of personalized medical treatment, with its ability to continuously monitor the health status of its user over time. To achieve non-invasive monitorization, a promising method is to test human sweat, which can reveal abundant physiological information. Major shortcomings of sweat-based and non-invasive biosensors previously included its inability to remain stable for long periods, with the lowest reported potential drift being 2-3 mV h^{-1}. The goal of this project is to optimize sensor stability all-around by minimizing the potential drift for sodium-selective sensors to 0.1 mV h^{-1}. We prepared sensors by inkjet-printing silver and carbon-based electrodes designed through AutoCAD, using PEDOT:PSS as the ion–electron transducer. We then tested variations in silicone rubber and concentrations added to our sodium-selective membrane cocktail, which was later dropcasted onto the electrode to form ion-selective membranes. Once dried, the sensor ran through short and long-term stability tests. We successfully developed a sensor more effective than those previously known, with an impressive performance of 0.00218 mV h^{-1} potential drift over 20 hours. The performance exceeded our goal by nearly tenfold, and the published record by a hundredfold.

Return Probabilities of Skip-Free Random Walks
Lin Lin Lee
Mentors: Leonard Schulman and Jenish Mehta

We consider a discrete random walk on the integers in which the range of allowed jumps is limited to an interval $\{-1,..,(k-1)\}$ for some integer k, and we study its return probabilities after various numbers of steps. Specifically, we wish to show that the probability of the walk returning to its starting point is largest in one of the first k steps. Our problem can be interpreted as an infinite-site version of a trace conjecture by Mehta and Schulman, which would verify the validity of a matrix construction demonstrating the breakdown of Cheeger's inequality for nonsymmetric matrices. We examine the random walk problem in several contexts, and we present combinatorial results demonstrating conditions under which our conjecture holds. Finally, we describe ideas for connecting the infinite-site random walk problem to the finite-matrix trace conjecture.

Passivation of Physical Defects in TiO_2 Thin Films Through Targeted Electrodeposition
Anna Li
Mentors: Nathan Lewis and Jake Evans

Photoelectrochemical (PEC) water-splitting devices produce hydrogen which stores energy in the form of fuel that can be burned on demand. Water-splitting in PEC devices is best performed under extreme pH conditions to avoid pH gradients that cause solution resistance, which decreases device efficiency. However, this causes corrosive degradation of semiconductor materials (Si, GaAs) used in such devices, thus motivating the need for effective protective films. Semiconductor materials can be protected by atomic layer deposition (ALD) of a-TiO_2, but this protective layer contains intrinsic pinhole defects due to the presence of atmospheric particles in the air, preventing full protection of the semiconductor and limiting device lifetimes. a-TiO_2 is a promising material for semiconductor protection for several reasons; It is stable under extreme pH, has a large band gap, is conductive through intraband states, and can be deposited electrochemically on semiconductor surfaces. Thus, this project aims to passivate physical defects in a-TiO_2 thin films deposited by ALD on p^+ GaAs through the targeted electrodeposition of TiO_2 within surface defects. Spherical TiO_2 growths have been observed to deposit on the surface of and within etch pits on ALD-protected GaAs, demonstrating selectivity in TiO_2 electrodeposition. Further work will be done to determine the conditions necessary for full passivation of electrochemically active surface area on ALD-protected GaAs.

Artificial Intelligence in Particle Streak Velocimetry
Daniel Li
Mentors: Beverley J. McKeon and Jacqueline Tawney

Flow visualization is extremely important in fluid dynamics given the ubiquity of fluids and humanity's inability to view flow with the naked eye. However, many flow visualization techniques are either qualitative (i.e. dye visualization) or relatively slow (i.e. particle image velocimetry, takes hours to process). The principal objective of this project is to apply machine learning to implement quick, cheap, and quantitative flow visualization with Particle Streak Velocimetry (PSV). PSV is a novel method of flow measurement in which a laser is used to illuminate non-disruptive particles in a fluid, and the fluid is photographed such that the resulting image contains streak-like structures following the particle paths. By constructing and training a Convolutional Neural Network (CNN), streaks within a window can be analyzed to predict average displacement and azimuth across the window. By breaking the image down into windows with overlap, this CNN can be applied to a full image of experimental or simulated data, producing the velocity field of an entire image. With optimization, this network has the potential to visualize flow in real time.

Eliciting Decision Algorithms for Choices Under Uncertainty
Eileen Li
Mentor: Kirby Nielsen

Economic models for behavior are usually created by asking individuals to make decisions over lotteries and estimating models to rationalize those choices. Such models account for properties that individuals may care about in a lottery, such as expected value or the maximum possible winnings. While some of these models are considered normative, they often fail to reliably predict an individual's choices. In this project, we have individuals create models themselves by constructing a decision algorithm. Individuals choose which properties they want to consider, and in what way. They then make binary choices over lotteries, which are compared to the choices their models would make. If there is any disparity between the two, individuals can decide if they would rather keep their own choices or receive the choices prescribed by their model. Finally, subjects will evaluate how much they prefer their own choices versus using a model to choose. Thus far, we have designed the interface subjects will be using and we will begin data collection soon.

A Search for Short Orbital Period Cataclysmic Variables Stars Using the Zwicky Transient Facility
Zhuofu (Chester) Li
Mentors: Shrinivas Kulkarni and Jan van Roestel

Cataclysmic variable(CV) stars are mass-transferring binary stars involving a white dwarf star and a regular sun-like star. CVs initially have an orbital period of a few hours which decreases to 70 minutes due to gravitational radiation during their lifetime. This project focuses on discovering rare short orbital period CVs using the rich dataset of the Caltech Zwicky Transient Facility(ZTF), a survey telescope that images the entire night sky every two nights. We developed an orbital-period-finding Python code to analyze the brightness measurements of white dwarf stars observed by ZTF. Based on a test sample of 2011 white dwarfs, we found that 1.5% of them are CVs with an orbital period between 60 and 120 minutes. Among this sample, we discovered a star with an orbital period of 78 minutes with an unusual light curve featuring two peaks. We will further investigate this star by obtaining new measurements. We will apply this code to all white dwarfs in the ZTF dataset to systematically search and find all CVs with a short orbital period. With the results of this search, we will be able to better understand the final stage in the evolution of CVs.

A Model-Based Metabolic Engineering Approach Towards Optimizing Protein Synthesis in Cell-Free Systems
Hannah Lim
Mentors: Richard Murray and Manisha Kapasiawala

Recent work has shown that synthetic cells encapsulating cell lysate can be programmed to perform behaviors that are observed in natural cells, such as to deliver cargo, process signals from environmental inputs, and make complex decisions in response to those signals. A key goal of synthetic biology is to produce proteins in synthetic cells to program these behaviors, but limitations exist in protein production efficiency due to the depletion of resources necessary for protein production, such as ATP and other substrates, as well as the accumulation of toxic metabolic products in cell-free systems. A systematic, model-based approach was taken in order to provide experimental guidance towards more efficient cell-free protein synthesis. Based on existing flux balance models of *E. coli* core metabolism, cell-free protein synthesis model was built as a chemical reaction network and simulated using Python packages BioCRNpyler and BioScrape. The model involves 93 metabolites and 138 reactions and was simulated using metabolite concentrations from experimental data. Experimental data measuring 329 metabolite concentrations in various cell-free extracts over 12 hours was compared with the simulated data to evaluate whether the model reflects cell-free dynamics. This model can be used to guide experiments by predicting the result of knocking out enzymes in cell extract to increase production of proteins or other molecules of interest.

Return Probabilities of Skip-Free Random Walks
Andrew Lin
Mentors: Leonard Schulman and Jenish Mehta

We consider a discrete random walk on the integers in which the range of allowed jumps is limited to an interval $\{-1,..,(k-1)\}$ for some integer k, and we study its return probabilities after various numbers of steps. Specifically, we wish to show that the probability of the walk returning to its starting point is largest in one of the first k steps. Our problem can be interpreted as an infinite-site version of a trace conjecture by Mehta and Schulman, which would verify the validity of a matrix construction demonstrating the breakdown of Cheeger's inequality for nonsymmetric matrices. We examine the random walk problem in several contexts, and we present combinatorial results demonstrating conditions under which our conjecture holds. Finally, we describe ideas for connecting the infinite-site random walk problem to the finite-matrix trace conjecture.

Ultralight and Flexible Luminescent Solar Concentrators for Space Applications
Yuying Lin
Mentors: Harry Atwater and Megan Phelan

Space solar power systems (SSPS) are desirable sources of renewable energy due to their ability to access unobstructed sunlight both in daytime and nighttime. Moreover, there is a 30% higher solar irradiance in space than on earth, enabling SSPS to produce higher power outputs than terrestrial photovoltaics (PV). Although this concept was proposed first in the 1960s, the realization of a deployable system has been inhibited by high costs. This issue can be mitigated by increasing the specific power (kW/kg) of the array. The objective of the Caltech Space Solar Power project (SSPP) is to maximize the specific power of SSPS PV arrays and to achieve practical designs in the 1-20 kW/kg range, representing a 10-100x increase in specific power. To reduce the mass of PV cells needed in the system, luminescent solar concentrators (LSCs) can be used to concentrate irradiation from a larger area to a smaller area as well as concentrate both diffuse and direct light. In space applications, the key advantages of LSCs are their potential to be ultrathin, to be radiation hard as well as their scalability to large scales. As such, this project aims to find the optimal geometric gain of the module (i.e., the ratio between the area of PV cells and area of the waveguide in the LSC) while ensuring its flexibility and mechanically stability during space deployment. Moreover, this project aims to minimize the thickness, and hence mass, of the LSC module polymer substrate (CP1). Through mechanical bending tests, it is found that arrays constructed with 1cm x 1cm Si heterojunction cells can reach a 2.41cm minimum radius of curvature before the cells fracture. Increasing the geometric gain has minimal effect on the radius of curvature, whereas reducing the size of the cells also reduces the radius of curvature. Spin-coating CP1 yields a cured film thickness of 5 microns. Initial work for a working prototype is demonstrated.

Improving the Panoramix Program for Assessment of Cement Related Materials
Jamie Littman
Mentors: Rupert Myers and José Andrade

In 2019, almost 4 billion tons of cement were produced, resulting in 7-10\% of our global emissions. In order to minimize the built environment's impact, efforts have focused on reducing production emissions while increasing durability of cement. A current approach includes incorporating supplementary materials such as fly ash or dust into the cement composition. However, a reliance on empirical testing has resulted in limited technical performance data for newer or less common materials. To address this, the Panoramix algorithm uses thermodynamic modeling through GEM-Selektor to analyze randomly sampled cementitious mixtures and understand how certain changes in the material composition impact emissions and durability. This first iteration of the program is verified against known CEM mixtures to show the accuracy of its modeling. The durability analysis will focus on a freeze-thaw impact assessment to demonstrate how different supplementary materials will impact longevity in colder climates. Ultimately this research will be used to design cement or cement related materials with optimized mechanical properties and significantly reduced greenhouse gas emissions.

Characterizing and Predicting Cytochrome P450-Reductase Interactions Using Machine Learning
Grace Liu
Mentors: Frances Arnold and Lucas Schaus

Cytochromes P450 oxidases are important metabolic enzymes with many applications in protein engineering, pharmaceutical sciences and in biochemical characterization of organisms. All class II P450 oxidases require a paired reductase domain to display catalytic activity, however, there are currently many oxidases for which no reductase has been identified. David Lamb *et al.* have recently discovered cytochromes P450 in viruses, but were unable to identify a reductase gene or find a viral-host reductase that pairs with them. We tackle the problem of unmatched oxidases using a machine learning approach. We have trained simple classifiers, ensemble models and neural networks to predict the corresponding reductase for a given P450 oxidase with 55% accuracy for the ensemble model. Due to the large size of the P450 oxidase dataset, memory and storage management became an issue. We have created a pipeline to generate protein embeddings in stream and pass them into an adaptive model to minimize the memory burden and avoid storage of large embedding files. We hope that this approach can help elucidate the function of viral P450s and allows unpaired P450s to be studied in future.

Laser Cooling of Polyatomic Molecules Using π-bonded Optical Cycling Centers
Adrian Lopez
Mentors: Nick Hutzler and Phelan Yu

Ultracold polyatomic molecules are powerful venues for studies of precision metrology, many-body physics, and fundamental chemistry. Laser-cooled polyatomics to date have been limited to open-shell, neutral species with an alkaline earth-like metal σ-bonded to a one-electron acceptor. In this project, we consider the feasibility of building laser coolable molecules with optical cycling centers π-bonded to a two-electron acceptor. We characterize several prototypical species using computational electronic structure methods, finding optical cycling transitions and rovibrational branching ratios that are highly favorable for direct laser cooling. We also elucidate unique features of our candidate systems, including metastable cycling states, high molecular dipole moments, magnetically insensitive ground states, and novel model-dependent sensitivities to new physics. Our work opens the door towards leveraging this new class of molecules for quantum science and measurement.

Alternative Mechanisms of Notch Activation in Neurons
Angelica Lopez
Mentors: Carlos Lois and Laura Luebbert

Notch is a key signaling pathway in vertebrate development. Once the ligand binds to the Notch receptor, the mechanical force caused by ligand endocytosis unravels the Notch receptor negative regulatory region. The extended negative regulatory region allows for cleavage by proteases, leading to the release of a transcription factor followed by the expression of downstream target genes. This region also forms the basis of the synthetic ligand-receptor system TRACT. Blocking endocytosis by inhibiting the vesicle scission protein Shibire in the TRACT ligand-expressing cells does not eliminate TRACT activation. This is surprising because several studies in Drosophila identify Shibire as an essential molecule in Notch signaling. Without it, the ligand pulling force is diminished or abolished. We have been investigating whether neurons can provide the mechanical force to stretch the negative regulatory region and activate Notch through an alternative pathway. We tested six candidate molecules other than Shibire for their ability to efficiently inhibit endocytosis. Of those six candidates, a Shibire RNAi proved to inhibit endocytosis comprehensively, and we used it to inhibit TRACT ligand endocytosis under the temporal control of a temperature-sensitive Gal80-inhibitor. TRACT activation leads to the expression of a fluorescent molecule which will be scored using fluorescence microscopy.

Influence of Slenderness on the Bearing Capacity of a Confined Granular Column
Graciela Lopez Campos
Mentors: José Andrade, Michael Mello, and Siavash Monfared

Creating reusable column structures with confined granular materials opens the possibility of balancing costs and bearing capacity for not only Earth but also space habitation construction applications. Since using granular columns on the upper levels of structures implies no resistance from the surrounding soil, there is a need to study the influence of slenderness and stiffness parameters on the confinement's ability to maintain the column shape as the lateral expansion rises due to the axial applied load. To do this, sand columns with different slenderness ratios were made with Neoprene 20A, 40A and 60A rubber confinement and tested on an ADMET eXpert axial-torsion testing system; each column was loaded until a 25% strain at a rate of 2.54 mm/min in order to study its behavior and failure mode. In addition, to investigate the initial elastic/plastic response of the samples cyclic compression was performed on each column. Results indicated the following: the bearing capacity of the column decreases when the slenderness ratio increases; the failure mode related to the transition slender ratio changed when using a stiffer rubber; and when applying cyclic compression there is always an irreversible plastic deformation in the structure due to the movement of individual sand grains.

3D Architected Lithium-Ion Battery With Electroplated Interpenetrating-Lattice Electrodes
Abdullah Al Maruf
Mentors: Julia R. Greer and Yuchun Sun

3D architected electrodes in lithium ion batteries (LIBs) are of great interest due to their high energy density, shape conformability, and tunable dimensions. But the current extrusion 3D based printing approach, such as direct-ink-writing (DIW), does not enable the full potential of fabricating electrodes with complex geometries to maximize the areal capacity in LIBs. In this project, we designed a series of novel interpenetrating electrodes with different lattice geometries, and additively manufactured them with a high resolution (~50μm) stereolithography (SLA) technique. Our primary goal was to increase the ratio of interface area between electrode and electrolyte (SA), and the volume of the electrode (V) for these electrode systems. Among the electrode configurations, we used a combination of interpenetrating octahedral vertex centroid (OVC) lattice, body centered cubic (BCC) lattice, welled gyroid, and finally, infilled gyroid beams in OVC lattice, resulting the highest SA/V of 9.0708 mm^{-1}. All of our manufactured electrode systems have higher SA/V than their counterpart electrode configuration, such as interdigitated or spinodal structures. Further work over summer would involve electroplating these 3D scaffolds with Ni and $LiCoO_2$ to make anode and cathode, respectively. The subsequent morphology and electrochemical characterization will be will be performed for each electrode system.

Developing a Low Cost and Open Source Syringe Pump
Kevin Marx
Mentors: Lior Pachter and Sina Booeshaghi

In microfluidics laboratories, it is important to have precise control over fluid flows. Syringe pumps fulfill this role, offering consistent, accurate, and pre-programmable control over the position of the plunger on a syringe. These devices tend to be prohibitively expensive for labs that need multiple pumps for complex microfluidics experiments. I am developing poseidon prime, an open-source and low-cost syringe pump that uses off-the-shelf parts, 3D printed components, and free software which altogether costs a tenth of other syringe pumps. The design is open-source so anybody can download, modify, and make their own poseidon prime. The syringe pump is highly customizable and can be mounted to rails for extra stability, 3D printed out of polypropylene for heat resistance, and adjusted to fit a variety of syringe sizes. Poseidon prime currently can perform basic fluid dispensing tasks, but going forward it will be able to perform more complex operations and undergo rigorous testing to verify its precision and reliability.

Learning Culturally Invariant Representations of Affect for Multimodal, Cross-Cultural Affect Perception
Leena Mathur
Mentor: Ralph Adolphs

Advances in the fields of artificial intelligence (AI), affective computing, and human-machine interaction are enabling the development of computational systems with an enhanced ability to sense, perceive, and respond to human affective states. In a multicultural world, affect-aware AI systems need to perform well at perceiving affect across cultures, especially for cultures on which the models are not trained. My research addresses this challenge by creating multimodal machine learning models that learn and leverage culturally-invariant representations of affect across six cultural populations. A novel domain adaptation approach is created and model performance is compared to multicultural baselines.

Exposition on Complex and Modular Representations of $\mathbf{SL_2}(\mathbb{F}_p)$
Haydn Maust
Mentor: Anna Szumowicz

Representation theory allows us to obtain novel information about a group by studying group homomorphisms from it to a set of automorphisms of a vector space. Precise description of representations of a particular group often yields new information about the group itself. We fill in the proofs from an exposition of Humphreys on representations of the group $\mathrm{SL}_2(\mathbb{F}_p)$. Results include complex characters, Brauer characters for representations over an algebraically closed field of characteristic p, Lie algebra representations, and principal indecomposable modules. We apply results proved by Humphreys for general Lie algebras to connect principal indecomposable modules of the regular representation of $\mathrm{SL}_2(\mathbb{F}_p)$ over K, for K an algebraically closed field of characteristic p, to those of the restricted universal enveloping algebra of the Lie algebra $\mathfrak{sl}_2(K)$. We also show how the modular representations of $\mathrm{SL}_2(\mathbb{F}_p)$ relate to its complex characters.

Tensor-Based Modal Analysis of Fluids Data
Nathan McAlister
Mentors: Beverley McKeon and Elizabeth Qian

A large goal in the field of fluid mechanics is to uncover underlying structure in an experimental system; one method of finding these structures is through the usage of modal analysis. The goal of modal analysis, then, is to decompose the data set into its most prominent linear components, or "modes". Two common forms of modal analysis are proper orthogonal decomposition (POD) and dynamic modal decomposition (DMD); each requires the storage of data points in a snapshot matrix. The singular value decomposition (SVD) of this matrix can then be used to find the most prominent modes in the set. In this experiment, we attempt to extend POD and DMD to the storage of data in a third-order tensor. To do so, many new operations must be used, including tensor-tensor multiplication and a tensor-based SVD algorithm (tSVD). We adopt the tensor operation definitions provided by Kilmer and Martin and will use them to calculate the tensor POD and tensor DMD modes of the data. Finally, the accuracy, runtime, and singular value decay of the algorithms will be compared.

Simulating the Radio Sky for the DSA-2000
Tyrone McNichols
Mentor: Gregg Hallinan

The Radio Camera Initiative has put forth a new approach to radio telescopes called the *radio camera* which is able to directly output science-ready image data to the end user rather than the normal visibilities. This approach bypasses the need for deconvolving the point source function of the instrument, a particularly expensive computation, greatly increasing the rate at which data products are produced and the potential scientific return of the telescope. The 2000-antenna Deep Synoptic Array (DSA-2000) is a proposed radio telescope that will pioneer this approach. In this project, two key aspects of the development of the DSA-2000 are addressed: survey strategy and forward modeling. The survey strategy was expressed as an optimization problem, and a framework for solving this problem and adding additional constraints was laid out. For forward modeling, model sky data is necessary to test the efficacy of the data pipeline. True sky images were constructed using catalogs of bright radio sources from previous sky surveys and populations of active galactic nuclei and star forming galaxies generated with the Tiered Radio Extragalactic Continuum Simulation.

CRISPR Interference Interrogation of Key Genes and Regulatory Genomic Elements in Early T-Cell Development

Alicia Mercado

Mentors: Ellen Rothenberg, Xun Wang, Boyoung Shin, and Tom Sidwell

T-cells play a crucial role in the adaptive immune system, circulating throughout the body to bind specific antigens. Several genes assist in the progression of T-cell development, including Il2ra, TCF7, and Bcl11b. Systematic perturbation of crucial genes and their regulatory elements in the genome is necessary for dissecting gene regulatory networks in mouse early T-cell development. Although CRISPR-Cas9 induced gene knock-out is a commonly used method, large non-coding regulatory elements still prove challenging to perturb. However, CRISPR interference (CRISPRi) may prove to be a solution. CRISPRi utilizes a dead version of Cas9 (dCas9) and guide RNA (sgRNA), fused with a chromatin epigenetic silencing protein domain, KRAB, to generate silencing histone modifications that perturb target gene expression. This work aims to understand the role Il2ra, TCF7, and Bcl11b non-coding elements play in T-cell development using guide RNA molecular cloning in retroviral vectors, introducing guide RNA using retrovirus for CRISPRi (dCas9-KRAB) in DN3 stage T-cells, and guiding CRISPRi to silence genes and non-coding elements.

Optimizing Sortase-Mediated Ligation Reactions for Structural Analysis

Jennifer Miao

Mentors: Rebecca Voorhees and Giovani Pinton Tomaleri

Sortases comprises a group of membrane-associated bacterial transpeptidases which anchor proteins to the peptidoglycan cell wall. As a tool, sortase has many advantages in that it can be used to covalently modify proteins after their purification. This can be important for creating fusion proteins that would be toxic or unstable in cells. Here I present my work towards leveraging this sortase-mediated ligation for structural analysis. In a simplified proof-of-concept system I identified the optimal concentrations, temperature, and time for sortase-mediated ligation of two purified proteins, and obained nearly complete ligation. I was then able to apply these conditions to covalently affix a membrane protein substrate to the nine-subunit human ER membrane protein complex (EMC). The EMC is an essential membrane protein insertase responsible for synthesis of a large range of membrane protein substrates. Though some information about its function is known, how it interacts with substrates to facilitate their insertion into the ER membrane is not well understood. Further optimization revealed ligation of the membrane protein substrate to the EMC at ~70% efficiency. This level of ligation efficiency would be sufficient for future structural experiments studying the interaction of the EMC with its substrates by single particle cryo-electron microscopy.

Charge and Energy Transport in Fluctuating Superfluid Hydrodynamics

Luke Mrini

Mentor: Anton Kapustin

The traditional formulation of hydrodynamics describes the behavior of macroscopic quantities such as energy and charge density via phenomenological transport equations but cannot incorporate quantum or stochastic fluctuations. Fluctuating hydrodynamics are incorporated in the Effective Field Theory (EFT) formulation, which uses symmetries and first principles from the Schwinger-Keldysh formalism to constrain an action. However, the EFT formulation has not previously been applied to non-relativistic, superfluid systems with charge and energy transport. These systems are more common than their relativistic counterparts in low energy situations and account for a number of phenomena of interest in condensed matter physics including the Josephson effect, thermoelectric effects, and Hall conductance. In this work, we write an action for fluctuating superfluid hydrodynamics with dynamical fields corresponding to charge and energy. We find that this formulation reproduces standard thermodynamics in normal phase and the conserved Noether currents have the same form as phenomenological transport equations in the absence of fluctuations. Further, we discuss the emergence of a non-decreasing entropy, the role of time reversal invariance and Onsager relations, and the possibility of a symmetry-breaking phase for energy variables.

Error Quantification of Particle Tracking in Large Eddy Simulations

Rithvik Musuku

Mentors: Guillaume Blanquart and Matthew Yao

Nanoparticles are used in many different helpful products, such as sun protection creams, wood preservatives, and tires. Nanoparticles can also be harmful. For example, the combustion of hydrocarbons can produce nanoparticles that cause health problems and adversely affect the environment. Because nanoparticles can have significant effects, it is important to track them in numerical simulations for predictive modeling. There are two main methods to track particles as they move through a flow field. Lagrangian methods track the motion of individual particles and Eulerian methods track particles as a group with different densities throughout a domain. Direct Numerical Simulations (DNS) are often used to simulate the flow fields, but due to their high computational costs, Large Eddy Simulations (LES) are often used as an alternative for turbulent fluid flow simulation. Although there have been studies about the particle tracking methods or the fluid simulation methods individually, there has not been a comprehensive study of the differences between different combinations of particle tracking methods and fluid simulation methods. This project is a comprehensive study of those differences.

Structural and Functional Characterization of Get3d in Cyanobacteria
Elizabeth Nelson
Mentors: William (Bil) M. Clemons, Jr., and Alexandra Barbato

Targeted delivery of membrane proteins is an essential and highly regulated process necessary for cells. Tail-anchored proteins, characterized by transmembrane domain (TMD) at their C-terminus, require additional, specialized post-translational regulation to chaperone the TMD prior to its delivery. One regulatory pathway that has been characterized primarily in yeast and humans is the Guided Entry of Tail-anchored proteins (GET) pathway. There are six proteins involved in the conserved GET pathway, Get1-5 and Sgt2. The exact function and structure of the targeting factor of the GET pathway, the ATPase Get3, has yet to be extensively studied in photosynthetic bacteria, hindering our understanding of the functional diversity of the GET pathway in other organisms.

Our study focuses on characterizing a homolog of Get3, called Get3d, in two genera of cyanobacteria, *Synechocystis* and *Nostoc*. We are studying functional characteristics with NTPase assays, Gibson cloning, pulldowns to identify interaction partners, and gene knockouts, and structural characterization through crystallographic methods. As the project continues, we seek to optimize cloning conditions and crystallization methods to continue working toward complete characterization.

The Transcriptional Regulation of Biosynthesis in Aleocharine Rove Beetles
Jack Nguyen
Mentors: Joseph Parker and Yuriko Kishi

Chemical compounds, such as small molecules and pheromones, play an important role in the ecology of animals by directly mediating interactions with their environments. Biosynthesis of chemical compounds is therefore a key process that is carried out in biosynthetic cells that often comprise a secretory organ, or a gland. Aleocharine beetles possess such a secretory organ in their abdomens, called the tergal gland that synthesizes and secretes sets of chemical compounds that vary by species. Making them tractable models to study how a gland cell deploys biosynthetic pathways, and to investigate interspecies chemical evolution. To understand how biosynthesis is transcriptionally controlled, we will be systematically knocking down upregulated transcription factors found in the gland cells in rove beetles using RNAi. We will test each as important regulators of biosynthetic pathways and by identifying these regulators, we will be able to better understand how enzyme biosynthesis pathways are transcriptionally regulated.

Development of a Biomimetic Fish Robot to Characterize the Optimal Trajectories of a Fish Fin Propulsor
Tyler Nguyen
Mentors: Mory Gharib, Cecilia Huertas-Cerdeira, Noel Esparza-Duran, and Peter Renn

Autonomous Underwater Vehicles (AUVs) and Remotely Operated Vehicles (ROVs) are used for deep sea survey, wreckage exploration, oceanic mine defusal, and other aquatic scientific and military operations that pose a danger to human-operated crafts or divers. AUVs are relatively inexpensive and less labor-intensive than their ROV counterparts, however current AUVs are limited in their permissible mission duration away from shore or charging station due to the lack in battery energy density and inefficient propulsion methods. The propulsion of fish has long been studied for its high efficiency, maneuverability, and thrust performance compared to conventional propellors; however, the optimal motion of fish fin propulsors in water has not been fully characterized and thus is not ready for implementation into AUVs. To determine the optimal parameters for fish fin trajectories in a variety of flow regimes and maneuvers, we developed a biomimetic fish robot that can perform complex flapping, spinning, and oscillatory fin trajectories. Testing the fish robot in quiescent water, we demonstrate the viability of the mechanism for further research into fin-based propulsion, and its potential as a more efficient alternative to conventional propellors.

Estimation of Turbulent Compressible Channel Flows Using Spectral Linear Stochastic Estimation
Micah Nishimoto
Mentors: Beverley J. McKeon and Anagha Madhusudanan

Within turbulent wall-bounded flows, coherent structures are phenomena that have significant effects on the dynamics of the flow, and can be observed across different wall heights. A methodology called spectral linear stochastic estimation (SLSE) has been applied in previous studies to incompressible turbulent channel flows to quantify coherence and estimate the dynamics at specific wall heights. Recent studies indicate the presence of coherent structures in compressible wall-bounded flows, which have nonuniform density distributions within the flow. Hence, we have utilized SLSE in this study to observe coherence and define estimates of fluctuations in velocity, density, and temperature in turbulent compressible channel flows. Energy spectra are calculated through

Fourier transforms of direct numerical simulation (DNS) data, and a linear coherence spectrum is derived from these spectra, indicative of the fraction of energy correlated between wall heights. This measure of coherence is used to calculate a transfer kernel, which is given DNS data at a specific wall height to estimate the fluctuations at a different wall height. The estimates of velocity, density, and temperature obtained from SLSE is compared alongside data in order to investigate the estimation technique.

Fabrication of Aligned Graphene Superlattices and Magic Angle Graphene Devices
Addison Davis Olmsted
Mentors: Stevan Nadj-Perge and Yiran Zhang

Graphene and related heterostructures provide a unique platform for exploring exotic electronic phenomena. For example, recent discoveries of strongly correlated insulating states and superconductivity in so-called magic-angle twisted graphene bilayers sparked interest in this and other systems that may similarly exhibit unusual quantum electronic phases. This project concerns itself with the fabrication of magic-angle twisted graphene devices of two and three layers, systems comprised of sheets of graphene twisted by a theoretical magic angle and stacked atop one another, and aligned hexagonal-boron-nitride/graphene superlattices (h-BN/G). We outline the methodology for the construction of these layered materials and investigate the transport phenomena of twisted trilayer graphene (TTG).

Progress Toward the Synthesis of Phorbasone A via a Convergent Strategy
Jaida Osman
Mentors: Brian M. Stoltz and Stephen R. Sardini

Phorbasone A, a novel sesterterpenoid, was isolated via an activity guided fractionation from the marine sponge *Phorbas* sp and elucidated as part of a continued search for compounds which induce osteoblast differentiation responsible for bone formation.[1] These properties make Phorbasone A a good candidate for osteoporosis treatment. We envision a convergent synthesis in which 2 synthetic sequences were employed with the eventual goal of fusing the 2 fragments. The retrosynthesis divided the molecule into 2 fragments: a hydroxy-carvone and a trans-decalin. We plan for the fragments to be joined together via a Suzuki coupling.

Determining Rupture Directivity of 2019 Ridgecrest Sequence Aftershocks With Gaussian Mixture Modeling
Samantha Ouertani
Mentor: Zachary Ross

Of the numerous earthquakes that occurred during the 2019 Ridgecrest sequence, only the mainshock and foreshock ruptures have been thoroughly analyzed. Given the existence of orthogonal faulting at many scales, we decided to investigate the rupture directivity of the smaller aftershocks to identify the most likely fault planes for each. To do this, we analyzed a large dataset of earthquake source spectra using a Gaussian Mixture Model (GMM). The GMM is a type of generative model that describes a dataset as a superposition of Gaussian distributions. Fitting a GMM entails inferring the latent variables that parameterize each Gaussian, where each Gaussian is a distinct mode. Here, we treat end-member rupture directivity modes as the GMM modes. We fit a GMM to apparent radiated energy values at each station for an ensemble of events. In total, we analyzed over 14,000 events across 40 stations. The resulting modal probability densities capture azimuth-dependent signals, and with a geographically-clustered approach, allow us to track how the rupture propagation probabilities evolve over the structurally complex Ridgecrest area.

Elucidating Mechanisms of Null Capsids
Morgan Owens
Mentors: Viviana Gradinaru and Miguel Chuapoco

Adeno-associated viruses (AAVs) are widely used gene delivery technologies. One limitation of AAVs is the lack of specificity which can cause toxicity in off-target cells. We want to find a way to engineer the capsids with no specificity to prove that they can still infect cells. Our lab has previously identified null mutations that lack specificity for all cell types. Since the Null1 and double mutant mutations break the capsid, we can see if the PHP.eB with overexpression of Ly6a can fix the capsid. After quantitative analysis using qPCR and flow cytometry, the results will confirm if the Null1 and Double mutant capsids show expression only when the PHP.eB and Ly6a are present. Then the results can be used to aid in creating a library. A library could give us information to find a capsid that goes to a specific area of the body and a specific cell type.

Developing Preference Based Learning Algorithm and Generalizations for a Lower Body Exoskeleton Gait Optimization
Ozioma Ozor-Ilo
Mentors: Aaron Ames, Maegan Tucker, and Amy Li

Preference based learning is a branch in machine learning using the classification method to analyze how users change during an experiment. For this research, we are trying to apply preference based learning algorithms to a lower body exoskeleton aimed at helping rehabilitate patients. It is much more sample-efficient to collect some information for each new user and slowly compile a larger dataset to predict preferred gaits of new users which is critical on the clinical side for rehabilitation and assistive device design. The focus is on optimizing exoskeleton gaits based on user preferences to find the optimal gait for each exoskeleton user through pairwise preferences such as "Does the user prefer 1 or 2?". Pairwise preferences are often more reliable than numerical scores or percentages. When building the preference learning algorithm, (1) analyze existing preference data (2) create action spaces from data (3) execute action spaces through a Gaussian Process (GP) model. Through this algorithm, a user's height and weight can be inputted and the algorithm would be able to theoretically determine preferences related to the lower body exoskeleton. As the dataset grows, the algorithm should become faster at identifying preferred gaits for new users. The goal would be accomplished when we are able to use the user attributes to correctly define a user's preferences.

Stochastic Delay Compensation Controller for Aggressive Multirotor Trajectory Tracking
Luis Alfonso Pabon Madrid
Mentor: Soon-Jo Chung

Time delays due to communication latency, motor response, and computation burden on multirotors can significantly degrade the control performance and even cause catastrophic failures in agile flights. Previous work quantified the influence of deterministic delays and proposed a compensation method using a one-step forward prediction of the multirotors' desired force. However, transport delays due to communication in real systems are usually stochastic rather than deterministic. This work augments the method to handle delays of a stochastic nature by estimating system delays in real time. We conduct numerical simulation to demonstrate that the augmented method improves the trajectory tracking performance of the first-order approximation when delays are stochastic. We experimentally verify the performance improvement of the novel method in a real quadrotor system with stochastic delays.

User-Friendly, Robust Data Analysis Software for Cryogenic Molecular Beam Data (CryoDAS)
Emily Pan
Mentors: Nick Hutzler and Arian Jadbabie

Currently, there are no dedicated data analysis systems designed for the cryogenic molecular beam data source, and existing analysis lacks modularity and a user interface. CryoDAS is an object-oriented, robust system that allows users to apply computations and plot data interactively. These computations include sorting and averaging, filtering, and integrating data, which can be applied to the data in any sequence. CryoDAS uses widgets to improve the user experience and plot readability, including sliders to change plotting bounds, checkboxes to indicate the computations done on the data, and buttons to save plots. CryoDAS also speeds reading and writing saved data by saving the data as objects that can be read directly. CryoDAS is a resource that any group analyzing cryogenic molecular beam data can use.

Evaluation of *Thermophilic Bacillus* F_1-ATPase Rotation Rate at Varying Temperatures
Nayree Panossian
Mentors: Sándor Volkán-Kacsó and Rudolph A. Marcus

Research on the temperature dependence for the rotation of a *thermophilic bacillus* F_1 adenosinetriphosphatase (F_1-ATPase) is ongoing. It was recently found that an additional sub step, called the temperature-sensitive (TS) reaction, is present at the binding angle (80°) where the sub steps of adenosine triphosphate (ATP) binding and adenosine diphosphate (ADP) release also occur. Information about the TS sub step is limited, especially at temperatures below the theorized glass transition temperature (9°C). In efforts to construct a kinetic model, activation energies and pre-exponential factors for the rotation of each sub step and overall rotation were extracted from single-molecule and ensemble experimental data, using Plot Digitizer and MATLAB as data analysis tools whilst utilizing the Arrhenius law. As a result of this evaluation, it was concluded that the large parameters related to the rotational rate of the TS reaction indicate it is the rate-limiting step in the binding dwell that necessitates a positive change in entropy. Furthermore, it was theorized that a conformational change occurs during the TS sub step for the transfer of ATP into the deep pocket after binding. Furthermore, this investigation can provide insight into the rate-limiting step within the entire mechanism in future studies.

Nanoporous-Copper for the Selective Electroreduction of CO_2
Bhushan Patel
Mentors: Harry Atwater and Aidan Fenwick

Existing CO_2 must be removed and recycled to reach net-zero emissions. Electroreduction of CO_2 is one favorable approach because it can utilize captured carbon to create industrial precursors that presently require fossil fuels to manufacture, reducing carbon in both ways. However, the CO_2 reduction reaction (CO_2RR) catalysts such as copper are not selective to specific hydrocarbons. It is hypothesized that this selectivity can be enhanced through a nanoporous catalyst morphology. A copper/aluminum alloy can be etched with phosphoric acid to achieve this nanostructure. Testing has been performed across a variety of alloy and etchant concentrations and durations to target an optimal cross-sectionally continuous nanoporous copper electrode. Scanning electron microscopy is utilized to verify the nanostructures. Electrochemical testing of these electrodes is also measured against a polycrystalline copper blank to compare Faradaic efficiencies of resulting products. Successful increases in selectivity can improve progress towards a long-lasting circular carbon economy.

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 itself to be less susceptible to viral infection. Metabolism is responsible for the available energy in the cell, and thus it is a key regulator in many cellular processes, especially those in immune cells. We are researching whether AMP activated kinase(AMPK), an important regulator in metabolic cellular processes, can be a potential target for these antiviral therapies. We use a live cell reporter, AMPK SPARK, to obtain a dynamic readout of AMPK activity in macrophages. Macrophages are notably hard to transfect with DNA due to their nonproliferative nature so we propose to express AMPK SPARK in macrophages via mRNA transfection. We will then stimulate the macrophages with immune and metabolic agonists and measure the activity of AMPK as a response to those stimuli to get a clearer picture of the role of AMPK in the immune response. Preliminary transfections of AMPK SPARK pDNA into HeLa cells and subsequent dosage with agonists indicate the reporter's success in capturing AMPK dynamics.

Development of a Powered Ankle Exoskeleton
Toussaint Pegues
Mentors: Aaron D. Ames and Maegan Tucker

Millions of people worldwide are affected by injuries or disabilities that impede their ability to walk. Devices that restore mobility take many forms, from the simplest canes to exoskeletons. Exoskeletons can also provide assistance to individuals with conditions ranging from muscle weaknesses to paraplegia. The goal of our exoskeleton is to provide additional torque at the ankle to reduce the amount of effort users have to expend by supplementing the torque exerted around the ankle during walking or running. This additional torque leads to a reduction in the metabolic cost, allowing the user to walk farther or carry more weight with less effort. The augmentation is achieved using motors coupled to handed shearing auxetic cylinders that extend when twisted.

Facilitating the Production of Large Surface Area Engineered Living Materials Using a Polymer Additive
Elana Peisner
Mentors: Julia Kornfield and Lealia Xiong

Engineered living materials (ELMs) can grow and adapt to different environments. The goal of this project is to engineer an ELM with *E. coli* bacteria as the living component that can self-regulate its temperature outdoors. Previously, the Kornfield and Shapiro labs engineered *E. coli* to express a dark pigment below 37°C, so the bacteria will warm up by absorbing light from the sun. The growth and temperature of proof-of-concept bacterial patches 1 cm in diameter have been assayed; however, for applications such as coating the exterior walls or roof of a building with ELMs, we must increase the surface area that our bacteria can cover. We used a doctor blade to coat a suspension of bacteria onto a polycarbonate backing, then incubated the patches on agar media to grow and develop pigment. We tested a panel of polymer additives and concentrations to optimize the viscosity of the suspension for spreading an even layer of bacteria. In addition, we varied the volume of bacteria suspension we deposited and the volume of agar media on which we grew the patches in order to reach the desired area and thickness of the sample. We have successfully increased the bacterial patch diameter to about 4 cm, which will allow for growth and temperature experiments that more accurately reflect the heat transfer and mass transport conditions of wall and roof living materials.

Interfacing a Monte Carlo Solver With Fluid Dynamics Software to Better Model Soot Formation in Non-Premixed Turbulent Flames
Jules Pénot
Mentors: Guillaume Blanquart and Matthew Yao

Responsible for the dark black color we associate with smoke, soot particles are highly mobile once released into the atmosphere. They can then be deposited on ice, altering our planet's albedo and accelerating climate change, and lead to increased risk of lung disease, asthma, and various types of cancers in humans. Increasing our understanding of soot formation in turbulent environments such as combustion engines and thermal power plants is therefore necessary to better mitigate these adverse effects.

Working with the Blanquart group's fluid dynamics solver to obtain key macroscopic variables for infinitesimal parcels of fluid along their trajectories in a turbulent flame yields these variables as a function of time. Interfacing this data with a Monte Carlo solver then allows the use of stochastic methods to solve for the soot particle population's complete size and number distributions as a function of time within these parcels. With a sufficient number of trajectories, this data can be extrapolated to the entire flame, yielding a more complete model of the soot particle distribution than current semi-empirical models. It is still necessary to calibrate this model for consistency with experimental data.

Simulating the Study of Exoplanets Using Photonic Spectrographs
Marcos Perez
Mentors: Dimitri Mawet, Pradip Gatkine, and Nemanja Jovanovic

Determining the atmospheric composition of exoplanets is necessary for understanding their habitability, formation, and evolution. The Keck Planet Imager and Characterizer (KPIC) on the 10-m Keck II telescope directly images and spectroscopically characterizes giant exoplanets using a bulk-optics spectrograph; however, photonic spectrographs offer a highly miniaturized, flexible, and stable solution on a chip that's easier to both operate in existing ground-based observatories and to implement in future space-based telescopes. Therefore, we conducted simulations to examine the capability of photonic spectrographs in characterizing and spectrally resolving exoplanet atmospheres. Our goal is to simulate the signal-to-noise ratio for various molecules in different near-IR wave-bands using the KPIC with a photonic spectrograph.

During this SURF, we developed a publicly available tool to simulate exoplanet observations with a photonic spectrograph. Specifically, we derived the Line Spread Function (LSF) as both a function of wavelength and spectral line width, the Full-Width-at-Half-Maximum (FWHM) as a function as a wavelength, and a calibration matrix to retrieve the input spectrum from the observed power in each channel of the photonic spectrograph. We observed that the wavelength dependence of the LSF was minimal, contrary to previous assumptions, and that the FWHM increases with the width of the emission line.

Development of High Crystalline Quality α-Phase Germanium Telluride Films Through Molecular Beam Epitaxy
Kaveh G. Pezeshki
Mentors: Joseph L. Falson and Adrian Llanos

Thin films provide a powerful method to study electronic and quantum phenomena due to the quality and control provided by growth techniques such as molecular beam epitaxy (MBE). Furthermore, growing material in thin-film form provides access to unique electrical properties granted by the reduction in dimensionality, anisotropic chemical profiles, and dissimilar heterointerfaces. Germanium Telluride (GeTe) is a promising candidate for thin-film research due to its novel applications in nonlinear optics. Observing these effects requires very pure films, granted by a substrate well-matched to the desired film as well as optimized growth conditions.

In this work, we have grown single phase α-GeTe thin films on lattice-matched Indium Phosphide (111) substrates, and characterized their structural and electrical properties. We followed an iterative growth procedure to develop GeTe films with high crystallinity. Optimization of growth temperatures, source material fluxes, and substrate thermal interface provided increased film quality as demonstrated by x-ray diffraction and atomic force microscopy. In parallel, improvements to the MBE apparatus and characterization tools enabled investigation of GeTe samples while enabling future growth techniques. The MBE apparatus was expanded with a custom vacuum gauge controller and automation features which enable shuttered growth, infrared temperature measurement equipment was characterized and calibrated, and new instrumentation and apparatus was developed to allow for low-temperature electrical measurement.

Synthesis and Characterization of Water-Soluble Megasupramolecules for Use in Mist Control
Derek Poletti
Mentors: Julia Kornfield and Hojin Kim

The dispersion and impact behavior of aqueous droplets is important in the safe and efficient deposition of active ingredients in fields ranging from agriculture to printing. Polymers are powerful additives for controlling droplet breakup during spraying and droplet adhesion during impact. However, ultralong polymers, the most effective ones, are degraded during routine handling. End-associative polymers discovered at Caltech resist degradation and provide mist control in fuels at concentrations as low as 0.3%wt (Wei, 2015). For use in water, we chose a different backbone (polyacrylamide), and end groups (terpyridine) to create a new water-soluble mist control agent. Terpyridine end groups allow supramolecule formation though chelation with divalent metal ions (Schubert, 2011). We synthesized terpyridine-ended polyacrylamide using a controlled radical polymerization with a terpyridine-ended iniferter (combined initiator and chain transfer agent). The viscosity of the solutions depends on the choice of ion (Fe^{2+}, Zn^{2+}, Ni^{2+}), polymer chain length, and concentration of both ions and polymer. Two terpyridine groups are bound by each metal ion, so we expected the highest viscosities to be found when the molar ratio of ions to terpyridine end groups is approximately ½ (Lewis, 2019). Instead, the viscosity peaked at metal:terpyridine ratio >0.6 and varied with flow history.

Electron-Phonon Coupling in Hexagonal Boron Nitride Single-Photon Emitters
Sahil Pontula
Mentors: Harry A. Atwater and Hamidreza Akbari

Hexagonal boron nitride (hBN) is a van der Waals material that has garnered much interest owing to the excellent single-photon sources it hosts, which possess high Debye-Waller factor even at room temperature. However, the local structure of these sources and the electron-phonon coupling they exhibit are not well understood. Both involve the phonon density of states (PDOS), which has been difficult to probe experimentally. Electron-phonon coupling manifests in features within the photoluminescence (PL) spectra of single-photon sources, including phonon side band (PSB) profiles and broadening effects. Here, we apply the Huang-Rhys fitting method to fit arbitrarily-shaped PSBs for hBN single-photon emitters. In addition to demonstrating excellent fit to the ZPL and PSBs of diverse emitter spectra, this method uses the Huang-Rhys parameter and PDOS as fitting parameters, giving an excellent way to both quantify electron-phonon coupling in an optical tabletop experiment and probe the PDOS. We further examine dependencies of these two parameters on isotopic and thickness-related effects, discussing their relationships to theoretical predictions and extracting information about both local vibrational modes and lattice phonon modes.

Estimating Small Failure Probabilities
Max Popken
Mentor: Konstantin Zuev

The objective of this project is to accurately estimate the probabilities of very rare events. These warrant closer inspection because they do not occur with great enough frequency that standard Monte Carlo sampling can accurately estimate their probability. Thus, more sophisticated methods are needed. The standard algorithm developed by Au and Beck is subset simulation. This involves randomly sampling points, and then updating them using Markov chains so that they approach the region of failure. By isolating points in this region, more failure points can be sampled and thus a more accurate prediction of the failure probability can be made. The goal of this project is to develop an algorithm that makes more accurate estimates than subset simulation. Three main classes of algorithms were developed: onion subset simulation, modified onion subset simulation, and ALIS. Each of these involve exploring the sample space and updating samples in the Markov chains in different ways. None of these algorithms were ultimately able to outperform subset simulation, but modified subset simulation performed best, followed by onion subset simulation, with ALIS performing worst.

Entropy of Motif Distribution and Robustness of Complex Networks
Anastasia Popova
Mentor: Konstantin Zuev

Networks can be found everywhere throughout the world, such as brain networks, biological systems, technological networks, or social networks. In network theory, graphs are commonly used to model these systems. These are modeled with points known as nodes and connections between them known as edges. A motif entropy can be calculated for each graph by looking at random uniformly distributed samples of induced subgraphs of a given size within the network. Motif entropy has been found to be a good differentiator between random graphs and real networks. Real networks have been found to consistently have higher entropies than random graph data showing that random networks are not good models of networks. However, real networks are also able to break down and lose edges or even nodes. These attacks can change the entropy and can possibly further help us classify the structural health of a network. In the future, motif entropy can be used to further characterize and classify the quality of models used to analyze real networks.

Sampling Noise Does not Change With Experience During Simple Choice
Trinity Pruitt
Mentors: Antonio Rangel and Brenden Eum

A large body of work has shown that choice accuracy and reaction time in simple binary choices are described by sequential integration models such as the Drift-Diffusion-Model. A feature of these models is that as the amount of noise in the value samples increases, choice accuracy decreases, and reaction times become insensitive to choice difficulty. Our hypothesis is that as subjects gain experience in evaluating options, the noise of the sampling process should decrease, with a concomitant gain improvement in the choice process. The goal of this project is to test this hypothesis using data from simple choice experiments. If noise decreases with the frequency an option has been evaluated over the experiment, then choice accuracy should increase with the frequency of the options have been encountered previously, and the reaction time curves should become steeper with previous experience. We tested these two predictions in two different datasets using hierarchical logistical regression for the choice data, and hierarchical linear regression for the reaction time data. We found no significant impact of previous experience on either choice accuracy or reaction times, which suggests that the noise in the value sampling process does not decrease over the course of a typical experiment.

Fourier Continuation Neural Operator for Nonperiodic PDEs
Derek Qin
Mentors: Animashree Anandkumar and Zongyi Li

Solving partial differential equations (PDEs) are traditionally a computationally intensive task. Recent Fourier-based machine learning methods for solving PDEs, specifically the Fourier Neural Operator (FNO), have vastly improved the speed and data requirements for solving PDEs. The FNO architecture is reliant on a Fourier Transform over the input domain, so the Fourier Continuation, which transforms a non-periodic domain to a periodic domain, presents a way to improve the performance of the FNO. A Fourier Continuation-Fourier Neural Operator architecture was tested on the 1D Burger's Equation, 2D Navier-Stokes, and 2D Darcy Flow on a bounded domain. While the 1D Burger's problem was too simple for the Fourier Continuation to offer much benefit, padding in the time domain significantly improved the model's performance on the 2D Navier-Stokes problem. Additionally, the FNO architecture effectively computes the Fourier Continuation if loss is only calculated on the target domain, excluding padding. Further research will consist of model training on newly generated, bounded domain datasets and padding with precomputed periodic functions.

Modeling Single-Armed Protoplanetary Disk HD34282 for Planet Search
Juan Quiroz
Mentors: Dimitri Mawet, Bin Ren, and Nicole Wallack

Protoplanetary disks help deepen our understanding of planet formation and their direct observation may be able to reveal large planetary companions. The disk around HD34282 is an interesting target given that it has a single spiral arm and currently spiral arms are currently attributed to either gravitational instability or planetary companions. By taking images obtained from Keck Observatory and using principal component analysis, we can remove the light from the star and obtain an image where the disk is visible. Using previous disk modeling code, we create potential disk models with different parameters and subtract them from our original data to obtain a residual. We use Markov Chain Monte Carlo techniques to sample the parameter space and find the best fit for our disk, which would be the one that minimizes the residual. Once we have a good model and we subtract it from our data, it can be easier to detect faint planets.

Using Immunoprecipitation-Mass Spectrometry Approach to Evaluate the Interactome of PLAA and p97
Emily Rainge
Mentors: Tsui-Fen Chou and Shan Li

p97/VCP is an AAA (ATPase associated with a variety of activities) ATPase that releases energy via hydrolysis of ATP to ADP to generate cellular processes such as proteasomal degradation, membrane trafficking, and DNA replication. Phospholipase A2-activating protein (PLAA) is a p97 cofactor that works with p97 and some other p97 cofactors to drive the clearance of ruptured lysosomes via autophagy. PLAA mutations have been found to cause brain disorders by disrupting synaptic vesicle recycling and neurotransmission. This summer, I used co-immunoprecipitation (IP) and LC-MS/MS quantitation approaches to explore how PLAA interacts with p97 under different conditions (overexpressing PLAA, WT p97, and ATPase-inactive mutant p97 in HEK293T kidney cells, and endogenous IP of PLAA in SH-SY5Y neuroblastoma cells). Comparison of these interactome proteomic profiles provides a deeper understanding of the functional role of PLAA in p97-associated processes.

The Influence of Gender on Social Perception
Heidi Redmond
Mentors: Ralph Adolphs and Nina Rouhani

How we perceive other people is essential to the way we live our lives, and the question of whether these perceptions are dependent on a person's gender provides insight into not only the process by which people make impressions of others, but also how that process interacts with a person's cultural background. Previous studies about whether someone's gender affects the perceptions they make and the perceptions that are made of them use only artificial stimuli, which fail to embody the complexity of organic social interaction. To correct this, we studied perception data derived from 15-minute long, text-based conversations between two real people in two settings: one in which participants directly interact with a chat partner and rate them on 108 traits and states, and a second in which participants read those chat transcripts and rate a target participant on the same states and traits. Analysis on these data have indicated that there are 41 states and traits on which men and women rate others significantly differently and 13 states and traits which are rated differently based on the gender of the target participant. However, thus far there is no evidence that one gender is better at determining the true personality of their partner as determined by the similarity between a participant's evaluation of their target and the target's self-evaluation.

Optimizing Metal Carbonate Precipitation for Carbon Capture
Jillian Reed
Mentors: Harry Atwater and Eowyn Lucas

Negative emissions technologies can play a pivotal role in keeping the total warming of the atmosphere at <1.5 °C in accordance with the Paris Agreement. Although CO_2 capture from point sources has been well investigated, CO_2 capture from dilute sources like the ocean is less studied and is more effective at combating decentralized emissions. This work explores the possibility of sequestering CO_2 from oceanwater through inducing the precipitation of metal carbonates like $CaCO_3$. We do this by raising the pH of the seawater, thereby shifting the CO_2 equilibrium towards carbonate ions and thus increasing the supersaturation state of the solution with respect to metal carbonates. To determine the optimal conditions for metal carbonate precipitation, we created a model system of synthetic seawater and probed the effects of different reaction conditions like initial pH. Crystal nucleation and growth were characterized via a combination of in-situ turbidimetric methods and ex-situ Raman spectroscopy and scanning electron microscopy experiments.

Characterizing Oxidation States of Transition Metal Polymers Using Electron Energy Loss Spectroscopy
Yolanda Reyes
Mentors: Scott Cushing, Levi Palmer, and Wonseok Lee

Electron energy loss spectroscopy (EELS) can probe numerous electron-matter interactions ranging from low-loss vibrational phonon below 1 eV to element-specific core excitations above 1000 eV. We implement EELS in scanning mode (STEM-EELS) to map the nanometer effects of bonding and reactivity in polymers synthesized with transition metal crosslinkers. Current research of hydrogel polymers use these transition metal crosslinkers to create high resilience, toughness and dynamic adaptability. We characterize the oxidation state and coordination number of the metal centers for Fe, Cr, and Al acrylates. Non-conductive samples like polymers have high beam sensitivity which lead to rapid degradation, making them difficult to characterize. This research implements a femtosecond laser to trigger photoemission at a Lab6 filament which is used in our TEM to produce electron pulses. We show STEM-EELS can reveal the local properties of metal center reactivity and bonding and we relate these effects to the polymer's bulk properties. Notably, we report a novel analytical approach for polymer characterization.

HOMES Lunar Dust Mitigation Through Electrodynamic Shielding: Designing the Microcontroller, Electronics Box, and Power Supply
Raha Riazati
Mentor: Soon-Jo Chung

Lunar dust poses a significant challenge to future space exploration. EDS, or electrodynamic dust shielding, provides a possible method by which this dust can be removed in indoor environments: rapidly varying electric fields attract and repulse the charged dust particles, moving them along a flat surface. Our team intends to build modular, space-grade panels that implement EDS for our original invention, HOMES (Habitat Orientable and Modular Electrodynamic Shield). I have been primarily responsible for designing, implementing, and testing the electronics of our prototype; I programmed and tested the microcontroller that coordinates the timing and sequence of the changing electric fields and handles transitions between operational modes of the system. I also designed and soldered PCB's for the prototype's electronics box, which houses the microcontroller and user interface, and power supply, which provides the high voltage required for EDS at a high switching frequency. Our electronic design has proven successful at removing lunar dust simulant and is now being optimized to ensure dust is removed as quickly and thoroughly as possible. In future, all prototype electronics will also undergo lifetime tests and exposure tests to verify their effectiveness for the proposed use case.

Using Dimensionality Reduction to Identify Transition Phase Galaxy Candidates
Patrick Rim
Mentors: Charles Steinhardt and Adam Blank

In the last 15 years, we have discovered a puzzling fact about galaxies, which is that the star formation rate seems to be consistent across galaxies that have varying features and properties. While we have been able to find many galaxies that produce stars at the rate that we have commonly observed and other galaxies that do not produce stars at all, we have been unable to find galaxies that produce stars at a different rate. Among the galaxies in the COSMOS2020 catalog, which contains over two million galaxies and thirty photometric bands for each galaxy, we attempt to find transition phase galaxies with a different star formation rate. We accomplish this using a dimensionality reduction algorithm called t-SNE to "cluster" galaxies in the catalog, which would be impossible to do without reducing the number of attributes, or "dimensions," describing each galaxy. By coloring the clusters generated by t-SNE with an attribute that we have more information about, we identify which galaxies seem different in some way and select them as candidates for further exploration.

The Surface Composition of Anomalous Asteroids as a Window Into the Early Solar System
Kate Roberts
Mentor: Katherine de Kleer

The mystery of our solar system's past can be uncovered by understanding the processes by which its individual components formed. M-type asteroids may hold answers regarding the evolution of early forming planets: given their high iron content, it is suspected they are stripped core remnants of destroyed planetesimals. It is suggested that other materials, like silicates, detected on their surface are the product of impact deliveries by smaller asteroids, but, due to the detection of these materials, it is also possible that the formation of M-type asteroids was a result of an entirely different process. Confirming the existence of these surface compounds is the next logical step in understanding their creation. We obtained 1.7-2.3-micron spectra of the M-type asteroid Psyche and the S-type asteroid Eunomia with the NIRSPEC instrument on the Keck telescope on September 8th of 2020. We measured the strength of the silicate absorption feature at 2.0 microns, a proxy for the abundance of silicates on the asteroid's surface. We present the feature strength as a function of rotation, and provide an interpretation of our results in terms of the surface composition of Psyche and Eunomia and the compositional variation across their surfaces.

Estimating Ice Shelf Melt Rates in the Bellingshausen Sea (West Antarctica) From Autonomous Underwater Instruments
Megan Robertson
Mentors: A. F. Thompson and M. M. Flexas

The West Antarctic Peninsula (WAP) has been subject to extreme ice shelf retreat over recent decades due to the melting of floating ice shelves by underlying warm ocean waters. The Bellingshausen Sea, located between the Amundsen Sea and the WAP, consists of two troughs which aid in the circulation and transport of water masses between the shelf break and coast. Within the Bellingshausen Sea, Modified Circumpolar Deep Water (MCDW), the warmest water mass found on the shelf, is transported through these troughs to induce melting of the ice shelf along the WAP. Observations of oceanic properties can aid in the determination of future melt rates; however, the Bellingshausen Sea has been neglected compared to the neighboring Amundsen Sea. To combat the lack of observations in the Bellingshausen Sea, the TABASCO project collected hydrographic observations in austral summer in 2019 and 2020 using ocean gliders, a type of autonomous ocean vehicle, and ship-based CTD stations. Measurements were collected in sections perpendicular to the transport phenomena. Using measurements of oceanic properties collected from the CTDs, calculations of meltwater fractions and temperature and salinity maps illustrate that a cyclonic circulation of water masses regulates the transport of MCDW and meltwater through the troughs on the Eastern side and out on the Western side along the ice shelf. For the first time, these field programs collected observations that provide insight into the connectivity between different shelf seas in Western Antarctica. Monitoring the stability of the WAP and the larger WAP oceanic system is reliant on the circulation and transport of MCDW and meltwater throughout the Bellingshausen Sea.

Characterization of the Broad-Band X-ray Spectrum of the Black Hole Binary MAXI J1820+070
Jennifer Rodriguez
Mentors: Fiona Harrison and Javier Garcia

Binary systems composed of stellar-mass black holes and companion stars allow for the study of the energetic radiation emitted in the regions close to black holes. Modeling the X-ray spectrum can show significant features produced from the radiation reflected from the accretion disk. Reflection spectroscopy is one of the techniques used to analyze the emitted radiation in order to identify physical properties of the black hole. MAXI J1820+070 is a black hole binary that was discovered after its 2018 outburst. The broad-band X-ray spectrum will be modeled using simultaneous observations from Swift-XRT, NICER, NuSTAR, and INTEGRAL. By investigating the coronal emission through different coronal models, we can gain an understanding of the geometry of the corona. This project aims at understanding if a multi-temperature corona is required to fit the observations of this source.

A Loser-Take-All DNA Circuit
Kellen Rodriguez
Mentor: Lulu Qian

DNA strand-displacement circuits are powerful tools for processing molecular information. The implementation of neural network computation in these circuits allows for completion of complex tasks such as pattern recognition. We develop a loser-take-all DNA circuit where an input amongst a set of nonnegative analog inputs has a corresponding output signal in an ON state if and only if that input has the least value of all inputs. We implement a three-input loser-take-all DNA strand-displacement circuit and perform fluorescence kinetics experiments in order to quantify the behavior of the system. We observe successful loser-take-all computation by the system; however, the performance of the system is sensitive to differences in effective concentrations of signal strands and reaction rates. We investigate ways to remedy this sensitivity and successfully improve performance through concentration changes catered to the system. This successful demonstration of the loser-take-all system serves as an expansion to the current architecture of DNA-based neural networks, opening the door for the potential implementation of other powerful DNA neural networks such as k-winner-take-all. Furthermore, the sensitivity of the system to variations in effective signal concentrations and reaction rates emphasizes the importance of and motivates the design for systems that are robust to such variations.

Understanding Sea Surface Height Variability at 10 km Scales
Daniela Rodriguez-Chavez
Mentor: Jörn Callies

In 2022, NASA will launch the Surface Water and Ocean Topography (SWOT) mission, which will send a satellite into orbit to collect data on ocean surface topography. However, even though the data will have a good spatial resolution, it will lack a strong temporal resolution due to the nature of the satellite's orbit, limiting our ability to distinguish between slow geostrophic eddies and fast wave motion. Thus, in 2019 a pre-launch campaign was carried out for 4.6 months to provide a foundation of robust time statistics for the future SWOT mission data. The in-situ campaign included the deployment of two moorings, placed 10 kilometers apart off the coast of California, where sea surface height (SSH) was measured every second. Using these in-situ data, we test whether previous predictions for the 10-km SSH signal are consistent with the observations. We calculate a prediction based on a model from recent work for the observable frequency power spectrum of SSH at both moorings and of the SSH difference across the moorings. We find that these predictions are generally consistent with the data. We discuss the implications of these results for the upcoming SWOT mission.

Investigating the Impact of Biomass Burning Aerosols on Urban Air Quality in Los Angeles
Mitchell Rogers
Mentors: John Seinfeld, Benjamin Schulze, and Christopher Kenseth

The extent of biomass burning (i.e. wildfires) has escalated dramatically in recent years. Despite the increasing frequency and severity of fire activity, however, there is a limited understanding of how aerosol particles derived from biomass burning impact urban air quality, particularly in regions with pervasive air pollution. Here, we characterize the influence of wildfire emissions on urban aerosol mass loadings and composition using data from a high-resolution time-of-flight aerosol mass spectrometer (HR-ToF-AMS) collected during the 2020 fire season in Los Angeles. Positive matrix factorization (PMF) is employed to identify and apportion sources of airborne particulate matter to those typical of urban atmospheres (e.g. combustion and cooking) as well as those unique to biomass burning. Wildfire plume transport and aging is evaluated using HYbrid Single Particle Lagrangian Integrated Trajectory (HYSPLIT) backward air mass trajectories. Compared to typical levels in Los Angeles, non-refractory submicron organic aerosol concentrations increased by over a factor of 10 during periods impacted by wildfire smoke. Future work will reconcile results with past models of simulated aerosol formation and chamber measurements.

The Effect of N-tol-pyridinium Deposition Time on Copper-Mediated CO_2 Reduction
Brith Milenia Rojas
Mentors: Jonas Peters, Madeline Hicks, Nick Watkins, and Yueshen Wu

Due to the rise of CO_2 emissions around the world, there is great interest in converting atmospheric CO_2 into useful multi-carbon products such as ethylene and ethanol. This goal can be accomplished by electrocatalytic CO_2 reduction (CO_2R) on copper electrodes. Our team has previously discovered that by using N-substituted aryl pyridinium additives, the selectivity of copper electrodes can be enhanced. As a hydrophobic organic layer is deposited onto the surface of a copper electrode, it suppresses the hydrogen evolution reaction (HER) and the formation of undesired side products such as CO and CH_4, leading to higher selectivity for multi-carbon products. Previously, the additive has been deposited *in situ* during electrochemical CO_2R and the precise film thickness has yet to be elucidated. This study is focused on analyzing the effect of additive deposition time, which may affect the film thickness, on our system's CO_2R selectivity profile. In conjunction, we are looking at the effect of deposition time on the electrochemical active surface area (ECSA). The ECSA represents the area on the copper electrode where CO_2R can occur. We suspect that a "sweet spot" deposition time may exist, in which the selectivity profile is optimized, and the resulting film thickness can be probed.

Characterization of Microstructure and Morphology of Thin Film Germanium Telluride Grown via Molecular Beam Epitaxy
Cristian Ruano Arens
Mentors: Joseph Falson and Adrian Llanos

Germanium telluride (GeTe), a ferroelectric semimetal which exhibits broken inversion symmetry, may give rise to exotic quantum mechanical and topological phenomena. However, experimental demonstration requires high quality, single crystalline thin films. To achieve this, we use the molecular beam epitaxy (MBE) technique which allows for precise control of single crystal growth by evaporating high purity source materials onto crystalline substrates. It has been shown that GeTe films have a strong tendency to form crystallographic twins during epitaxial growth which is a major barrier to achieving high quality. To characterize these and other structural defects, nanoscale imaging of the film surface is necessary. Using atomic force microscopy (AFM) and scanning electron microscopy (SEM), we study the surface morphology and microstructures of grown films and how they depend on the parameters used during growth. Alongside macroscopic techniques such as x-ray diffraction and electrical transport measurements, these nanoscale studies allowed us to efficiently optimize growth conditions and yielded high quality, single crystalline thin films.

Identifying the Correlation Between N-oxide Reduction and Resistance to Antibiotics in *Achromobacter xylosoxidans* Clinical Isolates
Juan Santos
Mentors: Dianne K. Newman, Steven Wilbert, and Zach Lonergan

A major area of study in cystic fibrosis (CF) research revolves around understanding the frequent failure of antibiotics to effectively treat opportunistic pathogens such as *Achromobacter xylosoxidans* (AX). Ironically, the microenvironment of the lung where these pathogens are found iis limited for oxygen. Tolerance to conventional antibiotics has been associated with a reduction in respiration rate in the absence of oxygen, making these organisms physiologically less susceptible to certain drugs. As a response to reduced oxygen levels some pathogens are able to reduce N-oxides in place of oxygen. The correlation, if any, with N-oxide reduction and antibiotic tolerance is not yet understood. The purpose of this study was to gain an understanding of how the respiration of the N-oxide, nitrate, influences antibiotic tolerance in comparison to that seen during aerobic respiration. Through the use of antibiotic disk diffusion and agar block biofilm assays, we concluded that AX clinical isolates display different responses to a range of clinical antibiotics when grown aerobically. When grown anaerobically in the presence or absence of nitrate, surprisingly, we found that not all strains grow the same, whereas aerobically, their growth is similar. We are working towards understanding whether and how differences in growth rate and antibiotic susceptibility are related under oxic and anoxic conditions.

Using Temperature Sensors to Track the Thaw and Erosion Fronts in an Experimental Permafrost Riverbank
Maria Schmeer
Mentors: Michael P. Lamb and Madison Douglas

As Artic rivers warm, more heat is available to thaw permafrost, which can destabilize riverbanks and affect Arctic riverside communities. The thermal characteristics and geomorphic processes active in Artic rivers change seasonally and inter-annually, making it difficult to isolate bank thaw and erosion patterns from field measurements alone. In particular, little is known about how the thaw interface within a riverbank migrates during warming and erosion. To investigate this process, we designed a frozen flume experiment with two phases to track the thaw and erosion fronts within a permafrost bank. In the first phase, discharge increased as the bank widened to keep velocity and boundary stresses constant. The sediment transport capacity was high during phase one such that eroded sediment was flushed downstream. In the second phase, the discharge was fixed as the channel widened, which created a backwater effect that resulted in lower boundary stresses and a layer of thawed sediment that draped the frozen bank. We used an array of temperature sensors in the bank to determine the thaw and erosion front locations throughout the experiment to assess whether bank erosion was thaw- or sediment transport- limited. Preliminary results show how temperature sensors can be used to track thaw and erosion fronts at bank locations, demonstrating their potential for field studies to assess riverbank erosion hazards for Artic communities.

Examining Mental Prototypes of Graphical Data Using Virtual Serial Reproduction Methods
Eli Seiner
Mentors: Shinsuke Shimojo and Daw-An Wu

Mental prototypes facilitate the process of compressing visual stimulus input into mental representations. Revealing prototypes can help explain some of the biases in human cognition and behavior. Serial reproduction tasks – a chain where a previous participant's reproduction of a stimulus is fed to the next participant as a stimulus – can be particularly useful at amplifying trends to reveal mental prototypes of visual stimuli. By developing a virtual system with serial reproductive features, this study aims to expand the reach of these studies, allowing scientists to learn more about a variety of mental prototypes and biases. More specifically, this study aims to compare the virtual environment with in-person laboratory experiments, to reveal mental prototypes and understand the mental biases associated with graphical data, and to use the virtual network to further assist the lab in other studies regarding cognition and prediction. Results of the validity of the study, as well as analysis of data gathered, will be discussed. Future work should include further expansion of the virtual system to include other psychological experimental methods to improve the access to subjects and efficiency of psychological studies.

Synthesis of Ni-CODH Active Site Model
Mya I. Serrano
Mentors: Theodor Agapie and Anna Scott

Biological systems have been developed by years of evolution to become highly efficient and thus are interesting to study towards the improvement of related processes carried out by humans. For example, enzymes are biological macromolecules that perform essential reactions within cells. One enzyme of interest is CODH, or carbon monoxide dehydrogenase. Specifically, Ni-CODH contains a [Ni-4Fe-4S] cluster responsible for the reversible transformation of CO_2 to CO in anaerobic microorganisms such as bacteria and archaea. As CO_2 is the primary greenhouse gas produced by humans, there is much interest in using it for synthesizing value added carbon products. Through the use of air free techniques like glove boxes and Schlenk systems, we have started the process of synthesizing this model. By starting with a [Et4N]2[Tp*WFe2S3(μ3-Cl)Cl3] cluster reported by Holms, we have synthesized many derivative clusters with NHC substituents, and we have successfully bonded a Ni center to the cluster. These clusters and synthesis' have brought us closer to the end goal of creating the Ni-CODH model. We will continue testing new reactions and adding new substituents and derivatives to focus reactivity towards the active site, and to study the kinetics of our model.

Nanophotonic Lithium Niobate Waveguides for Broadband Difference-Frequency Generation
Anna Shelton
Mentors: Kerry Vahala and Lue Wu

Difference-frequency generation (DFG), a second-order nonlinear optical process, plays a critical role in many applications spanning all-optical signal processing and optical frequency combs, which serve to increase the accuracy of modern time standards and the global positioning system. By combining telecommunication wavelengths, DFG can convert cheap, readily available near-infrared (near-IR) wavelengths to the more expensively produced and more challenging mid-infrared (mid-IR) wavelengths. One such highly nonlinear material, thin-film lithium niobate (TFLN), has emerged in recent years as a favorable candidate for producing DFG. However, due to its strict phase matching requirement, it has struggled to be implemented for on-chip broadband DFG use in producing mid-infrared wavelengths. Through the technique of periodic poling, where the crystal axis of TFLN is periodically reversed, the quasi-phase-matching condition (QPM) can be satisfied. We used Ansys Lumerical's MODE software to model nanophotonic periodically-poled LN (PPLN) waveguides, revealing an optimal poling period of 4.56 microns to produce broadband DFG. With the phase matching condition met, nanophotonic PPLN waveguides can be fabricated and implemented on-chip to create broadband mid-IR frequency combs.

Studying Electromagnetic Transients From Stellar Collisions in Dense Star Clusters
Riya Shrivastava
Mentors: Kyle Kremer and James Fuller

For massive stars, the dynamical interactions facilitated by the high densities in dense star cluster cores can lead to large numbers of stellar collisions and unique stellar evolution pathways not possible for stars evolving in isolation. One example is the formation of massive stars that undergo (pulsational) pair-instability supernovae, a process that is expected to have key implications upon the highly uncertain mass spectrum of black holes, yielding a prominent "gap" in black hole mass between roughly 40 and 120 solar masses for black holes formed through single star evolution. This has key implications for the massive black holes detected as gravitational wave sources by LIGO. Recent studies have shown that dynamically-mediated massive star collisions that occur within the first few Myr of a young star cluster may lead to the formation of massive stars that are able to circumvent the pair-instability process, potentially allowing creation of black holes within the proposed upper mass gap. Here we create hundreds of N-body cluster models that cover a wide range of star cluster properties to study the effects of stellar collisions/mergers on pair-instability supernovae and black hole formation. Furthermore, we study how various cluster properties, such as metallicity, affect these processes. We also examine the potential electromagnetic transients, such as pair instability supernovae, and make predictions for the rates of these transients in the local universe and how these rates depend on cluster properties. Doing so, we will advance our theoretical understanding of the various pathways through which intermediate and massive stellar black holes may form in dense star clusters.

Magnetic Materials and Magnetic Fields in Nanoscale Field Emitters
Kaushal Shyamsundar
Mentors: Axel Scherer and Changsoon Choi

In recent years Nanoscale Field Emitters have begun to emerge as a viable alternative to the CMOS technology that has dominated the electronics industry for the past 60 years. However, there are still many challenges that this new technology faces. Chief among which is finding low work function materials for the emitters and collectors of these devices. In this report we will investigate the use of magnetic materials such as Praseodymium to lower the work function of these filed emitters and allow them to become active at lower voltages. We will also take this opportunity to theoretically explore the general effects of magnetic fields in field emitters. First, we shall examine whether a magnetic field parallel to the electric field can be used to focus the field emitter's electron beam. Next, we will discuss how the addition of a magnetic field could bend the electron beam of the field emitter causing radiation to be emitted. Finally, we will conclude with a design proposal for a field emitter that could realize this radiation emission as the first step towards a nanoscale free-electron laser.

Simulations of Multiband Imager Design Choices to Optimize its Application to Studying Exoplanet Atmospheres
Uzair Tahamid Siam
Mentors: Dimitri Mawet and Ashley Baker

Studying exoplanet atmospheres give us insight into the composition of exoplanets as well as habitability. Existing multi-object spectrographs are commonly used for medium-resolution transit spectroscopy observations; however, these instruments are not optimally efficient and often are affected by instrument systematics that are difficult to calibrate out of the data. HIRAX is an upcoming instrument for Palomar that can image a star in multiple high throughput narrow bandpasses achieving R~2000, making it ideal for atmospheric characterization of exoplanets. In this talk, I will describe work simulating HIRAX observations to understand the optimal choice of the instrument's 5 bandpasses, including their center wavelengths and bandwidths in order to detect sodium in transiting hot Jupiter atmospheres. I will present signal-to-noise ratio calculations describing the expected sodium detection achievable for host stars of varying magnitudes for the various bandpass configurations as well as estimations of the number of confirmed exoplanets that could be characterized for each configuration. Finally, I will show the effects of Doppler shifts on the exoplanet spectrum with respect to the static HIRAX bands due to various system velocities and how the band placements overlap with characteristic features of the Earth's atmosphere.

High Precision Line-by-Line Radial Velocity Analysis
Jared Siegel
Mentor: Andrew Howard

As the catalog of confirmed exoplanets grows, Earth-size planets around Sun-like stars have proven relatively common. With the potential for Earth-size planets to harbor deep oceans or thick atmospheres, constraining the masses of these planets is vital to our understanding of Earth-like worlds. High precision radial velocity surveys, which characterize exoplanets through the wobbles they induce on their host stars, are thus in high demand. However, the doppler shift induced by an Earth-like planet orbiting a Sun-like star at 1 AU is only 9 cm/s, while magnetic activity on the stellar surface can produce noise at the m/s level. Here, we implement a recently proposed technique for measuring radial velocities, which considers the doppler shift of each spectral line independently. Since each line responds differently to stellar magnetic activity, this method has the potential to significantly reduce the effects of stellar noise. We develop a model to suppress stellar noise by selecting populations of active and inactive lines, based on their correlations with activity indicators. In the case of αCenB, we successfully reduce the radial velocity scatter from 3.3 m/s to 1.7 m/s. Line-by-line radial velocity measurements thus present an exciting pathway to achieving high precision radial velocity measurements.

Understanding the Photochemistry of Ni(II)-Based Cross-Coupling Catalysts
Breno Silva
Mentors: Ryan Hadt and David Cagan

Transition metal catalysts are widely use in cross-coupling reactions to construct new bonds necessary for the syntheses of pharmaceuticals and more. Recent discoveries have highlighted the application of photoexcitation to these reactions, allowing for new, sustainable pathways in bond formation. Nickel complexes can access a wide range of formal oxidation states and have been identified as photoredox transition metal catalysts. However, excited-state cross-coupling catalysis remains an underdeveloped area and understanding the chemistry behind these mechanisms poses a challenge in the field. Here, we report the characterization of a series of structurally and electronically tunable photoactive Ni(II)-complexes viable for such reactions. The purity of these compounds was confirmed by proton nuclear magnetic resonance (^{1}H-NMR) spectroscopy, and their photochemistry was then studied via cyclic voltammetry (CV), electronic absorption, and optical transient absorption spectroscopies. Given the broad scope of tunability, we have discovered trends in excited state and photochemical properties that guide mechanistic interpretations and future synthetic applications.

Recovering the Legacy of the Schuster Siblings and Arthur Schuster's International Science Efforts in 19th-Century Siam
Jay Siri
Mentor: Dehn Gilmore

The late nineteenth- and early twentieth-century marked a time of remarkable change for Britain, both technologically and politically. In the midst of this change lay the Schusters—four siblings who pushed the frontiers in their respective fields of law, science, politics, and philanthropy. This project aims to recover the fading legacy of the Schuster siblings by examining articles from the British Library Newspapers database, and to ultimately retell the story of their influence across Britain and the world.

Particular focus was placed on Sir Arthur Schuster's 1875 solar eclipse expedition to Siam, as it marked the first time a prismatic camera was used to observe an eclipse, as well as the first time the developing nation of Siam had initiated collaboration with the West on such a project. Details about the expedition were gathered from Arthur's scientific papers, his personal diary entries, database newspaper articles, and other secondary sources to create an annotated bibliography on the topic. Understanding Arthur's international science efforts are perhaps crucial to understanding the history of international scientific collaboration as a whole, and this particular collaboration provides insight into how the British Empire contributed to Siam's 19th-century modernization, despite the country's resistance to European imperialism.

Solving the Mystery of Life on Mars Using Sulfuric Isotopic Fractionation
Kayla Smith
Mentors: Yuk L. Yung and Danica Adams

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 were made from analyses of Mars rock aged 1.3 Ga (billion years ago). Similar abiotic processes may have happened at Mars, including SO_2 photolysis and thermochemical sulfate reduction. We develop an S-isotope budget model to determine if abiotic processes alone are (un)able to explain the measured fractionation, which will help us infer if there may have been microbial life at early Mars. We are working to apply these isotopes to a one-dimensional photochemical and transport model. We gain insight of early Mars's atmospheric chemistry by applying our understanding of sulfur chemistry and MIF at Venus and Earth respectively. We first adapt an existing Venus photochemical model to reproduce a published Mars model of H-N-O-C chemistry, which required careful examination and modification of the chemical network, radiation field, and planet-specific parameters. Furthermore, in continuation of this project, we hope to fully describe atmospheric S_MIF caused by this SO_2 photolysis, as well as sulfuric acid and polysulfur aerosols.

Semi-Supervised Learning Algorithms on Graphs
Saraswati Soedarmadji
Mentors: Elizabeth Qian and Bamdad Hosseini

Graph-based semi-supervised learning (SSL) is the problem of assigning labels to unlabeled data based on a small subset of labeled data points. In many real-world applications it is possible to obtain large amounts of unlabeled data, such as text and images on the Internet. However, obtaining labeled data is expensive, as labeling data points are very difficult and labor intensive. Thus, SSL algorithms have become very popular in recent years as they promise to minimize the required number of labeled data points. In this project, we implement and expand a recently developed graph-based SSL method called the probit method for binary SSL on graphs. Previous work on this method focused on theoretical analysis in the limit where the labeled data was accurate and the underlying labeled data was well-clustered. Here we test the probit method on various synthetic and realistic data sets that are far from these limiting settings and study its performance, accuracy, and robustness.

Coiling Stresses, Warping, Hygroscopic, and Thermal Mismatch in the Space Solar Power Project Structure
Leah Soldner
Mentors: Sergio Pellegrino and Eleftherios E. Gdoutos

The ability to collect solar power in space and transmit the energy wirelessly back to Earth allows for an uninterrupted source of power unaffected by location, weather, or time of day. The lightweight space solar power (SSP) system proposed by Caltech in 2016 includes ultralight deployable structures that support functional elements converting sunlight into DC power and radiating that power through microwaves. During structure prototype coiling demonstrations, unexpected warping and buckling were observed and attributed to thermal and hygroscopic mismatch between the Kapton (functional element surrogate) and the deployable structure. Previous studies have shown that certain Kirigami cut patterns in sheets can significantly reduce stiffness. Such Kirigami cut patterns were implemented in Kapton coupons attached to structural frames and an experimental setup was used to investigate the buckling of the structure as a function of humidity. The experimental setup included a humidity-controlled chamber and Digital Image Correlation (DIC) was used to quantitatively measure the structural deformation for different cut patterns. A pattern of major and minor Kirigami cuts was found to introduce sufficient compliance in the Kapton to mitigate warping. Further humidity chamber experiments were conducted to identify a cut pattern that can be implemented into the SSP deployable structure.

Startups Raising Capital Without Public Disclosures
Nina Solovyeva
Mentor: Michael Ewens

In the recent decades, there has been a shift in focus from public to private firms. Although private firms have gained importance, there still exists a lack of data on them. Part of this project is to build a public, free non-commercial use database of private capital markets, firms and investors to fill this gap. Specifically, we are focused on private firms with no associated Form D filings. It is important to consider these non-filers in order to include those firms raising money from individuals, angel investors or non-traditional financial intermediaries. We collected data through web scraping Venture Capital news sites to obtain startup financing data (company name, date, amount raised). We then classified each of the found companies as filers or non-filers by cross-referencing the name with the NASAA database. The initial data showed that filers tend to raise more capital than non-filers. We want to analyze more data to notice other differences between filers and non-filers and how they change over time. The acquired data and analysis can also be applied to building a model which predicts whether a company filed a Form D or not.

Design and Fabrication of an Alternating Current Calorimeter for Specific Heat Measurements in Diamond Anvil Cells
Yunxiang (Tony) Song
Mentors: Thomas Rosenbaum, Daniel Silevitch, Alex Wertheim, and Stephen Armstrong

When quantum systems are cooled to near absolute-zero, the tuning of the order parameter permits some materials to approach and cross a quantum critical regime. We aim to extend the experimental techniques used to study such quantum phase transitions, focusing on the case where the tunable order parameter is hydrostatic pressure suppled by a diamond anvil cell (DAC). Continuous quantum phase transitions involve a divergence in the specific heat as the quantum critical point is crossed. It is particularly challenging to measure the specific heat inside a DAC, given the dimensional constraints and fluid-filled environment. To meet these challenges, we designed a seven-layer alternating current calorimeter 400 microns in diameter and 50 microns in thickness, with the active elements placed on top of a 50 nm thick membrane. We then used nanofabrication techniques (photolithography and deposition) to realize this calorimeter, taking two separate approaches. We first tried to fabricate directly on transmission electron microscope grid chips (three millimeter diameter and 50 microns thickness) with prefabricated, suspended silicon nitride membranes; we then tried to fabricate on square silicon substrates (one centimeter side length and 500 microns thickness) with additional substrate thinning and membrane release protocols. While the fabrication is in progress, the successful realization of these calorimeters would enable the characterization of novel systems whose pressure-temperature phase diagrams remain unknown.

Implementing the Largest Exceptional Point on a Dissipative, Time-Multiplexed Photonic Resonator Network
Anna M. Soper
Mentors: Alireza Marandi and Christian Leefmans

Exceptional points are spectral singularities in non-Hermitian systems. At an nth order exceptional point, n eigenvectors and eigenvalues become degenerate, and the eigenvalues respond to perturbations with an nth root dependence on the perturbed parameter. The high sensitivity of eigenvalues to small perturbations makes higher order exceptional points potentially useful for sensing applications. Here, we use a time-multiplexed photonic resonator network to realize and measure a 63^{rd} order exceptional point. Although implementing the Hamiltonian for a 63^{rd} order exceptional point is relatively straightforward, measuring its order is very difficult due to the inherent uncertainties in the system. We are implementing two methods for measuring the order of the exceptional point. The first is to directly measure the eigenvalues of the system as a perturbed parameter is varied through the exceptional point. The second is to encircle the exceptional point in parameter space and measuring the topology of the energy eigen surface. Our optical network provides a scalable platform for realizing higher order EPs and will enable us to implement the highest order EP that has ever been measured on an optical system.

Microscopy-Based Live Cell Perturbation Screens Using dCas9-Mediated Genetic Knockdowns and Spatial Barcodes
Johnathon Soro
Mentors: David Van Valen, Morgan Schwartz, and Edward Pao

The function of a gene is often revealed by perturbing its expression in cells and observing the phenotypic response. Traditionally, each gene must be tested in isolation which limits the number of targets that can be investigated. Single cell sequencing allows for identification of a single perturbation in a pool of perturbations, but it excludes the analysis of many phenotypes, including live-cell dynamics. In contrast, microscopy allows for analysis of live-cell dynamics but cannot identify which perturbation a cell received. Unique visual patterns, called spatial barcodes, can be made using gRNAs and dCas9 to fluorescently label repetitive sequences of DNA. These barcode gRNAs can be paired with dCas9-mediated knockdowns to visually identify which perturbation a cell received. I have identified a set of 10 gRNAs with can barcode a pool of over 5000 perturbations. Distinguishing different spatial barcodes requires training of a deep learning model, so I have worked on collecting data to train and test the model. To increase the speed and accuracy of plasmid assembly, I optimized our assembly protocol and programmed a robot to automate the process. Future work includes validating dCas9 barcodes and knockdown function in live cells and completing small-scale pooled genetic perturbation experiments.

Development of an Acoustic 96-Well Plate Reader
Mohamed Soufi
Mentor: Mikhail Shapiro

Abstract withheld from publication at mentor's request.

Quantum Simulation of an Open Fermionic System
Emily Springer
Mentors: Austin Minnich and Hirsh Kamakari

Quantum computation allows for efficient simulation of quantum mechanics. One important problem of quantum simulation is finding the ground state of a system. A quantum imaginary time evolution (QITE) algorithm proves to be effective for such a purpose. We apply the QITE algorithm on a noisy intermediate-scale quantum (NISQ) device for an open fermionic system to determine the ground state of that Hamiltonian. As imaginary time goes to infinity, the system converges to the ground state. For complicated Hamiltonians, finding the ground state using classical computers is computationally hard, so a more efficient algorithm, such as QITE, is useful. Successful implementation of a quantum simulation algorithm could have groundbreaking advances in quantum chemistry.

CVD Growth of Monolayer Transition Metal Dichalcogenides
Vishvesha Sridhar
Mentors: Nai-Chang Yeh and Daniel Anderson

Monolayer transition metal dichalcogenides (TMDs) are materials of great interest due to their unique optical and electronic properties. Due to the breaking of inversion symmetry and spin-orbit coupling inequivalent valleys arise at K and K', providing an extra degree of freedom for charge carriers and allowing the two valleys to be addressed using circularly polarized light. However, it is difficult to synthesize large TMD monolayers. We present procedures of synthesizing two TMDs, MoS_2 and WS_2 using the chemical vapor deposition (CVD) method. We performed two sets of trials, one using silicon substrates and the other using glass as a substrate for growth. Raman spectroscopy is used to characterize the samples as monolayer or multilayer. Future work will include performing more detailed characterizations of the samples using X-ray photoelectron spectroscopy and energy dispersive X-ray analysis. Additionally, these CVD techniques could be used to synthesize magnetically doped TMDs.

Assessing the Accuracy of Two-Photon Lithography Nanofabrication for Photonics Devices
Irina Malina Strugaru
Mentors: Andrei Faraon and Gregory Roberts

Photonics devices that operate in the infrared and visible domains present a huge potential for fields such as photography, optical communications, and bioimaging. To be functional, however, these structures require subwavelength features, with dimensions around 500 nm for infrared and 150 nm for visible wavelengths, making it difficult to anticipate the accuracy of their fabrication. In this sense, we studied the characteristics and limitations of the two-photon lithography method for devices that operate in mid-infrared, and how various imaging techniques can be used in this analysis. The test patterns were 3D-printed using the Nanoscribe direct laser writing, and then observed with scanning electron microscopy to determine their dimensions and feature-shapes. Although no major defects were identified, a slight shrinkage of the features was noticed and will be further assessed. As ways to analyze how the inner layers of the structures develop, we compared the focused ion beam system and a series of fluorescent confocal microscopy methods. The confocal microscopy proved more advantageous for the test structures, and, in future experiments, the imaging resolution can be further improved with the addition of fluorescent dyes. Therefore, our study presents useful observations for imaging and evaluating 3D printed nanostructures.

Utilizing Correlation Functions to Develop a Multistate Model of *P. denitrificans* F_1-ATPase and Enhance Single-Molecule Imaging Resolution
Nathan Suiter
Mentors: Sandor Volkán-Kacsó and Rudolph A. Marcus

F_1-ATPase enzyme is a biological motor which hydrolyzes ATP. The enzyme has been observed via single-molecule imaging experiments wherein the enzyme is allowed to rotate freely while being recorded using a gold nanoparticle. During hydrolysis, the enzyme causes Brownian noise when rotating to new chemical states because of a size difference between the 4 nm enzyme and 40 nm probe. The unconvoluted rotary movement has been revealed using techniques including rotational correction, correlation functions, and comparison of average rotational jumps which contribute to developing a multistate model.

Within *P. denitrificans* F_1, the timestep used in experimentation is limited to 100 μs. After correction for tilting, a method for evaluating all three subunits uniformly was implemented in further evaluations. Using corrected data, the torsional spring constant of the rotary shaft was found to be near 50 pN nM. Implementation of the time correlation function which was proven to be stationary yielded a viscoelastic relaxation time around unity. The relaxation time provides a method for calculating a diffusion coefficient to develop a multistate model and elucidate hidden kinetic states of the functioning enzyme.

Augmentation of Skills Assessment Deep Learning Networks in Robot-Assisted Surgery With a Spatial Attention Network
Idris Sunmola
Mentor: Anima Anandkumar

With current interest in the minimally invasive surgery paradigm, there has been palpable interest in the nascent field of machine learning in robot-assisted surgery. Consequently, several attempts have been made to train neural networks that extract intelligible data from robotically controlled surgical procedures.

These attempts have focused on single data points (e.g. action recognition or surgical skills assessment), and have barely reached model training thresholds adequate enough to be deemed useful in the high-stakes surgical domain.

In this paper, we propose a neural network training regime that accounts for both surgical action recognition and surgeon skills assessment while also training above prior validation accuracy benchmarks. More specifically, we use an attention mechanism that mimics the visual perception attention mechanism humans use to solve domain specific tasks.

To incorporate an attention mechanism in the action recognition and skills assessment processes, our attention implementation simultaneously recognizes three information benchmarks: the visual information in each frame, knowledge of the ongoing task(s), and the spatial attention in previous frames. Our implementation resulted in a 10 percentage point average increase in top-1 validation accuracy of all surgical action recognition and skills assessment tasks.

High Speed Obstacle Avoidance With Quadcopters
Aiden Swann
Mentors: Aaron Ames and Andrew Singletary

Small quadcopters are an extremely agile test bed for collision avoidance and planning algorithms. We design a 7′′ quadcopter which can achieve speeds of 60 MPH and accelerate at 4gs in any direction. For control, we utilize an existing consumer flight controller. We wrap our collision avoidance system around this controller, which significantly simplifies our control model. We seek to use barrier functions to provide collision avoidance while a human flies the drone. Our autonomy will act as a supervisor, guaranteeing safety while the quadcopter is teleoperated. We will create a simplified racing environment in which the human is in control, but our collision avoidance keeps the quadcopter within a tube around the track. Next, we will apply our collision avoidance to moving objects. We will attempt to dodge objects thrown at the drone while a human operator completes a flight objective.

Deep Learning Aortic Valve Plane Localization
Brea Swartwood
Mentors: Albert Hsiao, Evan Masutani, and Melissa Hovik

Cardiac MRI is an essential technique for the clinical evaluation of the heart but requires skilled technologists to locate anatomical features to generate standard imaging planes. To aid the localization of valve planes in magnetic resonance imaging (MRI), we investigated the potential of convolutional neural networks (CNNs) to identify the aortic valve plane on three-chamber views of the heart. 3540 three-chamber cardiac MR images were obtained and manually labeled with the position and orientation of the aortic and mitral valves. U-Net CNNs were trained with heatmap regression to either localize (a) two points defining the aortic valve plane or (b) six points including those from (a), the aortic valve centroid, and three additional points along the mitral valve. The relative effectiveness of each strategy was evaluated by assessing mean landmark localization error. Preliminary results indicate that the six-point strategy is more effective for localizing the aortic valve plane, suggesting that the CNN training may benefit from concurrent tasks.

Improved Activity of Earth-Abundant MnSbOx Catalysts via Chemical Vapor Deposition for Water-Splitting
Madeleine C. Swint
Mentors: Nathan S. Lewis, Jacqueline A. Dowling, and Zachary P. Ifkovits

Through the coupled hydrogen (HER) and oxygen (OER) evolution reactions, carbon-free hydrogen fuel can be produced via electrolysis for long-duration energy storage. For the kinetically sluggish OER, the best catalysts are composed of iridium, a rare noble metal, whereas more earth-abundant materials would allow for electrolyzer scalability. Sputtered manganese antimony oxide (MnSbOx) catalysts have been utilized for acid-stable OER but have suffered from low activity (η = 735 mV at 10 mA/cm^2 for 168 hours). Herein, controlled chemical vapor deposition was employed as an alternate method to synthesize and investigate the activity-stability relationship of various MnSbOx catalysts. Of these, several were found to outperform the sputtered catalysts by over 150mV for 240 hours of operation at 10 mA/cm^2. Active and long-lived MnSbOx catalysts were developed, demonstrating potential for more scalable industrial use, which can assist in the transition to a carbon-free energy system.

Calculating Age Constraints for Glacial Units on Mars
Riley Tam
Mentors: James Dickson and Bethany Ehlmann

Geomorphological and geophysical evidence on Mars suggest that during periods of its history, water-ice was stable on the surface in the mid-latitudes, which it currently is not. This history can be reconstructed by performing Global Climate Model simulations under orbital configurations required for mid-latitude glaciation and compare those massive ice accumulation predictions with the mapped distribution of ice-related landforms. These reconstructions require absolute age dating to fully describe Mars' climate history. Surface ages for geologic units of known area can be estimated remotely by binning craters that have accumulated on them by diameter. To create a timeline for historical glaciation, we have mapped more than 14,000 impact craters over 220 glacial units in the Eastern Hellas region, located in the southern mid-latitudes. This project calculates age constraints for debris covered glaciers by integrating crater counts with isochrons derived from the lunar cratering record, adjusted for atmosphere and gravity. By dividing craters into morphological categories of fresh, degraded, and filled, we gain specificity to the overall timeline of events following crater emplacement that have occurred in this region. We will present a new estimate for glacial cessation age and an absolute timeline for when Mars was capable of mid-latitude glaciation.

Determining the Predictive Power of Pre-IPO Signals for Post-Public Stock Returns
Lance Tan
Mentor: Michael Ewens

The current method of trading sees many inefficiencies, specifically the lack of information about a company's financial history, ownership structure, investment decisions, and previous investors. Such information may be crucial for investors towards decisions to purchasing securities. Therefore, this project investigates alternative forms of data, which can help bridge the gap between investor's queries and knowledge about pre-IPO stock returns.

The first step is to gather varied sources such as registration statements (ie. S-1 filings with the Securities and Exchange Commission) published within a week before & after the IPO. The second step is to examine these financials and data from past IPOs, specifically how those companies performed before and after going public. The third step is to analyze which pre-IPO text variables from the S-1 filings hold predictive power. Such variables may include tone, sentiment, complexity, as well as frequency of certain keywords. Finally, an unsupervised machine learning algorithm will be developed to estimate post-public stock performance (specifically, stock price). So far, data has been collected on tone and sentiment (more to come), and analysis on the correlation between such variables and stock returns will be performed in the final upcoming weeks.

Ultrasound-Activated Drug Delivery in the GI Tract Using Gas Vesicles
Anna Tifrea
Mentor: Mikhail Shapiro

Abstract withheld from publication at mentor's request.

Vortex Fiber Nulling for Exoplanet Characterization and Observation
Katie Toman
Mentors: Dimitri Mawet and Dan Echeverri

A new interferometric method for characterizing exoplanets at small angular separations from their host star is an improvement over current methods via the vortex fiber nulling (VFN) technique. This method is particularly worthwhile because it allows exoplanet characterization at or within the theoretical diffraction limit of telescopes, a factor 2-3 times better than conventional coronagraphic techniques. By using this method, light from the host star can be differentiated from the planet, allowing characterization of the exoplanet atmospheric composition. The distinction of molecules in the exoplanet spectrum will provide significant data resources for the composition of exoplanets and ultimately biosignatures in Earth-like exoplanets. To find out what types of star-planet systems will be best detected using the VFN mode of the Keck Planet Imager and Characterizer (KPIC), simulations using authentic star and instrument parameters have been completed. The output of these simulations are sensitivity grids overlaid with mass v separation plots, showing how sensitive KPIC VFN is for a given star that has a companion with *x* mass and *y* separation. Filtering through these targets, the finalized target list will be optimized for the instrument's first on-sky observations in early 2022.

Developing a Dual-Tag Mass Spectrometry Technique to Examine Directional Protein Trafficking Between the Mitochondria and Nucleus
Haruna Tomono
Mentors: Tsui-Fen Chou and William Rosencrans

Organelle proteomes have often been characterized in isolation. However, contemporary research has described inter-organelle communication as an ever-present and necessary component of cellular physiology. Regulation of these protein pathways allows for maintenance of proteostasis and disruption can cause disease. Mitochondrial interactomes are of particular interest due to the mitochondria's involvement in energy production, apoptosis, and biochemical synthesis. Mitochondrial processes must be tightly coordinated between the nuclear genome and endemic mitochondrial DNA. To probe protein movement involved in mito-nuclear communication, proximity-dependent assays are conducted using biomolecules bound to proteins of interest. In this project, we aim to use BioID, a promiscuously active biotin ligase, fused to TIM29 to biotinylate proteins within a ~10 nm radius in the mitochondria and APEX2, an ascorbate peroxidase, localized to the nucleus to bind fluorescein isothiocyanate (FITC) to proteins within a ~15 nm radius in the nucleus. Proteins tagged with both biotin and FITC represent those moving from the mitochondria to the nucleus and will be analyzed using two immunoprecipitation assays and mass spectrometry. After proving this dual-tag mass spectrometry method, we can then apply it to other organelles such as the understudied peroxisome to increase understanding of its interactomes.

Modeling the "Bleed and Feed" Method of Nuclear Reactor Core Cooling
Gwendolyn Tsai
Mentors: Joseph Shepherd and Branson Davis

After losing power during the earthquake and tsunami in March 2011, the Fukushima Daiichi nuclear power plant attempted to prevent meltdown using a method referred to as "bleed and feed". This involves depressurizing the reactor's cooling system and feeding in water from an external source such as a pump or fire truck. This reactor was modeled using MATLAB and Cantera to gain a greater understanding of "bleed and feed" and to speculate on the viability of such an approach in the future. The Reactor Pressure Vessel (RPV) was modeled as a volume with an outlet that carries compressible and multiphase flow. The area and logic of the outlet was parameterized to model both the Safety Relief Valves (SRVs) and the Automatic Depressurization System (ADS). Additional considerations in the model were pump performance, fire hose head loss, and reactor decay heat. Following the events at Fukushima Daiichi, the U.S. Nuclear Regulatory Commission sought out more robust risk assessment and risk management capabilities for domestic reactors. The "bleed and feed" method has been a proposed approach for analogous situations in the future. Evaluating the viability of this approach will allow for more informed risk management.

Non-Venture Capital Backed Startups
Gabriella Twombly
Mentor: Michael Ewens

Historically, there is a gap in the data about non-venture capital backed companies versus companies and financing by traditional forms of investment. We are interested in documenting the financial landscape of non-VC backed startups in the US starting from the early 2000s including those backed by business angels, crowdfunding, accelerators, incubators, bank loans, and bootstrapping. Specifically interested in the extent of non-VC financing of high-growth startups in the US and the most productive means to systematically collect data on these difficult to observe events. We summarized academic literature on the topic, collected data on Form D's and government sites, scraped for sources of non-venture capital financing, and merged this data with previous information we already held. We are performing economic analysis on the data for further results and in order to connect it with other financial sources.

A Highly Sensitive Electrochemical Sensor for Simultaneous Multiplexed Detection of Purine Metabolites in Sweat
Chibuike Uwakwe
Mentors: Wei Gao and Yiran (Isabella) Yang

The concentration of purine metabolites, including hypoxanthine (HX), xanthine (XA), and uric acid (UA), in biofluids supplies key information regarding one's risk for perinatal asphyxia, renal failure, and gout. Noninvasively targeting these biomarkers in sweat with electrochemical sensors enables instantaneous and continuous health monitoring. The present study exploits the purine metabolism pathway, which involves the transformation of HX to XA and subsequently to UA via successive oxidation, to electrochemically determine the concentrations of these biomarkers in sweat. We fabricate the sensor using CO_2 laser-engraved graphene (LEG) electrodes as well as inkjet screen-printed carbon electrodes and test the sensor using cyclic voltammetry (CV) and differential pulse voltammetry (DPV). Modifying the sensor with cobalt-doped ceria nanoparticles (Co-CeO_2 NPs) augments its sensitivity for HX, XA, and UA. We examine the sensor's selectivity for HX, XA, and UA in the presence of tryptophan and tyrosine interference. We use scanning electron microscopy (SEM) to characterize the surface of the modified electrodes. The Co-CeO_2 NP modified LEG electrodes demonstrate promising simultaneous detection of HX, XA, and UA in 0.1 M PBS over the concentration range of 0.1–50 μM. We additionally evaluate the sensor's ability to reliably detect HX, XA, and UA simultaneously in sweat.

Using NED to Locate Host Galaxies of Gravitational Wave Events
Jynessa Valladon
Mentors: George Helou and David Cook

The recent breakthroughs in detecting gravitational waves (GWs), ripples in the fabric of space-time, have allowed for direct observations of the mergers of extreme objects. Efforts to narrow down the possible hosts of GWs observed by the laser interferometer gravitational wave observatory (LIGO) are difficult due to their large localizations. The NASA/IPAC Extragalactic Database (NED) can be used to search galaxies for GW counterparts in a prioritized order based on galaxy properties. In order to use NED effectively, we must examine possible inconsistencies in the data, which are revealed by abnormal features in the distributions of galaxies. My role is to investigate two potential inconsistencies impacting the order of prioritized galaxies: incorrect distances and galaxy type assumptions. After visually inspecting 3,000 objects in the abnormal spikes of a redshift histogram and the area with discrepant values on a star formation rate comparison graph, I uncovered that the spikes contained many faint/small objects at the same quantized redshift, and galaxies with discrepant values were early-type galaxies, whose physical properties are difficult to derive. The subsequent goal of this project is to repair both inconsistencies, thus providing robust data when searching for hosts of GW events.

Tracking Stress Hormone Dynamics in Sweat Using Wearable Graphene-Based Wireless Health System
Rohan Vemu
Mentors: Wei Gao and Jiaobing Tu

The CDC has reported an all-decade low in life expectancy due to stress-related causes, and the World Health Organization has classified "stress" as the health epidemic of the 21st century. Current methods of stress quantification, whether qualitative or quantitative, such as questionnaires or blood draws, are invasive and subjective. We investigate novel methods of stress hormone quantification via wearable laser-engraved graphene electrodes functionalized for detection of noradrenaline and cortisol in sweat. The system leverages immunosensing and electrochemistry to detect stress hormones at nanomolar detection limits. We focus on measuring sweat samples before and after the introduction of a stressor and have reliably shown a spike in noradrenaline and cortisol levels, consistent with expected biological response. The cortisol and noradrenaline sensors are currently separate, but ongoing work is focused on creating a multiplex wearable sensor able to detect both stress hormones at once. Additionally, the sensors will be integrated with existing Bluetooth modules and microcontrollers to create a minimally invasive wearable, point of care device with over 5 hours of continuous use.

Creation of the Keck Planet Imager and Characterizer (KPIC) Calibration Databases and KPIC Calibration Data Analysis
Taylor Venenciano
Mentor: Dimitri Mawet

By directly imaging exoplanets and obtaining their atmospheric spectra, the Keck Planet Imager and Characterizer (KPIC) at Mauna Kea enables the detection of molecules and the measurement of relative abundances in exoplanets' atmospheres, as well as makes measurements to determine exoplanets' radial velocities due to orbital motion, spin rates, and atmospheric properties. Within KPIC, the Fiber Injection Unit (FIU) uses a single mode fiber to feed the light of astrophysical sources of interest to the Keck/NIRSPEC spectrograph. The user must process this raw data using calibration data files to produce spectra that can be further analyzed for molecular compositions.

I developed a database that enhances the capabilities of the KPIC data reduction pipeline by organizing the storage of its calibration data files. This calibration database is user-friendly and fast. It enables a user to automatically manage and save their files and recommends a list of calibration files when the user reduces data. In addition, I analyzed how the calibrations change over time and under different conditions to aid in re-optimizing the current observing strategy.

I. Development of a Genetically Encoded Small Protein Tag for Live-Cell Imaging With Stimulated Raman Scattering Microscopy; II. Hydrogen-Deuterium Exchange in Proteins Monitored by Raman Spectroscopy
Amy Vo
Mentors: Lu Wei and Kun Miao

I. Although genetically encoded probes such as green fluorescent protein (GFP) have become ubiquitous tools for cellular biology, no such probe yet exists for use with Raman imaging. We seek to engineer a small protein consisting of amino acid homorepeats as the probe, which can be labelled with the corresponding deuterated amino acid, then imaged via stimulated Raman scattering (SRS) microscopy. Because amino acid homorepeats are structurally disordered, we performed directed evolution with a circularly permuted GFP (cpGFP) folding reporter to improve protein folding and minimize aggregation. If successful, our project will produce a genetically encoded Raman tag complementary to GFP.

II. Hydrogen-deuterium exchange (HDX) occurs in both the amide backbone of proteins and in alkynes. In amides, HDX is traditionally measured by MS or NMR and used to measure the solvent accessibility of different portions of the protein backbone. We instead use Raman spectroscopy, a vibrational spectroscopy technique, to measure amide HDX rates to probe the local environment of proteins in cells. In addition, to study the structure of the protein, we monitor HDX of alkynes incorporated as noncanonical amino acids at specific sites in the protein.

Continuous Authentication in Mobile Devices
Alexis Wang (Caltech) and Leila Sor (Bucknell University)
Mentors: Kiran Balagani and Adam Wierman

Continuous authentication in smartphones utilizes biometric recognition systems to verify a user's identity. The attempted user's biometric data is collected and compared with the user's stored biometric data, being classified as either genuine or impostor depending on the matching algorithm. As regular security measures like PINs and passwords fail to be robust against fraudulent methods, there is a need for accurate and efficient smartphone biometric recognition systems. The hand movement, orientation, and gesture (HMOG) dataset introduces a new set of biometric features for verification, including a hundred users' biometric data. We focus on sessions that involve sitting and swiping to extract swipe features & accelerometer measurements and utilize the scaled Manhattan distance formula as the matching algorithm. Successful implementation of such a system allows us to experiment with different algorithms in minimizing the equal error rate (EER) and improve accuracy, with potential real-world application in mobile devices.

Myrmecophily and Inter-nest Migration
Angel Wang
Mentors: Joseph Parker and Thomas Naragon

While previous work in the Parker Lab suggests the beetle *Sceptobius lativentris* mimics the pheromone profile of its host ant *Liometopum occidentale* by physically transferring the chemicals from the surface of the ant to its own body to avoid aggression from the ant, it is still unknown how the beetle initially integrates into newly formed colonies of the host ant. In moving from an old colony to inhabit a new colony, *Sceptobius* will carry the CHC profile of the old nest and be recognized as an intruder in the new colony. This project utilizes the Caltech High Performance Computing Cluster, anTraX machine vision software, and a video-recorded behavioral arena to analyze the interplay of ant and beetle behavior when beetles and ants from different ant colonies are introduced to each other. Metrics such as overall ant activity, ant aggressiveness, and beetle choice of grooming partner will be used to determine what strategies, if any, the beetle uses when coming into contact with a new ant colony. Understanding the strategies used to move between colonies will provide insights into how social symbioses are maintained and arise in the first place.

Gene Silencing by RNA Interference in the Oribatid Mite, *Archegozetes longisetosus*
Alana Weiss
Mentors: Joseph Parker and Adrian Brückner

The clonal, all-female oribatid mite species *Archegozetes longisetosus* is a model species to study chelicerate biology, biosynthesis, chemical ecology and evolution. *Archegozetes* has been used by numerous laboratories for the past 30 years, and recently molecular resources and well-annotated genomic data have become available. In this project, we performed a genome-wide screening for RNA interference pathway genes and pioneered RNAi gene silencing in *Archegozetes*. Using *in silico* methods, we found that the mite possess all core RNAi pathway genes needed for double-stranded RNA (dsRNA) uptake (*Rsd-3*, *Eater*, *SR-CI*), processing and amplification of RNAs (*Dcr-1|2*, *loqs*, *RdRP*) and translation repression (*Ago-1*, *Vig-1*, *Tsn-1*). To determine whether RNAi knockdown could be used for the interrogation of gene function in *Archegozetes,* we synthesized dsRNA against *vacuolar-type ATPase subunit A* (*vATPase A*), a highly conserved eukaryotic gene which is highly expressed in all cell types. Injecting dsRNA into young, age-matched young adults we were able to effectively silence gene expression and achieve RNAi gene knockdown that persisted over 7 days. Overall, we show that the core RNAi machinery is present and successfully established a robust RNAi methodology for targeted gene silencing in *Archegozetes* which will allow studying genes of unknown functions.

Using Resolvent Analysis to Visualize Vortices in Incompressible Boundary Layer Flows
Tomás Wexler
Mentors: Beverley McKeon and Salvador Gomez

Turbulent flow over vehicles, add to the drag acting on that vehicle. Due to the friction from the surface, vortices and other structures form in the flow. By targeting the most energetic coherent structures in a flow, we can reduce drag acting on the surface. However, studying control strategies with Direct Numerical Simulations or experiments are costly and can take weeks to months to complete. Fortunately, there exists a reduced order model known as resolvent analysis, a linear model that uses the Navier-Stokes equations that can predict dynamically relevant structures. Using predicted structures as degrees of freedom, flow fields can be reconstructed in mere minutes. This project aims to apply resolvent analysis to turbulent boundary layer flow to analyze coherent structures in different regions of the flow. Applying different vortex identification methods allows us to visualize coherent structures in the flow. From these structures, we can learn many important characteristics of the structure, such as shape and length scale. Using calculated mean flow and these parameters as inputs to the resolvent, we can then model these same structures in the reconstructed field and compare with the previously identified structures and parameters from the original data.

Site Saturation Mutagenesis on N-Acetyl-Alpha-Glucosaminidase (NAGLU) to Develop an Enzyme Suitable for Enzyme Replacement Therapy for Treatment of Mucopolysaccharidosis Type III C
Leo Williams
Mentors: Tsui-Fen Chou and Kai-Wen Cheng

Mucopolysaccharidosis III (MPS III) is a rare genetic disease in which an enzyme in the pathway which breaks down heparan sulfate, a glycosaminoglycan, does not work, causing a build up of heparan sulfate in neurons. This causes severe neurological symptoms including dementia, hyperactivity, seizures, insomnia and loss of vision. Enzyme Replacement Therapy (ERT) is a common treatment for MPS III, however one type, MPS IIIC, is currently unable to be treated using ERT because the affected enzyme, HGSNAT, is a membrane protein. In my research, we attempt to use site saturation mutagenesis in order to create a mutant of the next protein in the pathway, NAGLU, which can break down the HGSNAT substrate. We chose 9 specific amino acids in the active pocket, used site saturation mutagenesis for each site, and utilized a 4-MU enzymatic assay to measure the enzymatic activity. While a treatment ready enzyme is not yet available, we have developed NAGLU analogs that have an increased affinity for breaking down the HGSNAT substrate and look to improve these enzymes in subsequent experiments.

The Synthesis and Property Characterization of ZnO via Hydrogel Enabled Additive Manufacturing
Zhiqin (Echo) Xu
Mentors: Julia R. Greer and Rebecca Gallivan

Three-dimensional (3D) architected metal oxides are a new class of material that presents desirable properties for manufacturing and technology. Despite their advantages, few methods have successfully produced structures with micron-scale resolution. To resolve this gap, our group has recently developed a highly adaptable fabrication technique that involves swelling metal salts into 3D printed hydrogels and calcinating the swelled samples leaving only metal oxides. The "swell in" method allows for the manufacture of materials with complex architected geometries and provides specific control of material microstructure via manipulation of calcination parameters. Using zinc oxide (ZnO), a common ceramic due to its tunable electrical conductivity and antibacterial properties, we identify roles of the molarity of zinc nitrate solution, calcination temperature, and burn profile in resulting porosity and structural integrity using scanning electron microscopy (SEM). Mechanical characterization of these materials is conducted through nanoindentation, and analysis of microstructural features is performed using Electron Backscatter Diffraction (EBSD). Our results demonstrate the susceptibility of material integrity and microstructure to processing parameters and deliver requisite information about material properties of this additively manufactured (AM) ZnO for future research and applications. Additionally, our report provides valuable reference and baseline for designing microstructure and architecture of other AM materials.

Genome Reduction of *Mimecitini* Rove Beetle Social Parasites
Isabell Yang
Mentors: Joseph Parker and Sheila Kitchen

Symbiosis is a universal phenomenon that ranges from facultative epibionts to obligate endosymbionts. As symbionts become reliant on their host, they tend to undergo genome reduction through both the loss of genes now carried out by the host genome, as well as the loss of non-coding regions through genetic drift. Rove beetles, one of the largest families of metazoans, have evolved social symbiosis with ants in multiple independent events. One tribe of interest, Mimecitini, are blind, obligate social parasites of neotropical *Labidus* army ants. Genome assemblies from four Mimecitini species revealed gradual genome erosion within the tribe, with nearly 50% reduction of genome sizes of two nest-integrated species of *Pseudomimeciton* compared to the average rove beetle genome size of 148±73 Mb. We found intron length and number are reduced genome-wide in Mimecitini relative to free-living rove beetles, indicating that genomic features are eroded as a consequence of being a parasite. Orthology-informed gene analyses further identified specific gene families (eg. Opsins) and metabolic pathways (eg. Arginine biosynthesis) that have been lost in the lineage, which reflects the unique lifestyles of these beetles that live deep within ant colonies. This study presents the first example of genomic losses underlying regressive traits of symbiotic beetles and parallels losses observed in other subterranean animals such as cave fish and naked mole rats.

Stray Light View of Accreting Atolls
Lynn Yang
Mentors: Fiona A. Harrison and Renee Ludlam

Due to the open geometry of the mast on Nuclear Spectroscopic Telescope Array (NuSTAR), we can observe and analyze the light from nearby X-ray sources that fall on the detectors of the telescope, known as stray light. The focus of this project is on the object, GX 9+9, which is an accreting atoll source, determined by the island-shaped region of the source on a hard-intensity diagram (HID). I can utilize the NuSTAR stray light observations of GX 9+9 to enhance our understanding of accretion and the properties of neutron stars (NSs). Observing the location of observations on the HID can determine the spectral state of GX 9+9 over time. The stray light data allows us to model the continuum spectra and reflection emission of the accreting system. The fitted models of the spectra give us the appropriate values to also calculate the radius constraints and the extent of the boundary layer between the accretion disk and the NS surface of GX 9+9.

Quantum Gravity in the Noisy Lab
Andrew Yates
Mentors: John Preskill and Sepehr Nezami

The holographic principle allows us to study toy quantum-mechanical models which correspond to quantum theories of gravity. One realization of holography is the AdS/CFT correspondence, which asserts that a gravitational theory in the bulk of anti-de Sitter space is equivalent to a conformal field theory on its boundary. Recent work by Nezami, et. al. demonstrates how certain toy quantum systems, dual to traversable wormholes under AdS/CFT, are simulable via quantum computers. This allows us to perform table-top experiments of quantum gravity in the lab (QGL). In this work, we study the practicality of such experiments in a noisy environment. We demonstrate the effects of noise on the teleportation protocol, showcase the noise resilience of certain models, and propose noise mitigation methods. We conclude with a perspective on the feasibility of QGL experiments on existing quantum computers.

Synthetic Methods for Non-Symmetric Phenazines
Kala Youngblood
Mentors: Sarah Reisman, Conner Farley, and Lexie Beard

Phenazines are a family of natural products that are implicated as key secondary metabolites in the fitness of antibiotic-resistant bacteria such as *Pseudomonas, Streptomyces*, and *Pantoea agglomerans*. Unnatural phenazines have generated interest as redox-active antibiotics against these strains. However, these studies are hindered by low yielding extractions and limited synthetic access to the core tricyclic framework. Furthermore, existing methods are largely limited to the synthesis of symmetric dimers. Here, we report progress toward the development of a Pd-catalyzed cross-coupling reaction to access unsymmetric phenazines. Additionally, structure diversifications through metal catalyzed C—H functionalization reactions are discussed. It is envisioned that these results could be applied to the first completed total syntheses of biologically important phenazines such as Endophenazine A and Endophenazine B.

Simulations for Optimization of HOMES
Ga Eun Yun
Mentor: Soon Jo Chung

The Habitat Orientable & Molecular Electrodynamic Shield (HOMES) is a lunar dust mitigation system utilizing Electrodynamic Shielding (EDS) technology. This project aimed to optimize the HOMES design for peak performance as well as verify HOMES against potential issues that could arise in space-like conditions. Simulations in COMSOL Multiphysics software were used to identify the optimal voltage, frequency, rise and fall times of frequency, materials, and size dimensions of HOMES. Furthermore, thermal, mechanical, and vibrational simulations were also conducted to verify HOMES against extreme temperatures, strong vibrations, and heavy loads. Proper optimization and verification using computer simulations could allow HOMES to be more efficiently designed and prototyped without the waste of resources.

NuSTAR Stray Light Analysis of GS 1826-24
Sol Bin (Hazel) Yun
Mentors: Fiona Harrison and 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 present a X-ray analysis of GS 1826-24, a low mass X-Ray binary (LMXB). 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. Through stray light, we were able to obtain multiple observations of the source both during its hard and soft state. We detected multiple X-Ray bursts during both states and made spectral fits to illustrate the difference between the two states. Further work would involve analysing the continuum spectrum and the X-ray bursts of the two states.

UV Curable Polybutadiene-Based Resin for 3D Printable Polymer Electrolyte
Elizabeth Zhang
Mentors: Julia Greer, Fernando Villafuerte, and Yuchun Sun

Constructing a viable UV-curable gel polymer electrolyte is essential to the development of 3D architected lithium-ion batteries with high energy and power density. Here, we report progress in the development of a UV-curable polybutadiene-based gel polymer electrolyte with measurable ionic conductivity and mechanical strength. The UV-induced crosslinking of the polybutadiene network is achieved through the formulation of a photo-resin containing a crosslinker (1,4-butanediol diacrylate), photo-initiator (TPO-L), and photo-blocker (SUDAN I), and has been corroborated through the investigation of Raman spectra taken from resin samples before and after UV-curing. The next stage of the project will be to optimize the mechanical strength of the crosslinked polybutadiene by varying parameters such as curing time and concentration of crosslinker in the resin, and measuring the strength of the cured resins via nanoindentation experiments. The final stage involves swelling the polymer in solutions of 9BBN in hexane and organolithium reagent in hexane in successive steps to make an ionically conductive film, and measuring the ionic conductivity via electrochemical impedance spectroscopy (EIS).

Exploring the Effect of Media Consumption on Attitudes Towards Asian Americans
Emily Zhang
Mentors: Ralph Adolphs and Tessa Rusch

The COVID-19 pandemic has deeply affected people's individual lives and society, ranging from health concerns to norm-changes, and societal and economic inequities. Concurrent with the pandemic, a significant increase in the incidence of racial harassment towards Asian Americans were reported. This sudden change in racially focused incidents is suggested to be linked to the public blaming and scapegoating of Asian and particularly Chinese individuals as the origin of the COVID-19 pandemic (e.g. "China Virus" or "Kung Flu"). I aim to explore this relationship by assessing the effect of the language used in public news outlets on individuals' motivation to respond (un)biasedly towards Asians. A recent study conducted in my mentor's lab collected 1000+ U.S. residents' experiences over 10 months (April 2020 to January 2021) to explore socioemotional change across the pandemic. In this project, I use a subset of this data: (1) a questionnaire exploring participants' internal and external motivation to respond without prejudice and (2) self-reported news consumption; and relate (1) to the rhetoric in the consumed news outlets to explore the relationship between public language and personal motivations. To begin, I conducted extensive web-scraping to extract headlines from 31 online news sources. I then cleaned and prepared these headlines using natural language processing tools and used selected keywords to identify the distribution of articles and news outlets referencing Asia and/or the COVID-19 pandemic over time. Finally, I will compare the differences in Asia and COVID-19 related focuses across the news outlets with the questionnaire-based data on the internal/external motivation of the participants to determine if these two sets of measures are associated.

Monitoring Changes in Soft Pulse Profile Shape in the X-ray Binary Her X-1
Hongyu Zhang
Mentors: Fiona Harrison and McKinley Brumback

Accreting neutron star binaries provide test grounds for high energy physics under extreme gravitational and magnetic fields. In this study, we chose our source to be a low-mass X-ray binary Her X-1 with a 35-day superorbital modulation, a periodic change in X-ray flux with a periodicity longer than orbital period. While we have a simplistic, warped precession model of the accretion disk to account for the superorbital period, we have yet determined whether changes in soft pulse profile to be smooth, indicating a pure disk rotation, or stochastic, implying short term changes in emission or irregularities in disk. NICER's high-cadence data makes it possible to see detailed changes in soft pulse profile, and precisely constrain the geometry of the accretion disk. Our data set consists of 15 consecutive observations in a single superorbital cycle, out of which four occur during the bright "main-on" stage with strong pulsations and detailed pulse profiles. We observed fine features in both soft and hard pulse profiles which change over time. Our simplistic precessing accretion disk model may not be able to reproduce these features, and this may suggest more complex accretion structure. With limited high energy signal, we best fitted the spectra of these data by a absorbed power law, a black body component and two gaussian emission lines. We saw consistent spectral constraint during the main-on phase. We also investigated a full energy range light curve of a possible pre-eclipse dip, which showed partial filtering by the accretion stream.

Progress Toward Ssymmetric Pd-Catalyzed Conjugate Addition of Arylboronic Acids to β-substituted α,β-unsaturated Lactams
Tianyi Zhang
Mentors: Brian M. Stoltz and Alexander Q. Cusumano

Progress toward the first enantioselective Pd-catalyzed construction of all-carbon stereocenters via conjugate addition of arylboronic acid and its derivatives to N-protected β-substituted α,β-unsaturated lactams is reported. Reaction of arylboronic acids and β-methyl α,β-unsaturated lactams, using a catalyst prepared from $Pd(OCOCF_3)_2$ and a chiral pyridinooxazoline ligand, afforded enantioenriched products with β-quaternary stereocenters with up to 70% ee and 93% conversion. Notably, the reaction is highly tolerant of moisture and air, making it a green and practicable approach to the synthesis of β-quaternary centers from α,β-unsaturated lactams.

Probiotic pH Biosensors for Ultrasound Imaging of Intestinal Inflammation
Lian Zhu
Mentors: Mikhail Shapiro and Marjorie Buss

Abstract withheld from publication at mentor's request.

Imprinting of Nanostructures Generated by Inorganic Phototropic Growth
Fangyu Nathan Zou
Mentors: Nathan Lewis and Katie Hamann

Highly-ordered nanostructures were fabricated over macroscopic areas using a simple, two-step process in which the first step generated master films using inorganic phototropic growth, and the second step produced imprints of the masters with similar fidelity, but with reduced feature sizes. Inorganic phototropic growth was used to generate Se-Te nanostructures on conductive substrates over large, 1x1 cm^2 areas via light-driven photoelectrodeposition. The morphologies were determined by the illumination source: varying the intensity, wavelength, and polarization of the incident light effected unique nanostructures. The morphologies consisted of ridge-trench patterns, wherein wide ridges were separated by narrow trenches. Imprints were created using a liquid adhesive that cures after exposure to ultraviolet light. A thin layer of adhesive was applied to the master film surface for a long duration (up to 2 hours) to allow for sufficient infilling of the narrow trenches. Once cured under ultraviolet light, the hardened imprint was peeled from the substrate and analyzed via atomic force microscopy. Imprinting produced negative templates of the master films, with narrow ridges separated by wide trenches. This work demonstrates that the size of nanostructures generated via inorganic phototropic growth can be further reduced over large areas, although further analysis on the fidelity of the imprint is needed.