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STUDENT-FACULTY PROGRAMS

2021 STUDENT ABSTRACT BOOK

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2021 Abstract Book

This document contains the abstracts of the research projects conducted by students in all programs coordinated by Caltech's Student-Faculty Programs Office for the summer of 2021.

Table of Contents

Scanning Tunneling Spectroscopy of Quasiparticle Interference on $Cr_{0.15}(Bi_{0.1}Sb_{0.9})_{1.85}Te_3$

Sébastien Nā Kai ʻEwalu Abadi
Mentors: Nai-Chang Yeh and Akiyoshi Park

The ferromagnetically doped bismuth and antimony chalcogenides which are magnetic topological insulators (such as $Cr_{0.15}(Bi_{0.1}Sb_{0.9})_{1.85}Te_3$) fail to exhibit quantized edge conductance above sub-Kelvin temperatures, even for dopants that lead to Curie temperatures in the tens of Kelvin. It is thought that bulk contributions to conductance may drown out edge conductance at higher temperatures. These contributions would occur if the bulk valence or conduction band overlaps in energy within the surface band gap. The objective of this study is to characterize the band structure of $Cr_{0.15}(Bi_{0.1}Sb_{0.9})_{1.85}Te_3$ as a function of temperature and tunneling current. The band structure is to be determined via quasiparticle interference maps taken using a custom built ultrahigh vacuum cryogenic scanning tunneling microscope. Preliminary spectral studies as a function of the tunneling current at room temperature reveal increasing bulk band contributions with increasing tunneling current, whereas spectral evolution as a function of temperature has not yet been completed, but is ongoing.

Laser Heated MBE Growth of Rare Earth Oxides for Applications in Quantum Computing Networks

Adam Abbas
Mentor: Joseph Falson

The realization of large-scale quantum computing networks promises to bring about a new age of technology, with exponentially more powerful computing power. Rare earth oxides have emerged as promising candidates for the realization of these quantum computing networks, however current synthesis methods are incapable of producing materials pure enough for use in a quantum network. We look to grow these materials in thin-film form, using Molecular Beam Epitaxy (MBE) to achieve the desired purity levels. As a growth method, MBE allows precise control of growth parameters in ultra-high vacuum, resulting in high quality epitaxial growth. However, traditional coil-based heating breaks down at higher temperatures, forcing growth to happen at lower temperatures than desirable. These temperatures then limit the ability of the system to reach thermodynamic equilibrium – inducing an undesired concentration of defects in the grown film. To avoid these impurities, we turn towards a novel, laser-based heating system capable of quickly reaching temperatures significantly higher than the coil-based limit. We discuss the from-scratch construction of an oxide MBE chamber with this laser system implemented and analyze the resultant heating of substrates in the chamber.

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.

3D Navigation System for Catheter-Based Procedures Using a Flexible Printed Circuit Board

Olivia Addington
Mentors: Azita Emami and Saransh Sharma

Minimally invasive alternatives to conventional surgeries continue to grow in popularity due to their many associated benefits. One such example is catheter embolization, a non-invasive procedure used to treat abnormal bleeding, aneurisms, and hepatocellular cancer, which involves navigating a small thin tube intravenously to the surgical site. Current methods for catheter navigation rely heavily on the use of X-ray imaging, which exposes the patient and the medical team to extended periods of harmful radiation. Here we present a proof-of-concept for an MRI-inspired navigation system designed for implantation within a catheter that performs localization using non-harmful magnetic field gradients. The system consists of 3D CMOS magnetic sensor ASIC chips mounted on a flexible Polyimide printed circuit board (PCB) fabricated using standard commercial processes. An external microcontroller can be connected to the flexible PCB to perform necessary digital signal processing. The single layer PCB has surface area dimensions of 2.2 mm X 6 mm, which are compatible with a wide array of commercial catheters. Therefore this system prototype has the potential to serve as an alternative navigation method for catheter-based procedures that is both low-cost and free from harmful radiation.

Planet Detection & Analysis and Instrument Calibration Modules for High Resolution Spectroscopy Using Integrated Field Spectrographs
Shubh Agrawal
Mentors: Dimitri Mawet and Jean-Baptiste Ruffio

High Resolution Spectroscopy is a novel development in direct imaging of exoplanets and can be used to constrain radial velocity, spins, and atmospheric parameters. Integral field spectrographs like OSIRIS at the Keck Observatory can leverage high spectral resolution to search for new planets by detecting their distinct spectral signature compared to the diffracted starlight. We use this technique to search for planets around 12 targets in the Ophiuchus star-forming region of the sky. We investigate theories of formation and migration of gas giants and the sensitivity of IFSs. My work resulted in an instrument-blind reduction pipeline for data from spectrographs like OSIRIS, VLT/SINFONI, and KPIC that is now hosted on open-source platforms as the Broad Repository for Exoplanet Analysis, Detection, and Spectroscopy (*breads*). *breads* can detect and also characterize high-contrast companions, by letting users select their own instrument data, forward models, fitting methods (like MCMC, grid optimization, gradient descent), and sets of parameters. I developed modules to perform field-of-view dependent calibration of wavelength and resolution and measure sky transmission and star spectra using aperture photometry, and I applied these to our OSIRIS survey. Using our new repository, I discovered a new binary star system, demonstrating the power and applicability of our technique. Our codebase is fully open-source that can be installed from GitHub or as a Python package, and it lets a larger portion of the astronomical community to employ our techniques to do significant work in integral-field spectroscopy.

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.

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.

Visualization of Buoyancy-Driven Flow Inside a Heated Annular Vessel
Eric Amaro
Mentor: Joseph Shepherd

This project aims to observe and model the transitional flow created by natural convection inside an annular enclosure. We designed a transparent annular vessel where the inner cylinder is heated. By varying the size of either the outer or inner cylinder, we were able to look at laminar, transitional, and turbulent flows of the fluid inside the vessel. Finally, we then conducted Particle Image Velocimetry (PIV) to model this flow and produce quantitative velocity data. From our learnings, we are able improve our understanding of the flow regimes inside an annular enclosure. We can then apply this to ignition testing of a flammable atmosphere around a heated cylinder confined by a constant temperature outer cylinder.

Solving a Water Crisis: Identifying Chemicals in Metabolomic Samples Through Dimensionality Reduction
Emile Anand
Mentors: Charles Steinhardt and Rob B. Phillips

Civilizations have tried to make drinking water safe to consume for thousands of years. The process of determining water contaminants has evolved with the complexity of the contaminants dueto pesticides and heavy metals. The routine procedure to determine water safety is to use targeted analysis which searches for specific substances from some known list; however, we do not explicitly know which substances should be on this list. How do we answer the sampling problem of identifying which substances scientists should search? Here, we present an approach that builds on the work of Jaanus Liigand et al., which used non-targeted analysis that conducts a broader search on the sampleto develop a random-forest regression model, to predict the names of various substances in a sample and their respective concentrations[1]. This project seeks to develop convolutional filters and utilize dimensionality reduction to present a more accurate model using data from the European Massbank Metabolome Library to produce a global list of chemicals that researchers can then identify and test for when purifying water.

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.

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.

Contamination Model for Spacecraft Associated Surfaces
Nishka Arora
Mentors: Ashish Mahabal and Nitin Singh

To prevent interplanetary contamination, organisms that might survive in space environments must be removed from spacecraft-associated surfaces. Using datasets about traits of species, we create models to calculate the contamination potential of a species mainly based on the following traits - radiation resistance, sporulation, survival at extreme temperature, and anaerobic character. We train classifiers (Random Forest and Naive Bayes) on a curated dataset of ~1400 species, to predict whether the species are sporulating, radiation-resistant, etc, based on other available data about their traits. Using unsupervised clustering algorithms, we look at a 2-dimensional projection of the traits data to visualize if our predictions form discernible clusters. In calculating the contamination potential, we also use data about the number of reads of species found at spacecraft-associated locations. The classification models are unreliable and have low predictive power. This could be because of a lack of trends or too many imputations in the training data. The sporulation classifier performs better than the classifiers for other traits. More available data about a wider number of traits can make the predictions better.

Using Convolutional Neural Networks to Infer What a Person is Searching for Based on Eye Movements
Julio Arroyo
Mentors: Gabriel Kreiman and Markus Meister

We experimented with using convolutional neural networks (CNNs) as tools to infer what a person is searching for, given their eye movements. The data had been pre-collected on psychophysics experiments involving visual search tasks over array images (six objects against a uniform background evenly spaced forming a circle) and real-world images. We used it to build a CNN-based computer vision model to assess image similarity, which in turn was applied to target inference, based upon the assumption that people's eyes tend to fixate on objects that are similar, or share features, with the object they are looking for. We outperformed four competitive null models whenever there were multiple error fixations on the trial, providing empirical evidence for our underlying assumption and for the idea that computational models can infer human intentions from actions.

Mechanical Characterization of Nanoarchitected Materials
Juan Arvelo
Mentors: Julia Greer, Seola Lee, and Andrew Friedman

Interference lithography is an additive manufacturing technique that can create features on the nanometer-scale using a laser that activates a photoacid. By patterning a photoresist, this technique can 3D print structures significantly faster than traditional 3D printing. Its printing resolution goes down to the nano-scale size. This nano-architected material can be much lighter than traditional manufacturing techniques while still being stronger. An issue in this field is that mass-production can be impractical. One solution is scaling production by having the laser scan across the surface and then moving the surface away to pattern the newly exposed surface as a new tile. The first material being tested is SU-8 photoresist because it is a commonly used material for interference lithography due to its reliability. After these tests, PGMA, another photoresist, will also be tested to expand possible design possibilities. As polymers, both materials experience viscoelastic effects, which are analyzed to see strain-rate effects on the testing of the material's Young's modulus. Due to the way the material is tiled, the overlaps between the tiles need testing. For overlaps, their distinct modulus coming from extra exposure and their mode III, or tearing, fracture toughness of overlapping is what is important. Using these characteristics two developed photoresists, SU-8 and PGMA are investigated to see which applications they may have.

Financing Sources and the Trajectory of Innovation
Abdullah Ateyeh
Mentor: Michael Ewens

Over the past two decades, there have been significant changes in the way newly founded startups raise capital, which could have real consequences on the companies and ideas that grow and survive. Consequently, founders may gear the development of new ideas based on how fundable they are. Alternatively, it is also possible that the set of ideas cause Venture Capital investors (VCs) to alter their investment strategy. This project aimed to determine the role of VCs and other financial gatekeepers in the trajectory of an economy's innovation. Our approach for this project centered around utilizing patent data to represent the set of "ideas" in the US economy over time. When merged with VC and company data, we gain insight into the landscape of innovation and investment within the US economy through merging techniques, data visualization, and regression analysis. In the end, we find that it is possible for VCs hold some power as financial gatekeepers in determining the innovation within the US private market. With this conclusion, both investors and founders could use past information of VC investments to best predict the direction of the economy in the near future for better investment returns or higher chances of startup success.

Using Pulse Phase Resolved Spectroscopy to Study Accretion of Be X-ray Binary IGR J21347+4737
Wasundara Athukoralalage
Mentors: Fiona Harrison and Sean Pike

Be X-ray binaries (BeXRB) are neutron star X-ray binaries with donor stars above 8 $M_\odot$ that often show X-ray pulsations. As matter from the massive companion accretes onto the neutron star, it forms a disk which can reach temperatures up to tens of millions Kelvin, thereby achieving high luminosities in the X-ray. Studying the pulsations and the spectrum helps us to see how that disk interacts with the strong magnetic and gravitational fields of the neutron star. In this project, we study the BeXRB IGR J21347+4737 using observations from *NuSTAR* (the Nuclear Spectroscopic Telescope Array). We begin by describing the averaged spectrum originating from the accretion disk and the neutron star using models typical of Be X-ray binaries. Having determined the pulse period, we model the continuum spectra extracted during the pulse-on and pulse-off phases to characterize the region responsible for pulsations. We also search for cyclotron scattering features, in an attempt to directly probe the surface magnetic field of the accreting neutron star. Our work enables us to examine the geometry of pulse emission and understand the accretion history of the system. This will add to our current understanding of accretion applicable to many other systems.

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.

Flare Star Candidates in the Epoch 2.1 & 1.1 Footprint
Carlos Ayala
Mentors: Gregg Hallinan and Dillon Dong

We present a catalog of stellar transients exhibiting radio variability via implementing flares as a means of lowering the number of false associations between flare stars and extragalactic transients. Observations of our transients were taken from the 17,000 square degree Epoch 1.1 and 2.1 footprint of the Very Large Array Sky Survey (VLASS) with a 1 mJy sensitivity, and filtered to create a ninety-percent purity sample using the false alarm probability of each transient candidate. Calculating this statistic involved a crossmatch with sources in the Gaia catalog and took into account changes in position resulting from proper motion. Considering that most stellar flares can be attributed to a variety of mechanisms associated with coherent emissions at temperatures > 10^{12} K, we crossmatched our sample with multiwavelength all-sky catalogs to determine variability at other wavelengths, using the obtained statistics to classify each source by variable and spectral type while identifying the mechanisms responsible for each stellar flare. In particular, we used Gaia statistics along with observations from the Transient Exoplanet Survey Satellite (TESS) to identify binaries and determine the period of each transient, allowing us to develop plots including a Hertzsprung-Russell Diagram. Our sample serves as the most sensitive catalog of stellar transients to date, with potential implications for studying exoplanet habitability.

Fluorescence Assay to Track Intracellular Transfer of Mitochondria in *Drosophila melanogaster*
Reid Banciella
Mentors: Bruce Hay and Marlene Biller

Intracellular transfer of mitochondria (ITM) is a recently discovered phenomena where healthy cells donate mitochondria to neighboring cells. Recent studies have shown that ITM can rescue the respiratory function of cells that are undergoing oxidative stress. When the mechanism of ITM is characterized, it may be used to create therapeutics to treat currently incurable mitochondrial diseases. In order to characterize ITM, we have created a fluorescent reporter construct that assigns in-vivo *D. melanogaster* cells the role of either donor or recipient of mitochondria. Using the FLP/FRT system and KD recombinase, we can control the recombination of cell specific DNA so that mitochondrial donor cells express TdTomato (red) and recipient cells remain colorless until they receive mitochondria via horizontal transfer, after which they express mNeonGreen (green). This reporter allows for the analysis of ITM and comparison between unstressed and stressed tissues. Preliminary findings suggest that exposing *Drosophila* to chemicals such as intercalating and oxidizing agents cause increased rates of ITM compared to unstressed *Drosophila*. Future experiments will help verify this result and determine what classes of stressor increase ITM and which stressors have no effect or decrease ITM.

Simulating Titanium-based Millimeter-wave Packaging With High Kinetic Inductance
Junzhe (Bob) Bao
Mentors: Mohammad Mirhosseini and Chaitali Joshi

Superconducting qubits coupled to microwave photons are currently a leading hardware platform for quantum information processing. However, cryogenic temperatures as low as a few milli-Kelvin are necessary to circumvent thermal noise at a few GHz frequencies. The Mirhosseini Lab develops mm-wave superconducting circuits for operating quantum devices at liquid helium temperatures. Achieving low loss at higher operating temperature requires materials with superconducting temperature in excess of 4K, such as titanium nitride (TiN) and niobium titanium nitride. These materials possess high intrinsic kinetic inductance and exhibit nonlinear properties suitable for quantum applications.

The primary research objective is to design a mm-wave packaging consisting of a TiN coplanar waveguide that connects to W-band rectangular waveguides with E-plane probes. Kinetic inductance is successfully integrated into the simulation, and optimization of the W-band S-parameters is under way. Demonstration of the packaging's high transmission in mm-wave regime will enable characterization of nonlinear response of titanium-based superconducting cavities, which will expand the frontiers of quantum information processing using superconducting devices.

Regulation of Backpropagating Action Potentials by Input to Oblique Dendrites Modulates Coincidence Detection in Layer 5 Pyramidal Neurons
Alex Bardon
Mentors: Michael Hausser, Brendan Bicknell, Arnd Roth, and Thanos Siapas

Burst firing in cortical layer 5 pyramidal cells (L5PCs) is thought to signal the coincidence of feedforward signals to basal dendrites and feedback to apical tuft dendrites. This is mediated by an interaction between backpropagating somatic action potentials (bAPs) and voltage-dependent Ca channels in the apical tuft that produces backpropagation activated calcium spike firing (BAC firing). By associating bottom-up and top-down streams of information, BAC firing provides a powerful biophysical mechanism for implementing hierarchical computations and learning in cortical circuits. Previous work has shown that spike and burst rates in L5PCs can be controlled by varying the intensity or timing of basal or apical tuft input. Here, using a detailed biophysical model, we show that bursting in L5PCs can also be finely modulated by the balance of excitation and inhibition in apical oblique dendrites and the main apical trunk via regulation of bAP efficacy. This allows associative signaling and plasticity to be controlled by a third independent stream of input, representing, for instance, the state of the local network.
To make testable predictions about the electrophysiological signature of the proposed mechanism, we simulate extracellular dynamics of BAC firing. We compare these predictions with data recorded *in vivo* from mice performing a behavioral task, quantifying the relationship between burst rates, backpropagation efficacy, and putative dendritic Ca spikes. Our work highlights how the complex morphology and biophysics of L5PCs can enhance cortical processing, and provides a set of general computational tools for ongoing analysis of dendritic signals in *in vivo* extracellular recordings.

Engineering pH-insensitive Opioid Biosensors
Zoe G. Beatty
Mentors: Henry Lester and Anand Muthusam

The Lester lab has pioneered genetically encoded biosensors, or "iDrugSnFRs", for opioids and other neural drugs. iDrugSnFRs consist of a periplasmic binding protein (PBP) and a circularly permuted green fluorescent protein. Imaging studies in the Lester lab have supported the growing evidence that neural drugs act on their receptors inside the cell, rather than solely at the plasma membrane. To further support this hypothesis, we show that opioids accumulate in acidic compartments due to acid trapping. However, current sensors have limited operability in acidic pH due to protonation of the GFP chromophore resulting in diminished dynamic range.
I am re-engineering current Lester Lab opioid biosensors to function optimally in low pH environments. First, the fluorescent protein is mutated from GFP to mTurquoise, a relatively pH insensitive reporter. Then, the linker sequences are optimized to allow the binding protein to activate the fluorescent protein more effectively when drug is bound. We use the resulting biosensors for imaging opioids in acidic organelles of mammalian cells and in diagnostic cases where the sample pH is variable. These observations provide new insights into the subcellular mechanisms of neural drugs, as well as why some opioids are more highly addictive than others.

Investigation of Sensitivities of Mu2e Experiment for Low Momentum Electrons
Charles G. Beck
Mentors: David G. Hitlin and Bertrand Echenard

This project investigates the capabilities of the Mu2e experiment to detect a decay process of the form $\mu \rightarrow e + X$, where X is an undetected, unknown particle not featured in the standard model. We calculate sensitivities by calculating the minimum branching ratio required for the Mu2e experiment to detect this decay. We use the Mu2e software to simulate the Mu2e experiment for low momentum electrons and reconstruct momentum tracks for electrons in the tracker. We then analyze the data to find the branching ratio values for Muons that decay through $\mu \rightarrow e + X$ for varying masses of X. The resultant sensitivities will inform researchers whether or not the Mu2e experiment can detect X for a given mass of X and how effective the investigation will be at detecting this particle. These sensitivities will allow them to adjust the conditions under which they run the experiment, which will give them an optimal ability to see a new particle X that results from the decay of a Muon into an electron. The detection of such a particle would be a profound discovery.

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 aviable candidate for the removal of motion artifacts in MRI in the future.

Exploring Data Pipeline Implementation for Fast Radio Burst Observation on the STARE2 Cluster
Ivy Bennett-Ford
Mentor: Shrinivas Kulkarni

The study of millisecond duration fast radio bursts (FRBs) offers increasingly thrilling glimpses of the lifecycle of stars. Radio pulses from distant magnetars tell of vast stellar accretions, rotating transients, and ancient stars on the brink of collapse. As more FRBs are observed, the better we come to understand the lifetime of the universe. In this paper I will discuss how very long baseline interferometry (VLBI) is an active means of observation and investigation of radio transients. The ability to extend distances between receiving antennas drastically improves image resolution, not to speak of the added boon of increased likelihood of observation. A key challenge faced by observing FRBs lies in detecting and confirming the event despite noisy signals. During my brief and exciting time working with the Survey for Transient Astronomical Radio Emission (STARE2) antenna array, I have studied the preexisting data pipeline for FRB detection and confirmation designed by Bochenek et al. with a focus in filtering noise through to identify candidates as quickly as possible. The work done by the STARE2 team has influenced heavily the design of 'STARE3', or the Galactic Radio Explorer (GReX), a modular deployment of a powerful array. While the next hurdle for studying FRBs with VLBI will likely be overcome with arrays installed in the southern hemisphere, improvements and testing are ongoing using the existing hardware operating the on-board gate arrays (FPGAs), with the intent to improve observing bandwidth by hardware.

Studying the Light Output of the Barrel Timing Layer Sensors for the MIP Timing Detector
Nachiket Bhanushali
Mentors: Maria Spiropulu, Nan Lu, Anthony LaTorre, Lautaro Narvaez, Adolf Bornheim, Cristian Pena, and Si Xie

The LHC (CERN's particle accelerator) will become the High Luminosity LHC by increasing the collision frequency of protons. To meet the increased resolution demand of the higher collision frequency, the MIP Timing Detector (MTD) will be added to the LHC's CMS detector. The Barrel Timing Layer of the MTD will have modules of LYSO scintillating crystals and silicon photomultipliers (SiPMs). To determine the best bias voltage for SiPM operation, the light output of the module was characterized at various bias voltages. The module was exposed to radioactive sodium and laser sources and its voltage response was measured using an oscilloscope. For each bias value, several thousand events were recorded and the charge for each event was generated by integrating the voltage-time pulse. From the peaks of the resultant charge histograms for each bias value, the light output was calculated in units of number of photoelectrons per MeV. The light output measured at a typical bias voltage of 43.5 V was 1242 photoelectrons per MeV. The light output was in the expected region but smaller than previous measurements made by another lab. The nonlinear SiPM response was proposed as a cause for the smaller values but this requires further investigation.

The Effects of Electoral Institutions on Party Discipline: An Analysis of Speech and Votes in Mexican Congress
Camila Blanes García Cors
Mentor: Gabriel Lopez-Moctezuma

I study how electoral institutions affect political accountability and party discipline of politicians in Congress. Different electoral systems and nomination procedures shape the degree to which legislators respond to their party's interests versus their own. Moreover, when reelection concerns are present and voters can discipline legislators independently from their parties, legislators may step away from their parties' agenda to cater to their constituency interests. I explore these issues by analyzing the speech and voting behavior of legislators in Mexico's mixed-member electoral system. I employ a differences-in-differences estimator to compare the behavior of legislators elected in single-member-districts to that of legislators elected via proportional representation. To assess how reelection concerns alter the connection between electoral institutions and party discipline, I exploit an electoral reform in Mexico that allowed the consecutive reelection of federal legislators. To measure party discipline in both speech and voting behavior, I estimate the policy position of legislators using data on parliamentary debates and roll-call votes from 2006 to 2021. I find that party discipline in voting behavior is extreme, regardless of the electoral institution in place. However, legislators find more room for maneuver in their speech behavior, as party discipline reflects the electoral mandate, i.e., the speech of legislators under single-member-districts with reelection concerns move away from their party line to a larger extent than the speech of legislators under proportional representation and of those without the possibility of reelection.

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.

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.

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.

Determining the Effects of a Methionine Surrogate on Viral Production for Bio-Orthogonal Non-Canonical Amino-Acid Tagging (BONCAT)
Matticus Brown
Mentors: Victoria Orphan and Alon Philosof

Bio-Orthogonal Non-Cannonical Amino acid Tagging (BONCAT) is a tool developed by the Orphan lap with a wide variety of applications especially in terms of measuring viral production. However, this tool uses methionine surrogates which have been shown to impact metabolic rates in bacteria, thus, implying that viral BONCAT may cause a slowing of viral production, the very parameter it is used to measure. Therefore, quantifying the impact of methionine surrogates, specifically homopropargylglycine (HPG), on viral production is essential in order to improve BONCAT as a tool. To this end, multiple one-step experiments were performed in order to establish growth curves for growth media with and without methionine surrogates in both LB and M9 media in order to determine the effect of the methionine surrogates on viral production. Although growth curves have been obtained for LB media, more replicates are needed for conclusive results. Moreover, M9 growth curves are also needed for both control and methionine surrogate media. Future work also involves studying the effect of other methionine surrogates on viral propagation as well as other differences between control viruses and methionine surrogate supplemented viruses.

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.

Developing Assignments for CS 022: "Data Structures and Parallelism"
Antonio Caceres
Mentor: Adam Blank

CS 022, Data Structures and Parallelism, will be a new course in the winter term of the 2021-2022 Caltech school year. The course will teach students how to use advanced data structures to solve algorithmic problems. Students will need to implement their algorithms in Python under constraints that allow the automatic grading program to compute the complexity of the students' solutions. To program in the subset of Python we allow, students need to consider the control flow and complexity of their algorithm during implementation. This approach to algorithm design facilitates the proof process, since students will be aware of any subtleties of their algorithm that they could potentially ignore in a standard implementation.

Creating a new course requires developing problem sets and grading tools. Specifically, CS 022 will automate grading of implementations, which requires static analysis tools, correctness tests, and the complexity decider. I focused on developing the correctness tests, which students can run to quickly debug their submissions, and which CS 022 will use to grade student solutions.

Exploring Photoactivated Formulations for the Treatment of Degenerative Myopia
JC Daniel Calso
Mentors: Robert H. Grubbs and Christopher Marotta

Degenerative myopia is an ophthalmologic disease characterized by a thinning of the sclera, the "white of the eye". The eyeball progressively elongates along its axis, resulting in a high myopia (nearsightedness) that could ultimately fall outside the treatable range of corrective lenses. As degenerative myopia is linked to several pathologic eye conditions – including macular degeneration, glaucoma, and cataracts – its growing prevalence poses a public health concern to the ophthalmologic community. There is currently no treatment that halts, slows, or reverses the root cause of this disease: the weakening of the scleral structure of the eyeball. The Grubbs Research Group proposed a photoactivated formulation that would promote collagen crosslinking within the sclera to resist further axial elongation of the eye globe. We investigated a multitude of formulations that are activated with near infrared (NIR) light, analyzing their effects on rabbit sclera. The efficacies of these treatments were measured by examining tensile properties and resistance to enzymatic collagenase degradation. We report substantial improvements in scleral biomechanics in samples treated with select formulations and irradiation parameters, especially when compared to untreated scleral samples.

Linear Waves on Extremal Kerr-Newman Spacetime
Luis Camargo-Carlos
Mentor: Yannis Angelopoulos

In general relativity, the study of black holes is one of the most important topics. The goal of this project is to study the stability of certain extremal black hole spacetimes under linear scalar perturbations. A mathematically rigorous analysis of the full nonlinear stability of black holes has been achieved only recently for the case of special perturbations of the Schwarzschild metric. The goal of this project is to study linear waves near a charged, rotating black hole, the Kerr-Newman spacetime. Specifically, we do so for the extremal case where $a2 + e2 = M$^2, with a, e, M being the angular momentum, charge, and mass parameters, respectively, and conduct the analysis with no symmetry assumptions on the initial data of a linear wave. In order to deal with the difficulties presented by the fact that the spacetime is extremal, mainly the lack of a redshift effect, we assume that the angular momentum parameter is small, so that we can treat the metric as a perturbation of the extremal Reissner–Nordström metric where the behavior of linear waves is well understood (as opposed to the extremal Kerr case where the behavior of linear waves is understood only under the assumption of axisymmetry). Once completed, this study of the linear waves should be useful in the investigation of stability or instability of extremal black holes in the fully nonlinear regime.

Electro-Cycled Photoredox Catalysis for Benzyl Chloride Functionalization: A Mechanistic Investigation
Virginia Canestraight
Mentors: Jonas Peters and Mike Zott

The combination of photoredox catalysts and electrochemistry can yield incredibly reducing reduction potentials, affording the opportunity to break many challenging bonds. A previously reported PNP bis-phosphine amido bridged bimetallic copper system, $(CuPNP\ t\text{-}Bu)_2$, was used to reduce benzyl chlorides reaching reduction potentials of -2.8 vs. SCE. Time resolved fluorescence spectroscopy was used to construct Stern-Volmer and Marcus theory plots to demonstrate that an outer-sphere electron transfer mechanism is predominant. The steric profile of the catalyst combined with evidence of outer-sphere electron transfer explain the catalyst's tolerance of many functional groups. Stern-Volmer quenching rates were compared between benzyl chlorides and aryl chlorides of the same reduction potential to demonstrate that the long-lived excited state lifetime (>10 μS) may allow access to these sp^3 C–Cl bonds. Transient absorption spectroscopy was utilized to verify the presence of postulated intermediates in the mechanism as further proof of single electron reduction.

An Update on Detection of BFB in Cancer Cells Using Human Genomic Data
Ann Caplin
Mentors: Vineet Bafna and David Van Valen

Breakage-fusion-bridges (BFBs) are a type of chromosomal rearrangement that are associated with certain cancers, and their detection could help us better understand their role in cancer. Current widely-available sequencing data is not informative enough to directly reconstruct genomic sequences exhibiting BFB; instead, we rely on computational methods to do so. The Bafna lab has developed efficient analytical algorithms to use much of this data to detect BFB. In this project we use these algorithms as a backbone to develop a more heuristic method to detect BFB, which takes into account issues in the data that are common yet tricky to deal with that the current analytic software does not address. Our goal is to be able to generate a score that reflects how likely a genomic region is to have originated from BFB and to use this in tandem with other developed heuristic methods to get a good picture of a given genomic region.

Validating iso-ML, a Machine Learning Approach for Predicting Gene Isoforms From 10X scRNA-seq
Jacqueline Castellanos
Mentors: Lior Pachter and Rebekah Loving

Gene-level analysis using short read scRNA-seq technologies does not allow examination at gene isoform resolution. Since differential isoform expression has been shown to reveal more cell type information, we aim to explore how a single gene locus can transcribe into functionally different isoforms. iso-ML is a machine learning algorithm and pipeline for predicting gene isoforms from 10X data. The objective of this project is to determine iso-ML's ability to accurately predict gene isoforms. The SMART-seq data we are working with is full-length RNA-seq from mouse motor cortex cells. The SMART-seq cells are not the same as the 10X cells (also mouse motor cortex). Thus, in order to complete the validation, we must create paired cells between the SMART-seq and 10X. Therefore, we used KNN (K=15) to match SMART-seq cell's transcript abundance to the mean of the k-nearest 10X cell transcript abundances. After we ran iso-ML on the matched data, we assessed the quality of iso-ML's predictions in matching the SMART-seq data using correlation and visualizations. Once validated, iso-ML will provide an incredibly fast and inexpensive way of ascertaining isoform information, which is useful for targeted experiments in full-length sequencing to investigate the role of isoforms in regulation and development.

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.

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.

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.

Modeling Burst-wave Lithotripsy Treatment for Kidney Stones
Anjini Chandra
Mentors: Tim Colonius and Shunxiang Cao

Kidney stones affect 1 in 11 people in the United States. Current treatments include surgical removal, ureteroscopic procedures, and shock wave lithotripsy (SWL). However, surgical removal and ureteroscopic procedures are invasive treatments, and SWL may damage the patient's kidneys without fully breaking down the stones. It is therefore essential that we develop a safer, more effective, and noninvasive method of treating kidney stones. One emerging alternative to current treatments is burst-wave lithotripsy (BWL) which uses ultrasound waves to target and break apart kidney stones. Recent studies have found that BWL treatments can fracture kidney stones more effectively than SWL treatments and are safer for patients; however, the treatments have not yet been optimized for patients. In this study, we simulate the effects of BWL on various types of kidney stones and compare the results to both existing experimental results and analytical treatment predictions. Our results indicate that BWL treatments can be modified to target specific types of kidney stones and show promise for the development of a safer and more effective alternative to current treatments.

Using Remote Webcam-based Eye-tracking to Test Theories of Salience and Rational Inattention in Economic Decisions

Katherine Chang
Mentors: Colin Camerer and Xiaomin Li

Attention is scarce so the allocation of attention is influential in economic decisions. Past choice experiments with visual stimuli testing theories of salience and rational inattention separately show that both salience and rational inattention consume attention and influence resulting decisions made. Consequently, there is merit to relating salience and rational inattention theories in addition to recovering attention distribution priors by conducting a binary fruit piles choice experiment conducted remotely with webcam eye-tracking to determine the relation between eye-fixations and decision choices. In the experiment, participants were informed of the established value of each fruit then tasked with choosing between two fruit piles shown in an image stimulus. Gaze data and decision results were compared with outputs from the Saliency Attention Model and analyzed against different rational inattention models. We aim to replicate outcomes predicted by visual salience with gaze fixations as well as determine a rational inattention model which can best predict visual salience. Confirming the relation of visual salience with rational inattention provides further insight into the selection of valued bundles in a market setting.

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.

Decision Theoretic Uncertainty Quantification for Machine Learning

Diego Chavez
Mentors: Houman Owhadi and Peyman Tavallali

Machine learning models are ubiquitously used for predicting outcomes from available data; and it's very useful to know the approximate uncertainty associated with these predictions. Focusing on uncertainty that arises with naturally noisy data, current methods of uncertainty quantification (UQ) incorporate Bayesian or worst-case approaches. However, a fourth method of UQ, a hybrid between Bayesian decision theory and frequentist statistics, has been developed by researchers and tested with simple models. This UQ method applies a rarity assumption from frequentist statistics to the space of possible priors to pick from in a 2-player game that determines scores on the fit to the observed data. Here we show the efficacy of this UQ of the fourth kind (UQ4K) on different data sets for machine learning models, including linear regression, neural networks, and decision trees. We test our approach initially on the known California housing data set and then later with data collected measuring sea ice extent and related quantities. This UQ4K can be used in modeling in various different fields, and has potential to provide a supplemental evaluation of uncertainty to the other, more well-known methods of uncertainty quantification. In the future, it could become a more mainstream method for estimating uncertainties.

Analysis of Super Peraluminous Granite Rocks From the Proterozoic-Archean Transition Using Whole Rock Analysis and Mineral Separation

Rahul Chawlani
Mentor: Claire Bucholz

The Great Oxygenation Event during the Proterozoic-Archean Transition drastically changed the composition of Earth's atmosphere by increasing existing O_2 levels. Existing research has shown this change in sedimentary rock, but our project seeks to reflect these changes in igneous rock. To achieve this, we will first determine the whole rock composition of fused bulk samples using an X-Ray Fluorescence (XRF) spectrometer. Next, we will date the rocks by separating and analyzing zircon with a mass spectrometer. Results from XRF analyses will also ensure that

the samples are in fact, super peraluminous granites. Ultimately, this data reflecting both the age and whole rock composition of samples can help place them into context with the existing archive of SPGs.

Learning High-dimensional Non-gaussian Graphical Models via Neighborhood Selection Methods
Haoxuan Chen
Mentors: Youssef Marzouk and Andrew Stuart

In recent literature on learning probabilistic graphical models, the SING (Sparsity Identification in Non-Gaussian distributions) algorithm has been proposed to identify the conditional dependencies satisfied by a collection of random variables drawn from a non-Gaussian distribution when a sample dataset is given. However, for high-dimensional distributions, the computational cost of the SING algorithm can be intractably high, as it needs to jointly estimate the dependency between all pairs of nodes in the associated graph. In our project, we use a neighborhood selection method to develop a local version of the SING algorithm, which takes less run time and memory to learn the graph associated with certain high-dimensional distribution. Theoretically, we will prove that the localized SING algorithm is consistent for recovering the graph in the limit of the number of samples via statistical analysis. Practically, we will test the localized SING algorithm's performance on several high-dimensional distributions generated from some common models, such as the stochastic volatility model and the Lorenz-96 dynamical system.

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.

Analysis of Di-Higgs to Two Bottom Quarks and Two Photons With Machine Learning Techniques for the High Luminosity LHC
Stephanie Chen
Mentors: Harvey Newman and Nan Lu

This project focuses on the identification of gluon-gluon fusion di-Higgs production at the Large Hadron Collider (LHC) through the decay to two bottom quarks and two photons, with the aim to explore analysis methods in preparation for the upcoming LHC Run 3 and High Luminosity LHC. The search for di-Higgs is motivated by the importance of di-Higgs measurements in determining the shape of the Higgs potential field, a central part of the Standard Model. The samples of the signal and backgrounds were simulated for Run 2 conditions across 2016, 2017, and 2018. Backgrounds included resonant single Higgs to two photons and nonresonant photon, diphotons, and top quarks plus jets. Initial selections in C++ code were applied to the samples to reconstruct potential diHiggs candidates. Afterwards, machine learning techniques, namely sequential deep neural networks implemented using the Python keras library, were used to reduce the various backgrounds. Further improvements on this front may be found in targeting boosted signatures within the decay channel.

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.

Algebraic Structures of Homeomorphism and Diffeomorphism Groups of Manifolds
Yishu Pearl Chen
Mentor: Lei Chen

The algebraic structures of homeomorphism and diffeomorphism groups of manifolds and their actions are of great interest because of their diverse applications to problems in topology. We investigate in particular their commutator subgroups, isomorphisms between them, and the orbits of their actions on a finite-dimensional CW complex. Respectively in these cases, known results include that Diff_0(M) is perfect for a manifold M of dimension greater than 1 (Thurston), Diff^r(M) uniquely determines M up to diffeomorphism (Filipkiewicz), and every orbit of any action of Homeo_c(M) is either a point or the continuous injective image of a cover of Conf_n(M) for some n (Chen, Mann). Understanding more about these results in the case of different regularities for diffeomorphisms or dimensions for manifolds is interesting because they require fundamentally different techniques for their proofs.

Enhancing Ionized Gas Cloud Simulations With Machine Learning
Alice Cheng
Mentors: Thomas Greve and David Reitze

In order to understand the behavior and physical properties of the formation of certain galaxies, such as those with abnormal element abundance ratios or those at high redshifts, it is important to simulate line emission data. CLOUDY is a code which processes numeric simulations on ionized gas clouds and calculates various emission line data (intensities, emissivity, etc.). However, its complex computational nature results in excessively slow run times on the order of 24 hours for just 2,000 models. We aim to train Random Forest and neural network models on different CLOUDY parameter spaces (ex: dense gases, diffuse gases, etc.) to build an emulator which speeds up the process. With the CLOUDY emulator, we were able to reach mean prediction errors of less than 5% relative to the actual data and run 10,000 emulator models in 6 seconds, a big improvement from the original code.

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.

Generation of Meta-Features for Regression
Colin Chun
Mentors: Pablo Moscato and George Djorgovski

We report on a new approach to regression problems involving the generation of meta-features. While there are currently many approaches to regression problems, many of these approaches are problematic with regards to human understandability, computational runtime, and/or model accuracy. Here we show that the generation of meta-features helps to augment the learning capabilities of other regression methods. In particular, we show how a fast method like linear regression can be used in order to have both high accuracy and low runtime. We found that this algorithm performs better on average than many well-known algorithms on a large repertoire of datasets. While we focus on the use of linear regression as a base regressor, other types of regressors can be used as the base regressor of the algorithm to improve accuracy. Additionally, the meta-features generated by this algorithm can be used as the input to other regressors to further improve accuracy.

Actuated Particle Jamming as a Potential Foundation for Smart, Structured Fabrics
Norman Chung
Mentors: Chiara Daraio and Tracy Lu

In traditional structured fabrics like woven fabrics or chain mail, favorable mechanical properties can arise based on what constituent materials are chosen for the fabric and how the fabric is put together. However, these properties are typically fixed once a fabric has been made. It would therefore be convenient if there was a way to create smart, structured fabrics, i.e., actuated structured fabrics with adjustable mechanical properties best suited for a given situation. This summer, we investigated the potential of inducing jamming between particles on an interwoven sheet to create these smart, structured fabrics. The first part of this project focuses on the design, creation, and assembly of experimental apparatuses meant to facilitate particle jamming and experimentation. The second part of this project focuses on using Solidworks simulations to extract data for future comparison with experimental results. These preparations will make it possible to perform and evaluate loading tests on the interwoven particle sheets in the future.

Why Do Galaxies Die?
Thomas Clark
Mentors: Charles Steinhardt and David Hsieh

Although it is known that galaxies transition from a vibrant, star-forming stage into a quiescent, or dead phase, we do not know how or why galaxies shut down star formation. This is because observing galaxies as they shut down is difficult since they do not change their appearance until long after the process completes. Recent work demonstrates that a new fitting parameter "IMF temperature" has isolated two populations of star-forming galaxies, one with high temperatures and one with low temperatures similar to those of quiescent galaxies, suggesting the colder galaxies may be in the process of shutting down. Through further examination of these cold, star-forming galaxies and their properties, we conclude that these galaxies are indeed in an intermediate phase between star formation and quiescence. Based on the properties of these galaxies, we discuss which of several proposed mechanisms for the death of galaxies are still viable.

Investigation of Unknown Emission in Comet NEOWISE Spectra Using Comparative Spatial Profiles
Lily Coffin
Mentors: Geoffrey Blake and Maria Camarca

The Oort Cloud is a theoretical sphere of protoplanetary material surrounding the Solar System at a distance of 10,000 Astronomical Units (AU). Oort Cloud comets have undergone significantly less processing by the Sun than other types of comets and are thought to be the most pristine samples of protoplanetary material in the Solar System. Since the Oort Cloud is not directly observable at such a great distance, studying these comets gives us clues about the conditions of the protoplanetary disk which led to the formation of the Solar System. Comet C/2020 F3 (NEOWISE) is one such Oort Cloud comet. When comet NEOWISE made its first pass by the Sun in July of 2020, it was the brightest comet observed in the Northern Hemisphere since 1997. NEOWISE was studied with iSHELL at the NASA Infrared Telescope Facility following its perihelion passage from July 9th to August 1st, 2020. Then the comet was followed by NIRSPEC 2.0 at the Keck II Telescope later in August. Both telescopes are high-resolution infrared spectrometers with the ability to record narrow spectral peaks that originate from fluorescent emissions as the comet passes the Sun.

We worked on constraining spatial profiles of comet NEOWISE. In the initial analysis of the emission spectra, there were five unidentified peaks. In order to potentially match the spatial composition of known molecules with the spatial composition of the unknown molecules, we created spatial profiles from the spectra to compare. We first used a data reduction algorithm from NASA's Goddard Space Flight Center to crop and clean the individual orders and conduct spatial and spectral alignments on the orders to put the data in a usable form. For future work we will consider that the original dataset was taken with high spectral resolution telescopes, however, solid cometary materials are better detected with a low-resolution instrument that records broader band peaks associated with emissions from solids. By comparing multiple orders of the reduced data, we can resolve broad band peaks in the high-resolution dataset and constrain the spatial composition of solid materials in comet NEOWISE. Here, we present preliminary results on the spatial profiles derived from this analysis.

Helical-Structured Materials 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.

Neural Style Transfer for Improved Synthetic PC-MRI Image Quality
Adnan Contractor
Mentors: Shreyas Vasanawala, Matthew Middione, Julio Oscanoa, and Yisong Yue

A problem associated to Phase Contrast Magnetic Resonance Imaging (PC-MRI) in clinical settings is prolonged acquisition times and subsequent reduced measurement accuracy. An existing deep learning-based reconstruction technique termed DL-ESPIRiT has been supplemented with methods in parallel imaging and compressed sensing, of which the results have demonstrated reduction in scan times for two dimensional (2D) cardiac cine MRI by a factor of twelve. Recent applications of generative adversarial networks have suggested the potential of synthetic data to train DL-ESPIRiT, but the visual detail of synthetic data generated thus far has been simplistic. Here, we propose a neural style transfer model to improve the geometric detail and resolution of synthetic data. We apply a Pytorch implementation on real and synthetic PC-MRI image pairs, concatenate phase and magnitude components into a two-dimensional representation, and run LBFGS and Adam optimizers to create synthetic images with improved saturation and resolution. We study various alterations to the synthetic input such as rotations and color insertions to investigate degree of output change. Future work entails complete model training and accuracy analysis on DL-ESPIRiT.

Double Reductive Coupling Approach to Cylindrocyclophanes A and F
Stephanie Cortes
Mentors: Sarah Reisman and Sara Dibrell

We report a Nickel-catalyzed double reductive cross coupling of bis-electrophile substrates as an approach to a model system of cylindrocyclophanes A and F The cylindrocyclophane class of molecules is unique for its macrocyclic structure and the cytotoxic properties they express. Previous synthetic methods employ a dimerization method, wherein the dimerization substrate must contain both an electrophilic and organometallic reactive moiety. The recent advancements of Nickel-catalyzed cross electrophile coupling have motivated a new approach to the cylindrocyclophane core. This work will describe the application of Nickel catalysts in reductive cross coupling towards the cylindrocyclophane base structure, in hopes of elucidating a pathway towards cylindrocyclophanes A and F.

Changes in Electron Spin-Lattice Relaxation Rates in Nitroxyl Radicals as a Result of Spin-Phonon Coupling
Matthew Cox
Mentors: Ryan Hadt and Katie Luedecke

Except for exceedingly rare cases, the spin-lattice relaxation time (T_1) sets the upper limit for the coherence time of molecular qubits, the quantum form of the classical bit. As long coherence times are necessary for the use of qubits in applications such as quantum computing and quantum sensing, assessing factors affecting coherence times is of paramount importance. Recently, spin–phonon coupling terms describing S = 1/2 transition metal complexes were demonstrated to correlate with experimental coherence times; in particular, changes in the **g** tensor with respect to a coordinate Q_i along a normal mode of vibration *i* were shown to affect T_1 times. Following this, density functional theory (DFT) calculations at the B3LYP/def2-TZVP level of theory were performed on organic nitroxyl radicals to determine their normal modes of vibration and **g** tensor values at various displaced geometries along these vibrational modes, allowing for comparison of $\partial \mathbf{g}/\partial Q_i$ to experimentally determined T_1 times. Moreover, a physical cause of the **g** tensor's dynamicity—excited state orbital angular momentum mixing with the ground state—was investigated through both theoretical and experimental means.

Harmonic Maps and the Null Support Function
Miles Cua
Mentor: Peter Smillie

Results concerning harmonic maps have many consequences in both differential geometry and theoretical physics. In this project, we explore the asymptotics of harmonic maps to the hyperbolic plane by relating them to the geometry of entire spacelike constant mean curvature (CMC) surfaces in Minkowski space $\mathbb{R}^{2,1}$. We first apply existing results to describe a construction of spacelike CMC surfaces in $\mathbb{R}^{2,1}$ with appropriate monodromy data. We then study the support functions of entire spacelike CMC surfaces; in particular, we endow a topology on the set of such support functions and attempt to demonstrate a homeomorphism to the space of entire spacelike CMC surfaces identified by their Hopf differentials. Finally, we apply these ideas to relate the asymptotic behavior of null support functions to that of their corresponding harmonic maps to the hyperbolic plane.

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.

Investigating a Putative, Sexually Antagonistic Role of an Essential piRNA Pathway Component in *Drosophila melanogaster*
Suchitra Dara
Mentors: Alexei Aravin and Peiwei Chen

Abstract withheld from publication at mentor's request.

Developing Optimal U-Net Variant to Reconstruct Undersampled Magnetic Resonance Imaging (MRI) Images to Improve Image Quality
Rajeev Datta
Mentors: Shreyas Vasanawala, Yan Wu, and Doris Tsao

Although one of the most widely used image modalities, MRI scans can be lengthy. Long scans mean more discomfort for patients and higher chances of motion artifacts. A solution to this problem is to undersample the k-space. To prevent loss of resolution, neural networks could be employed to map undersampled MRI images into corresponding higher-quality images. Unfortunately, current predictions do not contain the needed level of detail for clinical settings. To address this problem, my project explored implementing self-attention, a mechanism that allows non-local relationships between points in images to be learned, to improve the quality of reconstructed images. We validated the method in MRI images of the knee. We investigated three models: V-Net, V-Net with self-attention in encoder, and V-Net with self-attention in both encoder and decoder. The models were trained using 44 subjects and tested on five other patients. The baseline V-Net had an average Peak signal-to-noise ratio (PSNR) of 44.160, while the other two models demonstrated a slight improvement with values of 44.168 and 44.187, respectively. We are currently implementing perceptual loss to improve performance. Afterward, we will test models on a publicly available dataset to ensure that their performance translates to other datasets.

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.

Blind X-ray Pulsation Searches in Millisecond Pulsars
Audrey DeVault
Mentors: Fiona Harrison and Amruta Jaodand

NASA's NuSTAR (Nuclear Spectroscopic Telescope Array) satellite is a telescope that extends through the hard X-ray range (5-80keV) and is used to observe many types of X-ray sources, including pulsars. Pulsars are neutron stars emitting coherent, pulsed emissions. Tracking these pulsations allows us to understand the intrinsic spin period of the pulsar and its evolution. Both of which may help answer a fundamental question as to how, sometimes, pulsars are recycled to spin frequencies as rapid as 700 Hz. Last year, we developed and tested a timing analysis pipeline to construct long term spin down solutions for a wide range of millisecond period pulsars. Most known pulsars are found in binary configurations with companion stars. Our initial pipeline utilized known orbital parameters of the binary as a starting point, and thus was only applicable to pulsars with pre-existing ephemerides. We have therefore developed a blind pulsation search pipeline capable of constructing timing models for pulsars without known parameters, enabling us to explore a wider range of candidates. This updated pipeline was developed through comparison with the previously developed pipeline using a well-studied test object, SAX J1808.4-3658, a nearby, bright, accreting millisecond pulsar. We present the effectiveness of this pipeline.

Why Do All Galaxies Evolve the Same Way?
Andrei C. Diaconu
Mentors: Charles L. Steinhardt and David J. Stevenson

Star formation depends upon the competition between gravity and thermodynamics in cool gas clouds. Since galaxies have different sizes, shapes, and colors, these clouds might be expected to have a variety of properties and thus galaxies should grow very differently from one another. However, recent observations indicate that galaxies have very similar star formation rates, a result known as the Star Forming Main Sequence (SFMS). We explore the relationships between mass, star formation rate, temperature, and environment for galaxies in photometry catalogs (COSMOS2020 and COSMOS2015) in search for a model that could predict the SFMS. We also use purely empirical methods to explore the data and provide new fits that could lead to the discovery of new effects that are responsible for this behavior.

Enhanced Circulation of Exogenous Gas Vesicles via Zwitterionic Polymer Coating
Tighe Didden
Mentors: Robert H. Grubbs and Jeong Hoon Ko

Gas vesicles (GVs) are naturally occurring protein structures that form nanometer-sized gaseous compartments. Recently, ultrasound bioimaging using GVs as genetically coded contrast agents have demonstrated much potential due to their superior imaging depth and low operation cost. However, the approach is mostly limited to GVs that are expressed in situ by cells themselves. Exogeneous GVs, which are produced externally and administered to the target organism, can be chemically modified with various functional groups but are currently hindered by limited availability after administration due to rapid immune clearance. In this project, I have functionalized the GVs with polymers to reduce their in vivo elimination. I have explored two approaches: (1) direct acrylate nanogel synthesis and (2) aqueous reversible addition-fragmentation chain-transfer (RAFT) polymerization combined with copper catalyzed azide-alkyne cycloaddition. For the RAFT polymerization approach, I have developed precursors to a new water-soluble chain-transfer agent which will be compatible for use with zwitterionic monomers that have good half-life enhancing ability. We conclude that zwitterionic polymer coatings improve GV half-life to allow use of GVs for various biomedical applications.

Graph Neural Networks for Cell Tracking
Rachel Ding
Mentors: David Van Valen, Erick Moen, and William Graf

Live cell imaging experiments hold significant promise for understanding dynamic cell processes and can aid in drug discovery for a variety of human diseases. While interpretation of imaging data provides valuable insight into cell processes, researchers spend countless hours on the computational analyses of cell image sequences, including identifying and tracking single cells and their divisions. To address this, the Van Valen lab has turned to adapting deep learning-based object tracking algorithms in computer vision to track cells across image sequences. One main adaptation is utilizing graph neural networks to create a more scalable deep learning model in order to enable single-cell analysis for others in the field. For this project, we apply the methods associated with graph neural networks to represent information of neighboring cells, replacing the method of cropping and reshaping each cell’s neighborhood. On the software development side, we modify and test methods that prepare datasets for training by the model. Using the python package spektral, we implement multiple graph neural network architectures within the model and systematically benchmark the performance of each on fluorescent nuclear images.

Exploring the Discovery Reach of the CMS Muon System in Detecting Long-Lived Heavy Neutral Leptons (HNL)
Gabrielle Dituri
Mentors: Maria Spiropulu, Christina Wang, Cristian Pena, and Si Xie

The goal of this project is to search for Heavy Neutral Leptons (HNL, explained by the see-saw mechanism), which are a type of long-lived particle (LLP), and determine how well the Muon System detects these particles. HNL are a Beyond the Standard Model (BSM) particle, meaning we cannot directly study these particles and must instead access them through decays of bosons (W, Z, or H). Specifically, we are looking for decay particle showers from these LLPs in the Cathode Strip Chamber (CSC), the endcap Muon System in the Compact Muon Solenoid (CMS). Simulated signal samples of LLPs with different masses, lifetimes, and decay modes are studied by analyzing the cluster of reconstructed hits (RecHits) deposited by the showering of the LLP decays. Furthermore, we wanted to understand how the number of RecHits are related to energy and the decay position of the LLPs. Preliminary study shows that the energy of the LLP and decay position affects the distribution of decay particles.

Simulating the Impact of Rockfall Erosion on Mars Topography
Patrick Donohoe
Mentor: Michael Lamb

Gullies on the walls of Mars craters have been conjectured to have been eroded by flowing water in recent Mars history. However, we hypothesize that dry rockfall could also be a mechanism to create gullies without flowing water. We tested this hypothesis by building a numerical model to investigate the impact of rockfall erosion on gully formation along the walls of Mars craters by modeling individual grains in rockfall as they travel down a surface. The model simulated the erosion of different topographic surfaces by calculating the erosion at each point where the individual grains bounce off the surface. The trajectory of the incoming grain relative to the slope and orientation at the point of impact set the trajectory of the next bounce. Topography was updated every 1, 100, and 1000 grains. The model has been run over several different types of surfaces, including a concave and convex surface, as well as a sloped surface with a channel already present. We observed that rockfall created channels on concave and convex topography. This is very significant in the context of Mars, because it means that gullies could have been formed on walls of craters without the presence of water.

Convergent Approach Towards the Synthesis of Ineleganolide
Emily Du
Mentors: Brian Stoltz and Tyler Fulton

We have pursued the early stages of a novel strategy for the total synthesis of ineleganolide, a complex tetracyclic norcembranoid. The strategy involves a late-stage intramolecular carbon-carbon coupling to generate the seven membered ring and bridging dihydrofuran from a tricyclic precursor. The precursor, which contains the necessary atoms to form the final carbon backbone of the compound, may be accessed from a bicyclic α-hydroxy ketone and *des*-methyl carvone derived-enone. We predict that establishing the stereochemistry of this molecule may be challenging due to its curved form and several stereocenters.

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.

Implementation of an Aerosol Activation Scheme
Isabella M. Dulá
Mentors: Tapio Schneider and Anna Jaruga

Aerosol particles suspended in the atmosphere can be nucleation points for the formation of cloud droplets. The chemical properties and concentration of an aerosol population have a significant effect on the complex and dynamic process that leads to the condensation of saturated water vapor around aerosol particles, also known as aerosol activation. Most global climate models, such as CliMA, cannot sustain a resolution high enough to directly resolve aerosol activation, and thus parameterizations are developed to quantify and predict the salient effects from these processes. This project implements and assesses an aerosol activation parameterization posited by

Adbul-Razzak and Ghan (2000). The parameterization takes as input parameters local atmospheric conditions and the aerosol population and outputs the number of activated aerosol particles in a given air parcel. This parameterization is a powerful tool that can aid in predictions surrounding clouds, precipitation, and the climate at large. The parameterization is nearly implemented and is currently undergoing an external validation against PySDM, a model that directly resolves the behavior of the aerosols. This will characterize off-nominal behavior of the parameterization and to ensure the outputs are consistent with higher-fidelity models. The aerosol activation scheme will be integrated into CliMA, an Earth system model.

Measuring the Time Resolution of the TOFHIR Chip for CMS Phase-2 Upgrade
Ismail Elmengad
Mentors: Maria Spiropulu and Anthony LaTorre

CMS or the Compact Muon Solenoid is a particle detector at CERN that has detected many novel physics events. One of the problems that CMS faces is nearly-simultaneous pile-up interactions that occur in bunch crossings. The Barrel Timing Layer (BTL) of the MIP timing detector is a cylindrical detector designed to detect MIPs with a time resolution of 30 ps and a luminosity-weighted time resolution of 40-50 ps. The BTL will be read out by an ASIC, the TOFHIR chip, which collects data from 32 silicon photomultipliers. The true timing resolution of the TOFHIR chip has been measured previously at several over voltages and MIP energies by peer institutions. This project provides a cross check for the previously obtained results as well as expected true time resolutions and luminosity-weighted resolutions over a larger parameter space including a new variable of threshold voltage. Using an ultraviolet laser to mimic MIPs, it is found that the TOFHIR chip achieves the desired time resolutions.

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.

Using Bayesian Inference to Quantify Uncertainty in Glacier Ice Friction and Velocities
Aaron Feldman
Mentors: Houman Owhadi and Peyman Tavallali

Models for estimating ice-sheet velocity are important for understanding the change in ice mass in Antarctica and Greenland and the corresponding impact on sea levels. To assess the validity of such predictions, it is important to quantify the corresponding uncertainty on these estimates. Here we demonstrate a Bayesian approach to velocity uncertainty quantification applied to the Ice-Sheet and Sea-Level System Model (ISSM). By viewing the velocities as a noisy transformation of the input friction field, we can use measured velocities to infer a distribution over the friction inputs, the output modeled velocities, and quantify the level of model error. Initial results indicate that our approach is able to provide appropriate velocity confidence intervals of varying levels evaluated using a hold-out set of measured velocities. Furthermore, we find that the uncertainty from model error dominates the uncertainty regarding model inputs. Specifically for the ISSM, these results suggest that efforts for improving velocity estimates should likely focus on reducing model error as opposed to providing more measurements. More generally, these results illustrate the viability of the Bayesian uncertainty quantification framework for ice-sheet velocity estimation.

A Family of pH-Tolerant Genetically Encoded Biosensors for Rapidly Acting Antidepressants (RAADs)
Eve Fine
Mentors: Henry Lester and Kallol Bera

The Lester Lab has previously used biosensors to study the localization and pharmacokinetics of rapidly acting antidepressants (RAADs) in cells. However, only neutral and alkaline parts of cells were able to be imaged due to the pH sensitivity of the circularly permuted green fluorescent protein (cpGFP) region of the biosensor. Typically, when a target drug molecule binds to its respective biosensor in the periplasmic binding protein, the cpGFP region of the biosensor fluoresces. In acidic environments, however, this action is greatly attenuated and the biosensors fail to serve as indicators of the drug's presence. So, by using site saturation mutagenesis on the cpGFP, I have created a new class of biosensors called intensity based RAAD sensing fluorescent reporters tolerant to acidic environments (iRAADFReTAs). These biosensors, unlike their predecessors, are able to have an acute fluorescent response to their corresponding drug in low pH environments. These new biosensors will allow the imaging of RAADs in acidic areas of the cell such as synaptic vesicles, vesicles, and the lysosome; RAADs have been previously thought to accumulate in these locations due to their slightly basic nature. The use of iRAADFReTAs will offer important insight into the localization of RAADs in cells, which may contribute to determining their overall mechanism.

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.

Synthesis of Electrolytes for Rechargeable Mg and Ca Ion Batteries
Tyler Fox
Mentors: Theodor Agapie, Meaghan Bruening, and Tianyi He

The development of safe, efficient, and sustainable alternatives to Li-ion batteries is a critical to the preservation of our electronics dependent society. While Li-ion batteries have been revolutionary for their recharging capabilities, the high cost, the scarcity of lithium, and the frequent formation of dangerously reactive dendrites drives research for alternative ion battery systems. We have been working in collaboration with the See Group to investigate potential electrolytes for Mg and Ca ion batteries. This project focuses on the synthetic development of these electrolytes, which have been characterized using multinuclear NMR and ICP-MS. Subsequently, the See Group uses their electrochemical expertise to analyze the electrochemical properties of the electrolytes. Our team is currently working on the clean synthesis of literature-based aluminates to compare to the electrochemical data from the unclean aluminates. We are simultaneously investigating novel phosphate electrolytes with compatible potentials for Mg and Ca ion batteries. Future work includes the continued synthetic and electrochemical characterization and development of Mg and Ca electrolytes.

Determining Atmospheric Formation of C5 and C6 ROOR Compounds
Tea Freedman-Susskind
Mentors: Paul Wennberg, Sara Murphy, and Reina Buenconsejo

Understanding the formation of secondary organic aerosol (SOA) is one of the defining challenges of modern atmospheric chemistry. In one such process, vast amounts of non-methane hydrocarbons emitted into the atmosphere interact with highly reactive oxidants and form peroxy radicals (RO_2), which go on to react with other compounds. Our work investigates the RO_2 self-reaction, forming an ROOR accretion product. We specifically investigated those originating from both cyclic and noncyclic C5 and C6 alkenes, such as cyclohexene, cyclopentene, and 1-methyl-3-butene. We studied C5 and C6 oxidation in the lab to detect ROOR formation using a GC-CIMS. We will additionally investigate these compounds in the ambient air during a field campaign on the Caltech campus during August 2021. Preliminary experiments provided direct confirmation that noncyclic C5 compounds form the ROOR accretion product and evidence that it is formed with cyclic C5 and C6 compounds as well, however the size of the molecules make them difficult to detect directly. We expect to directly detect or find evidence of relevant accretion product formation.

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.

Smart Fabrics With Active-Fiber and Interlocking-Particle Controlled Stiffness
Diana Frias Franco
Mentors: Chiara Daraio and Tracy Lu

Smart fabrics are a unique subset of wearable materials which can sense and respond to environmental stimuli by varying their mechanical properties—such as stiffness and drapability. The modular basis for these designed fabrics is discrete, granular pieces which, together in an assembly, are known to undergo changes in their mechanical properties during a process known as jamming—a phase transition which is independent of temperature changes and is instead controlled by local granular, geometric constraints. By varying the unit size of these particles, we can further understand the scaling laws that govern the jamming behavior of woven particle-sheets which are actuated by tension in a nylon wire. After designing apparatuses to measure specific material parameters—such as bending torque and interparticle friction— we can further quantify and characterize the particle-jamming, which will aid in future attempts to create fabrics with desired tunability and stiffness. The development of this project will allow for understanding and creating better haptic wearable devices.

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.

Computational and Experimental Framework for Understanding Dauer Development in Nematodes
Sahana Gangadharan
Mentors: Paul Sternberg and Vivek Venkatachalam

The dauer mode of development in nematodes under stressful conditions provides an interesting model to study phenotypic plasticity. Investigating this mode of development in different species, along with the normal mode in a single species, could offer potential insights into the evolutionary significance of the dauer stage. We carried out two projects that probe the dauer mode - an exploration of the extent of cross-species pheromone signalling between *C. elegans* and *O. tipulae*, and a comparative study of dauer-recovered and wild-type normal *S. hermaphroditum* worms. To further understand nematode behaviour, we set up a computational framework that enables whole-brain imaging and analysis by constructing a convolutional neural network which, when fed with volumetric raw image data and pre-processed versions of the same, learns to output the neuron labels. Future work will focus on extending this study to similar behaviours and other nematode species, and incorporating the segmentation network into a tracking pipeline, thereby facilitating the study of freely behaving animals for longer durations.

3D Mesh Sculpting From 2D User Input
Lucy Gao
Mentors: Santiago Lombeyda and George Djorgovski

2-dimensional and 3-dimensional spaces each have their split of advantages and disadvantages in our modern world-- while our day-to-day lives revolve around experiences in 3D, many users find sketching and brainstorming in a 2D workspace more intuitive. To address this, a web application that allows modeling and sculpting of a 3D mesh from 2D user input was created, with an end goal to generate organic 3D meshes based on the extruded projections of mouse input from two perpendicularly positioned 2D screens. Built utilizing web based technologies such as Babylon.js, the project utilizes constructive solid geometry with implicit surfaces, point rendering, and isosurfacing via marching cubes. The group has thus created a useful, robust 3D modeling tool for lab use, architectural design, and artistic modeling purposes that can be extended or embedded into virtual worlds or virtual reality in the future.

Dye Filling in Head Neurons and Characterization of Head Neuroanatomy in New Nematode Species
Pranjal Garg
Mentor: Paul Sternberg

Steinernema hermaphroditum due its mutualistic behavior with bacteria and entomopathogenicity holds significant potential to be used as a tool for studies related to these behaviors. To study this new experimental nematode, we, further examine its neuroanatomy to lay the foundation of further behavioural studies and provide a neuroscientific perspective of symbiosis and pathogenicity. The staining of head neurons is a useful method to characterize head neurons, especially amphids and inner labial neurons. Based on dye filling and spatial assessment, we have characterized *Caenorhabditis elegans* homologs of IL1, Il2, ASI, ADL, ASK, and ASJ in S. hermaphroditum. We also performed a series of experiments to determine the appropriate dye filling condition in different dye concentrations, incubation solutions, and staining duration.

Cardiac and Single Neuron Responses to Inter-Ictal Epileptiform Discharges in the Human Brain
Mahideremariyam Gessesse
Mentor: Ueli Rutishauser

In addition to seizures, patients with epilepsy exhibit abnormal and brief electrical discharges during the quiescent period between seizures. Although these Interictal Epileptiform Discharges (IEDs) are common in patients with epilepsy, it is not conclusive whether IEDs function to induce seizure onset or prevent it. Previous research has demonstrated a correlation between heartrate variability and IED occurrence in both humans and animals suggesting that the relationship between IEDs and the autonomic nervous system could serve as a biomarker for seizure onset.

Our research aims to identify a lockstep phenomenon in humans – where autonomic dysregulation is observed around an IED event – with the resolution of milliseconds and single neurons, which has not been previously done. We used cardiac data (2 lead EKG) and neural data (single neuron spikes) recorded simultaneously from patients with electrodes implanted for monitoring the source of intractable epilepsy. We developed a toolkit of features to assess heart-rate variability including, among other metrics, time-frequency analysis of the inter beat interval (IBI) series.

Our ongoing research will align IED events with the cardiac metrics and neural spike trains to identify any correlations - the analysis of which may help identify a biomarker for possible seizure onset.

Understanding Effects of Deep Brain Electrical Stimulation on Individual Neurons in the Human Brain During Memory Tasks
Adishree Ghatare
Mentors: Ueli Rutishauser, Clayton Mosher, and Mar Yebra

Electrical stimulation of the brain can help establish causal relationships between neuronal activity and behavior. In our lab, we use microelectrodes in human patients to track how stimulation affects single neurons and behavior. However, electrical stimulation creates an artifact that dominates the recordings, impeding our ability to identify neuronal action potentials during stimulation.

Here we aim to differentiate the underlying signal from the artifact to identify how stimulation affects neurons. Specifically, we hypothesize that, since different types of neurons show distinctive electrophysiological properties, certain cell populations can be targeted by parameterizing stimulation frequency, waveform, and location.

To test our hypothesis, we stimulated various deep brain structures at three frequencies (8, 50, 140 Hz) in human subjects being monitored for intractable epilepsy. We employed multiple algorithms to remove the artifact (e.g., frequency matching, template subtraction, principal component decomposition) and developed metrics to evaluate each algorithm's efficacy (e.g. comparison of power spectra, amplitude reduction). To evaluate ground truth efficacy, we added simulated neural spike data to the raw signal and determined the recovery rate of successfully detected spikes after cleaning.

Preliminary results suggest that removal algorithms yield higher efficacy on spatially closer channels with more distinct artifacts, with a template subtraction method as the most promising over low frequencies (<3 kHz). After identifying the optimal algorithm, we will determine how cells with different action potential waveforms are differentially impacted by stimulation.

Practical Limits on the Density of Neurochemical Sensors
Vale Glasser
Mentor: Jessica Arlett

Current neuroscience has a great need for useful means to measure dynamic, local neurochemical levels in a living brain. The probes to accomplish this must be very small in order to minimize damage to adjacent tissue, and must maximize sensor density in order to capture as much information as possible with minimal brain damage. In this paper, we focus on understanding practical limits to achievable electrochemical sensor density for enzymatic neurochemical sensors, chiefly the issue of chemical cross-talk. Chemical cross-talk is the process in which a hydrogen peroxide molecule produced in a reaction with the neurochemical of interest on a sensor surface travels to an adjacent sensor and is instead detected there. These false readings hamper the effective resolution of neurochemical signals that can be detected, motivating efforts to minimize this phenomenon. We have shown a catalase coating in the space between sensors to be effective at mitigating this in both static and dynamic flow regimes. A consequence of this is that sensor spacing is limited by the capacity to deposit thin lines of catalase, which we have demonstrated using a microplotter system.

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.

The Berkovich Projective Line as a Coarse-Graining of Non-Archimedean Space
Alan Goldfarb
Mentor: Sarthak Parikh

The Anti-de Sitter/Conformal Field Theory correspondence (AdS/CFT) is a conjecture which describes a deep equivalence between a theory of gravity in asymptotically anti-de Sitter spaces and conformal field theory on their boundaries. It is often desirable to work with analogues of anti-de Sitter space which consist of discrete geometries rather than continuous ones. One such analogue is formed by identifying the bulk of anti-de Sitter space with the Bruhat-Tits Tree T_p and identifying the boundary with the p-adic numbers Q_p. However, this identification carries dissimilarities with Archimedean AdS/CFT, so it may be worthwhile to examine other identifications. This project seeks to explore the potential of identifying the bulk of anti-de Sitter space with $C_p^* \times C_p$ where C_p denotes the completion of the algebraic closure of the p-adic numbers. To do this, we determine the relationship between $C_p^* \times C_p$ and T_p by performing a coarse graining on $C_p^* \times C_p$ to obtain the Berkovich projective line. The appearance of the Berkovich projective line is reassuring as it contains T_p as well as C_p and has a well-defined theory of analytic functions.

Simulation of Single- and Multi-Ingredient Food Designs for Three-Dimensional Food Printing
Shir Goldfinger
Mentors: Hod Lipson and Melany Hunt

Three-dimensional (3D) printing of food is a novel application of additive manufacturing that utilizes food as a substrate to create edible food products for consumption. While typical additive manufacturing techniques use one or two man-made materials (e.g. plastics, metals, glass, etc.), printing with food requires the use of pulverized ingredients that have unique viscoelastic characteristics. Because of the complexity of the properties of these food ingredients, it is important to be able to simulate single- and multi-ingredient food designs prior to printing as a means of validation. Just because one can design a multi-ingredient food structure in software, does not necessarily mean that it can be fabricated to the same degree of resolution. And so, we have developed a simulator that takes a 3D food printer's digital recipe file (.gcode) as an input and creates a physics-based fluid model of the corresponding 3D food printing process. Our simulator gives us the ability to adjust the ingredients' properties, such as the viscosity and color, as a means of replicating the physical printing process.

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.

A Quantitative Neumann's Lemma and Investigation of Group Growth
Elia Gorokhovsky
Mentor: Omer Tamuz

The *growth rate* of a discrete finitely generated group is the number of elements in the group of word length at most n as a function of n. The gap conjecture for finitely generated groups states that there are no groups with superpolynomial growth rates that are asymptotically less than $e^{\sqrt{n}}$. A crucial result related to this conjecture is Gromov's theorem, which states that any group with a polynomial growth rate is nilpotent. We investigate the gap conjecture and group growth with the goal of finding a new proof of Gromov's theorem. We study coverings of finite subset of groups by cosets of infinite index to prove a quantitative analogue of Neumann's lemma, which says that a group cannot be covered by finitely many cosets of infinite-index subgroups. We also present a probabilistic property of groups that is equivalent to virtual nilpotency. A proof that this property is equivalent to polynomial growth would imply Gromov's theorem.

Reaction Pathways for the Synthesis of Laser-Coolable Molecules
Aikaterini Gorou
Mentors: Nicholas Hutzler and Phelan Yu

Ultracold, laser-cooled molecules are powerful platforms for precision metrology, quantum information, and studies of fundamental physics. Over the past decade, several classes of increasingly complex metal-containing molecules have been shown to be laser-coolable due to their favorable internal structure. The chemical diversity and complexity of these new target species, however, requires non-traditional approaches for achieving efficient synthesis, particularly in cryogenic environments. One approach is to coherently prepare chemical precursors in long-lived electronic excited states, allowing reactions to proceed along energetically favorable pathways that are unavailable to ground state reactants. In this work, we generalize previous results to explore exothermic pathways for excited-state syntheses of a broad class of polyatomic, alkaline earth pseudohalogens that are laser-coolable. Using density functional theory, we characterize the potential energy surface, critical points, and dynamics of several reactions between the ^1S and ^3P states of alkaline earth metals and cryogenically compatible gas-phase reagents (e.g. H_2O and SF_6). These results further our understanding of optimal reagents and reaction conditions for efficient low-temperature production of complex laser-coolable molecules.

Separately, we also present results for the design, construction, and characterization of a tunable, narrowband 520 nm external cavity diode laser system for molecular spectroscopy and optical tweezer trapping.

Election Forensics and Anomaly Detection in the 2020 Georgia Election Cycle
Akshay Gowrishankar
Mentor: Michael Alvarez

In the current age of heightened partisanship and weakened trust in election results among many groups, it is crucial that we study the integrity of our voting systems to maintain trust in our democracy. In both of the last two presidential elections, concerns about election security were raised, with Jill Stein's campaign calling for a recount in Wisconsin in 2016 and with the Trump campaign unsuccessfully requesting investigations into the election results of six battleground states in 2020. Thus, we have analyzed precinct level election results from the November 2020 general election in Georgia and the January 2021 runoff election in Georgia, as well as demographic data and past election data from the state to search for anomalies in this year's results, which would be present if the Trump campaign's allegations of vote rigging and fraud were true. We have used a random forest machine learning model to predict the expected vote share for President Biden, as well as the total number of votes, in every precinct based on demographic data and the data from the Senate elections, and we identified the precincts that deviated the most from these expectations.

Extended DGNSS-Vision Integration for Relative Spacecraft Navigation
Hannah Grauer
Mentors: Soon-Jo Chung and Alexei Harvard

The Aerospace Robotics and Control laboratory at Caltech developed an algorithm for relative spacecraft navigation that fuses GNSS and vision technology. This novel method utilizes GNSS observations and monocular vision measurements collected from two spacecraft in high earth orbits. By tightly coupling the measurements from both methods in a batch filter which recovers the integer ambiguities, integer ambiguities are recovered much faster, along with a higher accuracy compared to using both approaches individually. This project focuses on implementation and extension of such algorithm for swarms of spacecraft. The algorithm uses a mixed integer graph that takes GNSS and vision observations to estimate the relative positions of the spacecraft. The extended algorithm was then combined with an existing visibility program and validated using GNSS signal generators.

Introducing miRNA Control Elements Into Gene Therapy Constructs
Anastasiya (Nastya) Grebin
Mentors: Viviana Gradinaru and Acacia M. Hori

Abstract withheld from publication at mentor's request.

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.

Effect of Acid Rain Conditions on Aluminosilicates
Tomas Grossmark
Mentors: Katherine Faber and Celia Chari

For the proper restoration and conservation of ceramic art pieces, an understanding of how acid rain conditions can alter aluminosilicates is necessary. In this study, the effect of sulfur-containing acids and hydration on the surface chemistry of aluminosilicate minerals, specifically mullite, kaolinite, metakaolin, and sillimanite, are evaluated. Powders of these minerals were immersed in sulfuric acid baths of various pHs. Additionally, powders were subjected to an environment of sulfur dioxide gas or subjected to an environment of high moisture using an exposure chamber. Using X-ray photoelectron spectroscopy, the aluminum-to-silicon ratio and change in binding energies due to exposure were observed. These observations were aided by Fourier transfer infrared spectroscopy to understand changes to the surface bonding. As pH decreases, the aluminum-to-silicon ratio decreases, and the Al 2p binding energy increases, showing both surface de-alumination and a shift from tetrahedrally bound to octahedrally bound aluminum. The mechanism of de-alumination is also probed through aluminum sulphate extraction experiments. This work supports previous predictions of kaolinite surface de-alumination from Density Functional Theory simulations and adds insights into the interactions between other aluminosilicates and sulfur-containing acids.

Coq Formalization of Alpha-Equivalence and Type Systems

Joshua Grosso
Mentor: Michael Vanier

Interactive theorem proving is the subfield of computer science and mathematics concerned with automated verification of mathematical proofs and computer programs. Despite the significant potential of interactive theorem proving, the corpus of machine-formalized material is quite small. We hope to help expand it by formalizing portions of *Types and Programming Languages* (Pierce, 2002), a seminal textbook in type theory, in the Coq proof assistant. We aim to formalize definitions, theorems, and proofs about polymorphic type systems, higher-order type systems, type systems with recursive types, and more. As part of this effort, we are focusing this SURF period on formalizing *Functional Pearls: alpha-equivalence is easy* (Altenkirch, 2002), which defines alpha-equivalence and -conversion in an elegant manner.

Designing Grating Couplers for Coupling to Hybrid Photonic Crystal Resonators

Wenyan Guan
Mentors: Andrei Faraon, Chun-Ju Wu, and Andrei Ruskuc

Optically interfaced solid-state spins are promising platforms for quantum technologies such as photon gates and quantum networks. Various systems with nanophotonic cavity structures have been widely investigated as promising candidates. This project works on the spin-photon platform of single $^{171}Yb^{3+}$ ions inside an yttrium orthovanadate (YVO_4) host crystal coupled to a gallium arsenide (GaAs) nanophotonic cavity. At zero applied magnetic field, the $^{171}Yb^{3+}$ ions are coupled to the GaAs resonators which enhances the light-matter interaction and optical emission rate via the Purcell effect. Several techniques are available for coupling the light from devices to the free space mode. Grating couplers (GC) can be used to extract light from planar waveguides and radiate it out of the plane to far-field radiation modes and single-mode optical fibers. To provide good mode matching to optical fiber single modes, we simulate and design a single step etched GC based on 2D photonic crystal subwavelength grating (SWG) with apodized structure.

Development of a Meta-Feature Generation Algorithm for Univariate Regression

Rishi Gundakaram
Mentors: Pablo Moscato and Claire Ralph

It is well established that a machine learning model's ability to fit and generalize on data is improved when features are engineered from existing data using knowledge about the problem, called meta-features. However, the feature engineering process can be time-consuming and expensive because it may require research and consultation. Thus, we aim to automate the meta-feature generation process. Meta-features are typically produced by combining features through operations such as multiplication, division, and addition. We developed an iterative algorithm that progressively generates meta-features. We evaluated the performance of this algorithm on eighty datasets from the Penn Machine Learning Regression Library using different regressors after the meta-features were generated. The algorithm improved the performance of regressor algorithms such as XGBoost, Random Forest, and Linear Regression over the eighty datasets. Parameterization of the meta-feature generation algorithm for specific problems may lead to significant improvements in performance compared to using a regressor alone. In the future, we aim to adapt the meta-feature generation algorithm to the problem of fitting piecewise polynomial functions to data.

Using Cell-Free DNA to Noninvasively Analyze Tumor-Infiltrating Lymphocytes

Bilge Gungoren
Mentors: Aadel Chaudhuri, Irfan Alahi, Abul Usmani, and David A. Van-Valen

Characterizing tumor infiltrating leukocyte (TIL) populations in patients with cancer could help develop personalized immunotherapy and lead to better prognosis for patients. Here, we propose using cell-free DNA (cfDNA) as a biomarker to characterize TILs via a liquid biopsy, attainable via routine blood draws. We are developing a novel bioinformatic method of in silico cytometry to estimate proportions of cell types/states in TILs based on bulk whole genome bisulfite sequencing (WGBS) data by tracking CpGs, methyl groups attached to the DNA, at the single molecule level. We are identifying differentially methylated regions (DMRs) in whole genome bisulfite sequencing (WGBS) data obtained from purified reference cell types/states, and we aim to apply this reference to the bulk mixture. This way, we hope to identify individual cell types/states in the bulk mixture by comparing to the reference (ultra-high-resolution digital cytometry). Upon completion, our hope is that through the analysis of methylation signatures, cfDNA can aid in specializing immunotherapy to improve prognosis in cancer patients.

Robust Image Classification Using GAN Inversion
Brandon Guo
Mentor: Anima Anandkumar

Modern neural networks are often susceptible to corruptive effects on images. For example, additive noise (Gaussian, impulse) and weather effects (snow, fog) can completely alter a neural network's semantic understanding of an image, whereas humans remain relatively robust to these corruptions. Here, we propose a zero-shot, unsupervised image classification method that takes advantage of the latent representation given by the StyleGAN generative adversarial model (GAN). In particular, we use an encoder-optimization approach to find the optimal code in W+ space that generates an image (reconstruction). Using this code, we build a classifier that takes advantage of both the image representation (as do typical models) as well as the estimated W+ code. Additionally, since the W+ codes are disentangled for a given image, we perform different types of augmentations on these codes to generate fictional images that retain certain semantic meaning. To evaluate our method, we curated a database of corrupted images from the CelebAHQ dataset, which we call CelebAHQ-C as a testbed for model generality to corruptions. We test our methodology against certain baselines, such as the ResNet and other recent models in literature.

Developing and Testing Lumped Element Kinetic Inductance Detectors for the LMT and TIM
Tanmay Gupta
Mentors: Charles M. Bradford and Reinier M. J. Janssen

One of Cosmology's many pursuits is the history of star formation. When were the many stars that populate the sky born? When searching for an answer, previous sky surveys have focused on only the brightest galaxies. This leaves most galaxies at the peak of star formation 7 to 10 billion years ago unaccounted for as they are in the background. The Terahertz Intensity Mapper (TIM) is a NASA stratospheric balloon mission that aims to map star formation activity in these overlooked galaxies between redshift $0.5 \leq z \leq 1.5$ using line intensity mapping. TIM employs a new detector technology called Lumped Element Kinetic Inductance Detectors. These detectors are composed of arrays of superconducting resonators which can all be read out simultaneously. This summer we made further diagnostic measurement pipelines to move from a 64-pixel array to the 1000-pixel array, and ultimately the whole 8000-pixel array. In particular, we focused on ensuring the accuracy of measurement systems.

SuperSpec is an on-chip spectrometer developed for deployment on the Large Millimeter Telescope in 2022. SuperSpec will focus on star-formation between redshift $4 \leq z \leq 8$. It uses similar technology to TIM and we have started working on the required infrastructure for installation.

Analysis of Composite Columns: Granular Material In-Fill Inside a Confining Annulus
Utkarsh Gupta
Mentors: José E. Andrade and Siavash Monfared

Affordable housing is becoming a fast-growing problem in all major parts of the world. The rising cost of land and construction has made housing more of a luxury than a basic human need. This study aims to analyze structural columns made using a confining annulus infilled with granular material. These columns will be not only be sustainable, but also reduce the transportation cost associated with bulky materials like cement and aggregates.

We modeled analytical structures of residential buildings in commercial analysis software to understand the range of loads the columns are expected to bear. With this data, Yield Strength equations for composite columns have been developed using different lateral pressure theories. Using the Buckingham-Pi theorem, we have derived pi-constants for the derived equation. Our study shows that the two most important parameters that determine the strength of the composite column are the Yield Strength of the confining material and the thickness of the annulus. We also concluded that using recycled metal as a confining material, we can achieve the required strength in composite columns for low rise residential structures.

Using Machine Learning to Classify Transients From Palomar Gattini-IR Telescope
Xander J. Hall
Mentors: Mansi M. Kasliwal and Dmitry A. Duev

Gattini-IR is a wide-field, near-infared robotic survey that is used to observe transient events such as Nova, Supernovae, and Variable Stars. These objects are found every night through real time alerts and are scanned for daily. Here we use a convolutional neural net to perform phenological classes of Gattini alerts. This classifier separates objects into nine different classes. We present promising outlook on the ability of the classifier.

Structure of the Karyopherin Alpha and NLS Complex
Tiba Hamza
Mentors: André Hoelz and George Mobbs

The Nuclear Pore Complex (NPC) is a megastructure composed of over 30 proteins measuring over 1,200 Å in humans, made up of a large symmetric core embedded within the nuclear envelope, decorated with asymmetric structures on both the nuclear and cytoplasmic faces. Karyopherin alpha (Kap-α) is a nuclear transport factor, which recognizes nuclear localization sequences contained within cargo proteins and acts as an adaptor to permit transit across the nuclear membrane. Karyopherin alpha is mainly used to bind to proteins to facilitate transportation for proteins larger than 40kDa since they cannot passively diffuse through the pore. It typically binds to a nuclear localization sequence of proteins that make up the pore along with that need transport. An investigation of karyopherin alpha has shown its potential usage in the assembly of the nuclear pore complex. Utilizing a biochemical approach large quantities of both NLS and Kap-α proteins have been expressed and purified used nickel affinity, ion, and gel filtration chromatography to form a complex for crystallization. Solving the structure will establish the molecular basis of these kinds of structures, having implications for understanding the binding of karyopherin alpha to nuclear localization sequences.

Detecting and Deterring Harmful Online Speech Directed at American Election Officials
Sarah Hashash
Mentors: Michael Alvarez, Danny Ebanks, and Claudia Kann

The integral role social media played in the dissemination of information and general political discourse during the 2020 American election has spotlighted the misinformation and conspiracy theories that circulate on these platforms. This misinformation has resulted in hate and attack speech directed towards officials and lawmakers involved in the electoral process, distracting them away from their work and potentially materializing as real-life attacks. Through the collection of Twitter data, retweet networks are created given a seed list of known election official accounts. These retweet networks are used to create machine learning methods to detect social media attacks and hate speech directed at election officials, in real time. The primary objective is to build tools to detect social media attacks on election officials and on the integrity of their work, tools that work in real time, and which can identify the underlying networks of those who are promoting and perpetuating these attacks.

Constraining HCN Production via HCN_2 at Titan for Applications to Prebiotic Chemistry
Kimia Hassibi
Mentors: Yuk L. Yung, Danica Adams, and Michael L. Wong

HCN is an attractive biological precursor that is vital in creating proteins and the nucleobase adenine, and it is known to be created in planetary atmospheres. However, the formation pathways of HCN in both Titan's and early Earth's atmosphere has not been fully described. While previous studies have modeled the atmosphere of Titan, they exclude HCN_2, which forms from CH + N_2 and reacts with H to form HCN. Here, we extend a photochemical model for Titan's atmosphere by adding HCN_2 and reactions involving it. To constrain the rate coefficients of these reactions, we compare our results to Cassini data of Titan's atmosphere and create a box model to simulate the laboratory setup of Trainer et al. (2012), which measured the nitrogen content of photochemical aerosols. Modern-day Titan has atmospheric chemistry similar to the chemistry in the Archean atmosphere. By determining the rate coefficients of the reactions of HCN_2 that likely occur on Titan, we can further determine the amount of HCN_2 and HCN in Earth's early atmosphere. This information will provide a more robust understanding of the conditions that led to the spontaneous generation of life on Earth and that could form life elsewhere in the universe.

Discovering Drugs That Act as Specific Inhibitors of DNA2
Marguerite Hewitt
Mentor: Judith L. Campbell

The protein DNA2 has a prominent role in restarting stalled replication forks, double-strand break resection, and 5' RNA/DNA flap removal on Okazaki fragments during DNA replication. Thus, the inhibition of DNA2 would make it more difficult for cancer cells to recover from damage done by more traditional cancer treatments. In the Campbell lab, we have identified compounds that exhibit an inhibitory effect on DNA2 in *in vitro* nuclease assays. *In vivo* tests with human cell lines, including breast cancer (BT549) and osteosarcoma (Saos-2 and U2OS) cell lines, were conducted to determine the half-inhibitory concentrations (IC50s) of the compounds. In addition, a variety of experiments were conducted which showed that the compounds were not interacting with the DNA directly but rather were on-target and were affecting cell growth via their inhibition of DNA2. In the future, the structure of the promising compounds identified in this project will be tweaked to make them even more specific to DNA2, and these tweaked versions can be re-tested with similar methods to identify the most effective drug, which will then move on to pre-clinical trials.

Impact of Rebroadcasters on Online Display Advertising Auctions
Sujai Hiremath
Mentor: Matthew Shum

An important revenue stream for many online businesses across the world is online advertising; websites attract consumers to their online content, and then sell ads on that content to other businesses who are looking to advertise their products. One of the fastest growing methods for facilitating the buying and selling of ads is 'real-time bidding' (RTB). As opposed to selling ads in bulk, an algorithmic auction is held where various companies submit bids, and the highest bidder wins the right to have their advertisement served to the consumer. A key component of these auctions are companies known as rebroadcasters: they receive bid requests in these auctions, but do not directly bid on the ad opportunity. Instead, they use their own technologies to send advertisers extra information about the consumer, allowing them to potentially bid twice in the same auction. This paper explores the presence and effect of such rebroadcasters on the market dynamics of the Yahoo! exchange.

***E. coli* Genome Minimization via REXER-GENESIS Re-coding**
Martin Holmes
Mentors: Kaihang Wang and Russell Swift

REXER-GENESIS developed by Dr. Kaihang Wang allows for the re-coding of genomes through the sequential replacement of large portions of E.Coli's genomic DNA (gDNA) with synthetic DNA fragments beginning at a specific loci. This is achieved by the excision of the synthetic fragment from an episomal replicon by CRISPR followed by homologous recombination (lambda red type) of that fragment into the wild-type genome. This method can be repurposed to produce genome minimization events that allow for extensive deletions within the E.Coli genome. Synthetic fragments are designed for REXER-GENESIS to contain "keep" (where essential genes are placed) and "delete" regions of the genome. Any essential genes that are placed in the "delete" regions may be reintroduced into the gDNA via recombination events using the flanking "keep" regions. A minimal genome sequence is of much interest for understanding the processing and complexity of bacterial life and by proxy biological life in general.
A single minimization event has been successfully implemented into the E. Coli genome and future minimization events are being constructed. Additionally, minimization events are being set up at different starting gDNA loci to allow for the development of different minimized genomes arising from differential recombination events in "delete" regions.

Construction of Novel Genelet Circuits for GFP Production
Halle Holzbauer
Mentor: Richard Murray

In synthetic biology, an important step in creating artificial cells and multi-cellular systems is developing genetic regulatory networks. Genelets are partially double-stranded DNA molecules that, when bound to a single-stranded DNA activator to complete its strand, produce RNA strands by *in vitro* transcription reactions. I propose to advance this research by building new reporter logic circuits that can facilitate communication between genelet circuits in different vesicles without having to use intermediaries. The goal of this project is to build a genelet circuit that implements a logic gate and produces green fluorescent protein (GFP). There are two input genelets that, when activated by single-stranded DNA strands, produce RNA repressors that inhibit the output genelet, which produces GFP when activated. This circuit will be encased in a vesicle and reactions will be run in the cell-free extract PURE. When complements to the DNA activators of the two input genelets enter the vesicle through membrane channels, they bind to the activators, thus activating the output genelet. We believe this genelet circuit can be used in future experiments and projects pertaining to circuits operating in cell-free extracts and vesicles.

A Versatile SHOP-type Nickel Catalyst Platform for Copolymerization of Ethylene and Polar Monomers
Alexandria Hong
Mentors: Theodor Agapie and Shuoyan Xiong

Abstract withheld from publication at mentor's request.

High Mass Stars Stripped in Binaries Missing at Low Metallicity: Tests of Stellar Astrophysics and Gravitational Wave Progenitors
Beryl A. Hovis-Afflerbach
Mentors: Ylva Goetberg and James Fuller

While there have been a large and increasing number of detections of gravitational waves from high mass binary black hole (BBH) mergers, only a few black holes of lower masses (~10-20 $M_\odot$) have been detected. Envelope stripping of the BH progenitor star, resulting in a stripped star, is thought to be important for the creation of merging BBHs, but recent models suggest that massive stars in binaries at low metallicity do not become fully stripped of their hydrogen rich envelopes until very late in life. This could affect the future evolution towards a BBH merger, possibly explaining the lack of lower mass merger detections. We investigate this possibility by modeling stripped stars in the Small Magellanic Cloud (SMC), which has a low metallicity similar to that in which BBHs are expected to form. Our model of the mass distribution shows a drop in the number of stripped stars with masses >7 M⊙. Using stellar evolution and spectral models, we convert this distribution to an observational one of brightnesses and colors. Recently produced UV/optical catalogs make our results testable, providing a first observational test of the late expansion of massive stars at low metallicity. A lack of high mass binary stripped stars in the SMC would not only confirm the theoretically predicted late expansion of massive stars -- it could also have important implications for the production of black holes in low metallicity environments.

Large-scale Genomic Rearrangements in *E. coli* Using Programmable, RNA-guided Transposons
Hannah Hu
Mentors: Samuel Sternberg, Leo Vo, and Kaihang Wang

The insertion of transposable elements by guide RNA–assisted targeting (INTEGRATE) system achieves site-specific and marker-free integration into the bacterial genome. The application of this system using genomic cargo can expand its abilities to cover long-attempted ventures into large-scale genomic rearrangements, including both transposition and inversion. The flexibility and convenience of the INTEGRATE system is apparent in comparison to other genome-wide engineering systems, but the limits on how large the engineered bacterial transposon system and its cargo can be scaled up has yet to be determined. Here, we use homologous recombination to insert the transposon ends of the INTEGRATE system into the *E. coli* genome to accurately remobilize up to 100-kb of genomic, suggesting that even larger rearrangements may be achievable. This method of accurate remobilization of large-scale genomic cargo would lift the efficiency and programmability limitations that recent genome-wide engineering efforts have encountered, as well as introducing the idea of library-scale rearrangements by taking advantage of the mass-programmability of the RNA-guided transposon system. Some useful applications among many include convenient cloning of genomic segments onto bacterial artificial chromosomes for conjugation between bacterium, or mapping of epistatic interactions between genes by reshuffling the genomic loci.

Characterizing Enteric Neural Elements With Hybridization Chain Reaction to Understand *de novo* Neurogenesis
Claire Hu
Mentors: Marianne Bronner and Wael El-Nachef

The enteric nervous system (ENS) is essential to maintaining the homeostasis and function of the gastrointestinal tract. Though believed to be terminally differentiated after embryonic development, recent evidence has shown this to not be the case. Several theories on the source and mechanism by which new neurons originate are being investigated, including the involvement of Schwann cell precursors (SCPs) and enteric glia. The aim of this project is to optimize the usage of hybridization chain reaction, a riboprobe-based assay that fluorescently labels designated mRNA from specific genes, on the adult zebrafish intestine so that these enteric neural elements may be characterized and later examined. In order to do so, we tested several modifications to improve the signal quality, including using smaller gut sections, changing fluorescent hairpins, cutting the gut open, and removing the epithelial layer. In the process, we found that with *dhh* probes, which label SCPs, signals appear to originate from the external gut layer, which has implications on how SCPs repopulate the ENS. These findings will aid us in the process of defining these elusive cell types and identifying directions of research potential to study *de novo* enteric neurogenesis.

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.

Optimization Based Methods for Model-Based Reinforcement Learning
Kevin Huang
Mentor: Anima Anandkumar

Model-based reinforcement learning methods use trajectory sampling methods, such as the Cross-Entropy Method (CEM), to select optimal action sequences for a controller. Because the CEM algorithm, and other similar strategies, rely exclusively on random sampling, they can be inefficient, especially for large prediction horizons or in high dimensional action spaces. We explore how trajectories can be optimized directly through standard optimization algorithms such as gradient descent, without the need for large amounts of samples.

Using Computer Vision to Classify Stars and Galaxies
Teresa Huang
Mentors: Andreas Faisst and Ranga Ram-Chary

Essentially, the problem we want to solve is to combine the data from telescopes and observatories, such as Euclid, Nancy Grace Roman Space Telescope, and Vera C. Rubin Observatory. This will allow us to study galactic and extra-galactic sources across multiple wavelengths, hence studying different physical properties and processes (such as spectral types of stars, star formation, and stellar mass of galaxies). We developed a computer vision algorithm to accurately identify stars and galaxies based on a previously trained neural network of categorized sources. The algorithm reads each photo pixel by pixel and classifies the stars based on measured location, shapes, brightness, and sizes of sources in the co-spatial space-based surveys, accounting for color gradients in the source and the color-dependent point spread function and fitting for their flux densities in the lower resolution ground-based data. Correct identification of stars and compact objects is necessary because the new telescopes rely on compact objects to align datasets from a variety of missions across a range of wavelengths, seeing conditions, and time intervals. Precise alignment is important to measure the brightnesses of the source across these datasets consistently. Results will be discussed in further detail.

Nascent RNA Sequencing Reveals a Role for Malat1 in Co-transcriptional Splicing
Wesley Huang
Mentors: Mitchell Guttman and Prashant Bhat

Many nuclear-retained long noncoding RNAs (lncRNAs) have long been implicated in serving a diverse set of functions such as gene expression regulation. The metastasis-associated lung adenocarcinoma transcript 1 (Malat1) is one such lncRNA that is evolutionarily conserved, abundantly expressed in mammalian species, and primarily localized within the nucleus at actively transcribed genes. Malat1 has been shown to be a critical driver of many cancers, as its overexpression correlates to splicing defects in various carcinomas. However, the mechanisms by which Malat1 drives disease are unknown due to a lack of understanding of its cellular functions. Here, we report on the effects on splicing in Malat1 full-length knock-out (KO) cells. We observe significant splicing defects by performing nascent RNA-seq and find that Malat1 likely plays an important role in coordinating co-transcriptional splicing.

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.

Engineering Robust and Tunable Synthetic Oscillations of CAR Expression in T-Lymphocytes: Towards Enabling Functional Therapeutic Longevity in CAR-T Cells
Isabella Hurvitz
Mentors: Mikhail Shapiro and Shirin Shivaei

Abstract withheld from publication at mentor's request.

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.

Finding Millisecond Optical Transients and Variable Sources in Zwicky Transient Facility Data Using Unsupervised Anomaly Detection Techniques
Derek Tian-Hua Ing
Mentors: Mansi M. Kasliwal and Igor Andreoni

While it is known that our universe is ever-changing, the space of transient sources that vary on sub-second timescales in the optical spectrum have hardly been explored. The Zwicky Transient Facility (ZTF) is a time-domain astronomy survey with a large 47 degree^2 field of view. The new Readout While Exposing (RWE) observing mode at ZTF can produce observations with a 6-millisecond time resolution, allowing us to discover sub-second variable stars, binary systems, black holes, neutron stars and exotic transient phenomena. We have obtained a dataset of 1842 objects and their light curves with the RWE mode. Using unsupervised machine learning anomaly detection techniques, I determined which objects are potentially variable. I also created an SQL database of known variable sources from existing catalogs, including x-ray, radio, eclipsing binaries, pulsating, rotating, eruptive, active galactic nuclei, and cataclysmic sources. I will attempt to crossmatch the objects detected from the ZTF dataset with known variable sources with my database. I hope that I am able to develop a working method that can be applied to larger RWE ZTF datasets to detect fast variable sources.

Brain Parcellation With Causal Feature Learning
Daniel Israel
Mentor: Frederick Eberhardt

Causal Feature Learning (CFL) is a learning algorithm designed to find “macrovariables” from low level “microvariable” data in an unsupervised manner while preserving causal relations. In neuroscience, it is common to inquire about how the brain can be divided into regions such that each region corresponds to specific functions. This is accomplished by dividing high-resolution data into coarser measurements across “parcels” of the brain characterized by their activity, connectivity with other regions, or other defining features. Here, we apply CFL to low-level neural data from the Human Connectome Project (HCP) in order to recover regions that are causally important. We replicate past work identifying the default mode network, a region that is especially active in the resting-state brain. CFL provides a novel way to parcellate the brain based on causal relationships as opposed to correlative or anatomical features.

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.

Design of a Soft Robotic Ankle-Exoskeleton Using a Novel Actuation Technique
Neil Janwani
Mentors: Aaron Ames and Maegan Tucker

Ankle-exoskeletons have been studied in many contexts and apply to a wide array of fields–from studying gait generation algorithms to assistive devices. Current robotic ankle-exoskeletons are bulky, and thus counteract the gait-altering support they provide. Using hand-shearing auxetic (HSAs) devices developed by Washington University to change the set-point of a spring, however, a non-obstructing and ultra-light ankle-exoskeleton can be developed. By lowering the setpoint of the spring during the midstance and heel off stages of the bipedal gait, passive energy can be stored in the spring through compression. This energy can be translated as a force on the top of the foot during push off, thereby generating a short burst of torque about the ankle and helping propel the individual forwards. The setpoint of the spring can then also be raised to prevent difficulty in completing toe lift. This design's novelty comes from the use of this HSA and the placement of the compound system on the front of the shin. Thus, gait algorithms, like preference based learning, can be tested on the device to determine if it can reduce muscle effort as read by electromyographic sensors.

Analyzing the Effects of Community Diversity on Microbial Strain Transmission in *ex vivo* Human Gut Communities
Rashi Jeeda
Mentors: David Relman, KC Huang, and Katherine Xue

The gut microbiome is a diverse ecosystem implicated in several aspects of human health, including immune response, nutrient uptake, and neurological function. Adult gut communities tend to develop a stable, individual composition over time and typically display colonization resistance. However, microbiome therapeutics such as probiotics or fecal transplants require introduction and maintenance of new species in gut communities, making it important to understand the conditions under which colonization can occur. We hypothesize that strain transmission and subsequent colonization is likely to occur between dissimilar communities, as communities are more likely to have open ecological niches for strains unlike those they already contain. Similarly, we hypothesize that communities with lower diversity, such as those that have undergone recent perturbation, will be more prone to colonization due to an abundance of open niches. To investigate effects of community diversity on strain transmission, we utilized *ex vivo* microbial gut communities derived from stool samples collected by cohabiting individuals before and after an antibiotic perturbation. We performed controlled mixtures of pre- and post-antibiotic communities and conducted 16S rRNA sequencing to detect taxa transmitted between starting communities. Data from these experiments will shed light on the role strain transmission plays in community recovery following perturbation.

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.

Modulating Factors of Household Transmission of SARS-CoV-2 in a Community-Based Study
Jenny Ji
Mentors: Rustem Ismagilov and Alexander Winnett

Hesitancies to receive vaccinations and new emergent variants support an ongoing need to reduce community and household transmission of SARS-CoV-2. To identify factors modulating household transmission, we collected demographic, household composition, infection-control practice, and COVID-19 risk perception data from individuals in the Los Angeles region of Southern California who either recently tested positive or were at risk of infection from a household contact. After grouping by households with observed transmission and those without, we calculated adjusted odds ratios to evaluate whether any of the self-reported infection-control practices (e.g. disinfecting surfaces, isolating sick household members in their own room, and maintaining social distance from other household members) are associated with transmission risk. From the adjusted odds ratios, we found that families who reported daily disinfection of household surfaces (e.g. doorknobs and light switches) and shared rooms (e.g. kitchen and bathroom) were more likely to exhibit household transmission during enrollment. The efficacy of these factors will be further investigated by analysis of responses from individuals who were initially infected in the household, became infected, or did not, to examine the role of individual behaviors and to ultimately identify specific interventions to reduce household transmission of SARS-CoV-2 globally.

Advancing Molecular Beam Epitaxy of Oxide Materials
Abigail Jiang
Mentor: Joseph Falson

The Falson Lab specializes in growing thin film materials using the method of Molecular Beam Epitaxy (MBE). MBE is known for its capability to synthesize materials with pristine structural purity, controlled composition, and accuracy in atomic layering. Oxide materials are widely explored in MBE because of their range of structural phases and electronic properties. For example, ε-Fe_2O_3 (epsilon iron oxide) is a metastable phase of iron (III) oxide, reported to have both ferroelectric and ferrimagnetic properties. As material quality increases, these intrinsic properties become easier to probe and observe. In preparation to grow materials such as ε-Fe_2O_3, we implemented custom systems used to synthesize oxides of the highest quality possible. This included a 1kW CO_2 laser system and corresponding optics, used to rapidly heat and prepare substrate surfaces, and an ozone generator, used as a highly reactive oxygen source. Each system is used by very few MBE groups in the world, and rarely in conjunction. Design, installation, and testing were completed across the board, including characterization of substrate surface properties due to laser heating. The implementation of both systems provides a strong foundation for all future growth of oxides within the Falson Lab.

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.

Neural Operator on Fluid Control Problems
David Jin
Mentor: Anima Anandkumar

Fluid dynamics is often difficult and time-consuming to study due to the nature of its simulations being computationally costly; however, it is also very critical in multiple fields, including aerospace, material science, biology, meteorology, etc. In particular, there are many cases where fast forecasting, such as for aircraft control, are at a premium. Therefore, with the power of machine learning, we want to investigate the potential of accelerating the simulations of fluid turbulence. Recently, a group of researchers have generalized the learning mappings of neural networks between finite-dimensional Euclidean spaces to mappings of neural operators between function spaces \cite{li2020fourier}. We will investigate control problems in fluid dynamics using traditional method and neural operator. Both methods will be evaluated and compared from aspects of efficiency, accuracy, and generalizability in multiple settings of fluid control problems.

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.

Estimating the Computational Complexity of Uryson Width

Ely Jrade
Mentors: Fedya Manin and Peter Smillie

Uryson k-width is roughly a measure of how well a metric space can be approximated by a k-dimensional simplicial complex. Recent results have implied that global Uryson k-width does not necessarily agree with local results and this can be strengthened through proving that it is computationally ‘difficult' to estimate Uryson width. Through utilizing chains of manifolds with small local Uryson width but ambiguous global width, our attempted methods of reduction from the NP-Complete problem of 3-SAT to a decision problem related to Uryson width help eliminate ineffectual techniques of reduction and lends credence to the idea that the remaining, but more difficult, procedures will be necessary and auspicious in ultimately finding a reduction and proving this problem to be NP-Hard.

Modeling Combinatorial Transcription Regulation in Metazoans

James M. Jusuf
Mentors: Michael Elowitz and Bo Gu

Combinatorial transcription regulation refers to the way that a gene's transcription arises as a combination of a diverse set of regulatory factors. While some examples of combinatorial transcription regulation in prokaryotes have been successfully understood, existing frameworks fall short of explaining how the process occurs in eukaryotes, particularly metazoans, whose mechanisms of gene regulation are significantly more complex. It is believed that a protein complex called Mediator lies at the heart of combinatorial transcription regulation in metazoans, though the exact manner in which Mediator integrates signals is unclear. Using concepts from equilibrium statistical mechanics, allostery, and ligand-receptor binding, we develop a model to describe the interactions between the numerous subunits of Mediator, transcription factors, and the transcription machinery. Analysis of the model yields insights on the possible roles of Mediator in combinatorial transcription regulation. Furthermore, our results provide a plausible explanation for the context-dependent function of transcription factors observed in metazoans. Ongoing experimental work in the Elowitz Lab may help validate the model or shed light on how the model can be improved.

On the Carbery Rectangle Problem

Mandar Juvekar
Mentor: Nets Katz

Given a positive real number ε, what is the maximum measure of a subset of the unit square in R^2 that does not contain the corners of any axis-parallel rectangle with are greater than ε^2? In 1999, Carbery, Christ, and Wright proved that the measure of such a set must be at most $O(\varepsilon(\log(1/\varepsilon))^{1/2})$. Whether this bound is tight remains an open question. We present this problem along with some known results. We also investigate the problem in a class of special cases that are parameterized by graphs, and which we think could provide insights into resolving the problem in general. In particular, we recover the known bound on our class of examples via a new argument and discuss possible applications of methods from extremal graph theory as a way of improving the estimate.

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.

Triggering Mechanochemistry With Acoustic Cavitation
Elin Kang
Mentors: Mikhail Shapiro and Yuxing Yao

Abstract withheld from publication at mentor’s request.

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.

Towards an Intra-Tumoral Gas Vesicle Cavitation and Checkpoint Inhibitor Payload Therapy Achieved via Bacterial Delivery
Rohit Kantipudi
Mentors: Mikhail Shapiro and Avinoam Bar-Zion

Abstract withheld from publication at mentor's request.

Analyzing the Higgs to WW Mass Regression Using Particle Net
Ish Kaul
Mentors: Maria Spiropulu, Cristina Mantilla Suárez, Raghav Kansal, Javier Duarte, Cristián Peña, and Si Xie

The discovery of the spin-0 particle consistent with the Standard Model (SM) Higgs boson (H) in 2012 by the ATLAS and CMS experiments has propelled further study into the various properties of the Higgs boson and tests of the SM. We perform a search of the Higgs decay to W bosons (W): $H \rightarrow WW$, in the final state of four quarks (qqqq), an electron, neutrino and two quarks ($e\nu qq$), and a muon, neutrino and two quarks ($\mu\nu qq$) along with a background from QCD as well as top quarks. Each of these classes is provided appropriate weights first. We then train an architecture based on Particle Net, a Dynamic Graph Convolutional Neural Network, to reconstruct the Higgs and background masses from a GEANT4 Monte Carlo based simulated dataset. The Higgs mass is reconstructed well and agrees with the softdrop mass to a large extent, while the QCD reconstructed masses show a shifted peak. We also test this model on the Higgs decay to b quarks: $H \rightarrow bb$. In the future we plan to optimize this model for better QCD mass sculpting and subsequently use it in real data.

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.

Controlling the Morphology of Swell-in Architected Tungsten Structures
Chan Gi Kim
Mentors: Julia R. Greer and Max A. Saccone

Brittle yet hard, tungsten has traditionally been a difficult material to process. Using a polymer-based additive manufacturing technique, we demonstrated the fabrication of 3D architected tungsten and tungsten oxide structures. Digital light processing stereolithography was used to print poly(ethylene glycol) diacrylate organogels which were swollen in aqueous solutions of ammonium metatungstate. Removal of ammonium, crystal water, and polymer material during calcination resulted in tungsten trioxide structures. Oxide structures reduced in forming gas were converted to sub-stoichiometric oxides WO_x ($x<3$) or tungsten metal depending on the amount of hydrogen available for reaction. These samples were characterized using x-ray diffraction and qualitatively evaluated using scanning electron microscopy. Additionally, we demonstrated control over the porosity of these structures by optimizing the ammonium metatungstate concentration and heating profile. After testing various concentrations, we found that swelling in a 2M ammonium metatungstate solution led to a reduction in porosity compared to both higher and lower concentrations, and that that slower heating rates led to lower porosity in the final structures. Subsequent work will aim to describe the processes that generate suboptimal morphologies such as porosity, and also to understand the phase transitions that occur during the calcination/reduction process.

Understanding Mechanism of N-terminal Methionine Excision in Bacteria

Jiwoo Kim
Mentors: Shu-ou Shan and Chien-I Yang

In bacteria, N-terminal methionine excision(NME) is carried out by deformylation of fMET residue by peptide deformylase(PDF) followed by methionine excision by methionine aminopeptidase(MAP). Despite the known ribosome binding sites of various ribosome-associated protein biogenesis factors(RPBs), the precise mechanisms by which ribosome affects the NME reactions of nascent protein remains unclear. The Shan lab previously observed NME is inhibited for a substrate with a hydrophobic transmembrane(TMD) within 10 residues of N-terminus. Furthermore, they observed strong inhibition of the NME reactions by signal recognition particle(SRP) and slight enhancement by trigger factor(TF) for ribosome nascent chain(RNCs) with TMDs near the N-terminus. To further understand the interplay between various RPBs on NME, the binding affinity(Kd) of PDF/MAP for RNCs with different hydrophobicity level was measured in the absence and presence of SRP/TF using equilibrium titrations based on a Forster resonance energy transfer(FRET) assay. Both MAP and PDF showed similar Kd to RNCs with various hydrophobicity without any RPBs. However, unlike PDF which showed no statistical difference between RNCs and negligible difference in Kd upon SRP/TF addition, MAP showed weakened binding upon SRP/TF addition and higher variability of Kd values with different RNCs. This supports that MAP enhances the specificity of substrate selection after deformylation by PDF in co-translational protein biogenesis pathway and further demonstrates that molecular crowding at the ribosome exit must compete for not only ribosome binding but also access to the nascent polypeptide.

Identifying Brain Rhythms During Innate Behaviors in the Laboratory Mouse

Joseph H. Kim
Mentors: David J. Anderson and Stefanos Stagkourakis

In vivo recording methods in the hypothalamus have increased our understanding of the neural encoding of fear, anxiety, and other innate behaviors. Notably, brain rhythms have not been identified in this part of the brain due to its inaccessibility. Here we perform the first (to our knowledge) analysis of brain waves—via local field potential (LFP)—in recordings acquired through a high-channel density silicon probe, ranging from the hypothalamus to the thalamus and habenula. Our current analysis has identified brain rhythms in the thalamus and habenula, but further analysis is required to elucidate whether such phenomena occur at the level of the hypothalamus. As a next step, we will apply the developed analysis pipeline to different animals implanted with different types of silicon probes, to investigate whether rhythmic LFP activity occurs at neuroanatomically defined hypothalamic nuclei.

Granular Dynamics in Microgravity: Transition From Stick-Slip to Fluid Behavior

Alexandra Klipfel
Mentors: Karen Daniels and Joseph Kirschvink

As spacecraft missions to asteroids and small moons become more common and more complex, often involving landings and sample retrievals, it is necessary to understand the dynamics of granular materials in low gravity environments. We experimentally characterize how granular materials subjected to small effective gravities respond to low-impact applied forces and probe insertions. To accomplish this, we designed and built an air table apparatus capable of supporting a 2D layer of photoelastic grains upon a cushion of compressed air. By tilting the air table about a horizontal axis, the simulated regolith experiences a tunable effective gravity, parallel to the table surface. We then use high speed video recordings of probe insertion events to analyze force chains in the system made visible by the experiment's optical setup. Motivated by a previously observed phase transition from stick-slip to fluid behavior occurring between micro- and lunar gravity, we present a multidimensional phase diagram detailing how the system's behavior depends on various physical parameters including effective gravity and probe width. In spite of the limitations of this laboratory analog, we anticipate similar behaviors to occur in real-world systems. This could be verified by future 3D experiments or through *in situ* measurements by spacecraft.

Thermal Studies on the BTL Readout Module for the CMS Phase II MIP Timing Detector

Esme Knabe
Mentors: Maria Spiropulu, Lautaro Narvaez, Adi Bornheim, Irene Dutta, and Cristian Pena

To prepare for the increase in particle collision data per bunch crossing within the high luminosity version of the Large Hadron Collider (HL-LHC), the CMS experiment is undergoing multiple concurrent upgrades. These include the addition of the MIP Timing Detector (MTD), a new layer that allows for four-dimensional particle vertex reconstruction with a time resolution of 30 picoseconds. The readout modules in this layer must be cooled and thermally optimized to reduce the production of dark current, which can negatively affect the achievable time resolution values. This project investigated different methods of minimizing thermal gradients across two prototype modules. A mock version of the cooling system that will be utilized in the detector was constructed, and assorted thermal conduction materials were tested under varying conditions within this setup in order to determine the optimal thermal cooling mechanism for the module. The experiment was also modeled using SOLIDWORKS Thermal Simulation software, which confirmed that the type and application of thermal conduction materials has a large effect on the thermal gradients across the module and thus the eventual dark count rates within the detector itself. Finally, the thermal testing process was optimized and fully automated to prepare for the transition of the CPT laboratory into a testing hub for the production stage of the MTD modules.

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.

Modeling and Testing of an Electrically Heated Hotspot
Athena Kolli
Mentors: Joseph Shepherd and Donner Schoeffler

Accidental ignition of a flammable atmosphere due to an electrically heated surface is a source of hazard in industry. We investigate the ignition of n-hexane and air mixtures due to an electrically heated hotspot. The temperature profile of an electrically heated stainless steel disk (Ø 2") was studied, with the requirement of reaching ignition temperatures (~1100K) at the hotspot. We utilized Abaqus/CAE to build thermal models of the disk and conduct a design study to determine parameters for the experiment. Based on these results, we created engineering drawings for the experiment in SolidWorks, and will carry out the experiment once the parts are made. As the experiment is performed, data describing the temperature profile of the disk will be collected and compared to the profiles generated through our Abaqus models. We predict that we will see a resulting profile that is similar in shape and peak temperature to the simulated result. We also predict that we will see ignition in the flammable atmosphere once the hotspot reaches approximately 1100K.

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.

Exploring the Spatial Super-Resolution Models for National Wind and Solar Data
Rupa Kurinchi-Vendhan
Mentors: Steven Low, Lucien Werner, Björn Lütjens, and Ritwik Gupta

As the United States is increasingly implementing renewable energy forms such as wind and solar power, the spatial variability of these sources introduces challenges in operational decision making, scheduling, and resource allocation. To address the fact that current forecasting models predict wind speeds and solar irradiance at a coarse resolution, an image-processing technique called super-resolution can be applied to spatially enhance this data. Generative adversarial networks (GANs) have been applied to SR in recent years, capable of increasing the resolution of coarse 100-km climate data by 50x for wind velocity and 25x for solar irradiance data. To benchmark the accuracy of this model, we investigate three super-resolution models: the state-of-the-art GANs method proposed in 2020, the enhanced deep super-resolution network (EDSR) proposed in 2017, and the enhanced super-resolution generative adversarial network (ESRGAN) proposed in 2018. As expected, all models outperform simple bilinear interpolation on all metrics. Additionally, we found that the EDSR model outperforms the GANs models in terms of accuracy on standard metrics. However, since standard image quality metrics do not account for the high-frequency data that is characteristic of GANs output, both GANs models outperform EDSR in power spectrum analysis, suggesting that we should let GANs models only predict high-frequency features.

Collapse of Fuzzy Dark Matter in Simulations
Shalini Kurinchi-Vendhan
Mentors: Andrew J. Benson, Xiaolong Du, and Philip F. Hopkins

In modern cosmological simulations, dark matter builds the backbone for galaxy formation. Through gravitational collapse, so-called dark matter *halos* pulled surrounding gas into their cores, which then cooled and condensed into the first galaxies. While the current dark matter paradigm is able to capture the large-scale structure of the Universe, it predicts more small-scale structure than is actually observed. This issue may be resolved with the theory of *fuzzy dark matter*, which is made of ultra-light, wavelike particles. The mechanism that suppresses halo collapse in this model is called *quantum pressure*, which arises from the Uncertainty principle. However, its behavior has yet to be fully understood in present theoretical models. Using 3D numerical simulations, we performed a comprehensive analysis of how quantum pressure affects the collapse of fuzzy dark matter halos. Then, we make use of a semi-analytic treatment to predict how likely it is for the halo to collapse, and thus explore small-scale structure formation in the Universe.

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 pCO2. 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.

Reaction Optimization and Limitations of Pyridine Cyclizations With Glutaryl Chloride
Pik Hoi Lam
Mentor: Sarah Reisman

This report describes a one-step cascade cyclization between pyridine and glutaryl chloride to diastereoselectively form the tetracyclic core of the lupin alkaloid isomatrine. A library of 20 pyridine derivatives was investigated to gain insight into the scope and limitations of the cyclization reaction. Substitution at the 2 position of pyridine, electron-withdrawing groups, and halogen substituents were unsuccessful in the cyclization. Substituents located at the 3 position of pyridine underwent partial cyclization, while substitutions at the 4 position were successful. The final substrate scope provided key electronic insights into the mechanistic clockwork of the cyclization.

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.

Electromagnetic Actuation System (EMAS): Haptic Guidance for Enhancing Motor Sequence Learning
Anna Lapteva
Mentors: Shinsuke Shimojo and Mohammad Shehata

In a world dominated by the forces of globalization, industrial competition, and technological advancement, the ability to learn quickly is crucial for success in many academic and professional environments. Consequently, methods for acceleration of learning are highly sought-after. We seek to assess the influence of an Electromagnetic Actuation System (EMAS) on motor sequence learning. EMAS is a human-machine integration that physically drives the body, while allowing participants to retain their volition. By eliminating the structural rigidity of exoskeleton systems and the undesired haptic sensory inputs from electrical stimuli, the EMAS is a functionally superior resource for examining the effect of haptic guidance on motor learning. Subjects' performance will be evaluated under two conditions: base (EMAS off for all trials) and experimental (EMAS alternating on-off during training trials). Performance will be assessed in terms of absolute timing offset, hit rate, and score; analysis of statistically significant differences in timing offset between conditions will be conducted using Python. If we observe significant differences, we will demonstrate that the EMAS is a valuable psychophysical instrument for expediting the motor learning process. Such findings will inform our understanding of how to optimize learning in various contexts, like musical performance, education, and even space travel.

Quantifying Regeneration in *Drosophila* Tibia
Iris Lee
Mentor: Lea Goentoro

The Goentoro lab has observed that autonomous regeneration of amputated tissues can be induced in common fruit flies using commonly available nutrients. This novel observation requires the development of methods to quantify regeneration. In the first method, single fly tracking, we carefully track individual flies after amputation and quantify growth through images taken of the amputated leg on successive weeks. This has allowed us to demonstrate growth over time in a small set of flies. In the second method, we chemically tag cells that have grown since amputation using the thymidine analog EdU and visualize the tagged cells fluorescently after a given number of days. This method will allow us to quantify cells grown by a time point after amputation for a larger set of flies. The imaging process for this method requires thorough penetration of the fly cuticle, and this penetration is to be optimized using chitinase digestion and mechanical dissection.

Synthesis, Analysis, and Preliminary Computational Modeling of Novel Si-Cu-Ca Icosahedral Quasicrystal FormationJina Lee
Mentors: Paul Asimow and Jinping Hu

Quasicrystals, or quasiperiodic crystals, are a class of solid materials with ordered structures that have forbidden rotational symmetries such as 5 and 10-fold rotation axes, only made possible due to the absence of periodic translational symmetry in three dimensions. While quasicrystalline materials have been synthesized for several decades, their occurrences outside controlled laboratory settings are rare. We investigated a previously unknown icosahedral quasicrystal with composition $Si_{61}Cu_{30}Ca_7Fe_2$, recently discovered in trinitite, the glassy material created during the 1945 Trinity nuclear test. A multimodal approach was implemented, first performing shock recovery experiments to attempt to recreate the conditions for Si-Cu-Ca quasicrystal formation in trinitite. Second, real trinitite samples were analyzed to search for more examples of the original or possibly other quasicrystalline phases. Third, molecular dynamics simulations were created to model the kinetic and thermodynamic factors that may determine the growth of quasicrystals under shock compression. Computational models will be verified in the Al-Cu-Fe system, where the stability of the icosahedral phase is already known, and then extended to Si-Cu-Ca. This system of interest is specific, but this work lays a general foundation for understanding of quasicrystalline structure, composition, formation, and stability, and paves a path towards predicting undiscovered quasicrystals.

Return Probabilities of Skip-Free Random Walks
Lin Lin Lee and 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.

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.

Optimizing Memetic Algorithm for Symbolic Regression
Depei Li
Mentors: Pablo Moscato, Andrew Ciezak, and George Djorgovski

This research tries to optimize the existing memetic algorithm to better fit difficult datasets. The memetic algorithm is an evolutionary algorithm that uses thirteen agents in a ternary tree, each performing a local search every generation. Previously, the existing memetic algorithm utilizes a solution representation in the form of a continued fraction, with each element of the continued fraction as a linear function of the domain variables. It also uses the Nelder-Mead algorithm as a local search algorithm between generations. We propose that three things may further help the memetic algorithm to fit hard datasets: using objective functions that take into account the error at all depths of the continued fraction (not just the last depth), weighting data-points as a function of absolute value error between iterations of the Nelder-Mead or depths of the continued fraction in the objective function, and using a different solution representation where each term of the continued fraction has a linear term multiplied by a cosine of linear term and exponential of a linear term.

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.

Doubling Cavity for Atom Interferometry With Momentum Squeezed States for Gravitational Sensing
Sophie Li
Mentors: Mark Kasevich. Shaun Burd, and Maria Spiropulu

Atom interferometers are evolving rapidly and are used in a variety of applications in fundamental physics such as the precise measurements of gravitational constants, curvature and, more recently, waves. The Kasevich group has begun constructing a new atom interferometry experiment based on Strontium with the objective of using spin squeezing to demonstrate quantum-enhanced inertial sensors. The experiment will incorporate a large-momentum-transfer (LMT) Bragg interferometer on the 461nm $^{1}S_0 \leftrightarrow {}^{1}P_1$ transition in ^{88}Sr to coherently generate and control well defined atomic momentum state superpositions. A ring resonator with a bow-tie configuration was designed, built and optimized to convert 922\,nm light from a Ti:Sapph laser to 461\,nm. The Pound-Drever-Hall technique was implemented to lock the cavity resonance to the laser frequency. Up to 1W of 461nm light was produced with a conversion efficiency of 60%. Noise suppression was achieved by cancelling mechanical FIR notch filters and stabilization with acousto-optic modulators.

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
Ha Eun (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.

Digitalizing Twentieth Century Parisian Death Records to Build a Searchable Database

Damon Lin
Mentor: Jean-Laurent Rosenthal

In the era of big data, the ability to search for and filter through information is becoming ever more important. The Paris Archives website only contains photographed images of death records, with the option to search only by year and district. As a result, searching for an individual record can be extremely time consuming because one has to look through entire volumes of death records, which may be up to 100 pages each. Hence, this project involves building a searchable database of these records for the period from 1942 to 1974. This is done by first extracting raw text from the photographed images using AWS Textract and then processing the raw text by separating each record into specific categories (date and place of birth, date and place of death, occupation, parent information, and relationship status). After obtaining the processed text, we will be able to build a database that is searchable by name, allowing for individual death records to be found more easily. From the database, we will be able to do research on the social and economic trends that occurred in Paris in the twentieth century using the data we obtained about migration patterns and occupation of every individual.

Developing Biosensors for Rapidly Acting Antidepressants (RAADs) in Various Organelles

Elaine Lin
Mentors: Henry A. Lester and Kallol Bera

Unfortunately, many popular antidepressants can take months to begin exerting their effects. Thus, it is pertinent to develop more efficient antidepressants. Rapidly acting antidepressants (RAADs) are known to begin relieving depression in < 24 hours and continue to exert antidepressant effects over multiple days. RAADs come in the form of multiple structures. Available RAADs include ketamine enantiomers (S- and R-ketamine), its metabolites [(2R, 6R)-HNK/(2S, 6S)-HNK], or ketamine analogs such as methoxetamine (MXE), radafaxine (Rad), and scopolamine (Scop). The mechanisms of action of many RAADs are still unclear. Thus, we have developed the "**i**ntensity-based **RAAD**-**S**e**n**sing **F**luorescent **R**eporter" [iRAADSnFR] genetically encoded biosensor family for RAADs to visualize RAAD accumulation in cells, their pharmacokinetics, and their pharmacodynamics. We have developed effective iRAADSnFRs for the aforementioned RAADs and are utilizing them to detect and quantify RAADs in primary neuronal cells. We include targeting sequences to express the iRAADSnFRs in organelles such as the mitochondria and peroxisome, which have been hypothesized to be targets of antidepressant action. Lastly, we aim to use adeno-associated virus (AAV) capsids to express iRAADSnFRs in the central and peripheral nervous system of zebrafish to study the mechanism of RAADs in more complex models.

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.

Towards Integration of ERT With Virtual Worlds
Joy Liu
Mentors: Santiago Lombeyda and George Djorgovski

The OVRAS group at Caltech aims to build new paradigms for digital interaction in the age of remote learning and virtual reality with the ERT ecosystem, which provides teaching and lab spaces in virtual reality. Although interacting with models in web browsers and virtual reality had already been demonstrated, the possibility of incorporating Virtual Worlds into the ecosystem was yet to be explored. The goal of this project is to establish a real-time connection between Second Life and the other ERT clients; specifically, a physics game where users must complete assigned objectives by creating and manipulating objects would be built and used to demonstrate the power of ERT. The project is built using React and Babylon.js and Corrade, a bot that allows users to send commands through socket communication, connects the app to Second Life. The physics-based game tests ERT's ability to synchronize views across clients, utilizes a real-time running simulation, and expands the capabilities of Virtual Worlds with external coupled web-based applications. Thus, we have integrated Virtual Worlds with the ERT ecosystem through an enjoyable physics game, which in the future can be extended to other platforms such as Virtual Reality, web browsers, and other Virtual Worlds platforms.

Multi-Task Deep Learning Reconstruction for Jointly Training Multiple Contrasts or Anatomies
Victoria Liu
Mentors: Shreyas Vasanawala, Kanghyun Ryu, Cagan Alkan, and Adam Blank

MRI is a vital diagnostic tool in medicine, but long scan times pose issues for patients who cannot stay still during the scan. For routinely acquired contrasts, unrolled variational networks can leverage the abundant data to reconstruct diagnostic-quality images from undersampled k-space. However, for non-routinely acquired contrasts, scarce data prevent traditional variational networks from learning good reconstructions. To address this issue, we propose multi-task learning (MTL) methods that generalize unrolled variational network-based reconstructions for small datasets. The scarce dataset (e.g. coronal PDw-FS knee images) is combined with an abundant dataset (e.g. coronal PDw knee images), and the MTL network learns how to reconstruct the scarce dataset using information gained from the abundant dataset. Challenges include negative transfer and overfitting, and these issues are tackled through architectural and loss function considerations. Specifically, we introduce a shared-encoder-split-decoder scheme, multiple shared trunks, and attention-based weight sharing along the unrolled network. For loss weighting, we examine dynamic weight average, uncertainty, and Pareto weighting. Ultimately, our MTL networks are able to learn better reconstructions, as measured by SSIM and PSNR, of the scarce dataset than single-task variational networks can learn.

Detecting Animal Breeding Violations Through Satellite Imagery
Xiaoqi Long
Mentors: Daniel E. Ho, Brandon Anderson, and Michael Vanier

Concentrated animal feeding operations (CAFOs, defined by the Clean Water Act) produce livestock manure that could pose a dangerous threat on the cleanliness of air, water, and land. Among the many environmental risks caused by CAFOs, land applications, or the illegal dumping of biosolids, is a major threat to public health. However,

there is a significant lack of information on the size, type, and locations of CAFOs, and the land application events, as the EPA has admitted. Enforcing restrictions against such environmental violations has been difficult.
We experimented with several models to automate the process of detecting illegal CAFOs and land application events. We apply our models over a dataset of satellite images of over 900 CAFO locations in the winter from 2018 to 2020 selected from the PlanetScope Dataset from Planet Labs. An unsupervised clustering combined with supervised classification approach is proved to be insufficient for the complexity of this task. We further propose a deep-learning-based approach that utilizes a shared pretrained backbone for inputs of stacked images and multiple heads for semantic segmentation and binary change segmentation. This approach is promising in aiding the enforcement of environmental restrictions on CAFOs, and therefore gradually decrease the amount of manpower and fieldwork that is currently needed to detect these harmful violations.

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.

Exploring Singlet Fission in Bipentacene Compounds
Nathan Lopez
Mentors: Ryan Hadt, Theodor Agapie, and Ryan Ribson

Novel bipentacene products such as the metalation of HDPP-Pent and compounds similar to HDPP-Pent are synthesized and analysis via UV-vis Absorbance and Fluorescence and Transient Absorption (TA).
UV-vis spectroscopy and TA reveal facts about the electronic structure of these novel complexes and may assist in explaining why certain factors may influence rates of singlet fission. Mono ligation of HDPP-Pent to platinum proved to be difficult to isolate, however, that of zinc exhibited high fidelity comprehensive spectroscopic analysis was performed. Other novel bipentacene compounds such as bi(pyridyl-pent), phenyl bi(pyridyl pentacene), and HDPP-mesityl were synthesized and their characteristic spectra analyzed. Rates of singlet fission among these results were compared and their results detailed below. Full characterization of high yield products is to come, but preliminary data for characterization is given for Zn(DPP-Pent)Et. A combination of structural changes and presence of metal center may illuminate the factors governing singlet fission.

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.

X-ray Spectroscopy and Parameter Variation Analysis of Active Galactic Nuclei
Hanbai Lyu
Mentors: Javier García, Guglielmo Mastroserio, and Riley Connors

Active galactic nucleus (AGN) refers to a compact region at the center of a galaxy that exhibits a high luminosity (higher than produced by normal stars) over certain portions of the electromagnetic spectrum. This usually results from the accretion of matter by a supermassive black hole at the center of its host galaxy. We study multiple groups of X-ray spectra of an individual AGN centered in the Seyfert galaxy SWIFT J2127.4+5654 from Nuclear Spectroscopic Telescope Array (NuSTAR) exposures in 2012 and 2018. We apply, improve, and statistically compare several models to deduce the structure and physical mechanisms of the accretion disk. Properties including the high energy cutoff power-law, Fe K emission line, intrinsic absorption, and the reflection component are used to model the energy spectrum of the source. Moreover, we investigate how the cut-off energy E_{cut} and photon index Γ vary with X-ray flux based on spectral fits to verify predicted patterns from the yet unclear coronal physics.

Exploring Methods to Improve Usability of Computer Vision Models for Behavior Analysis
Eric Ma
Mentors: Pietro Perona and Jennifer Sun

Processes in the brain ultimately serve to control behavior, so a comprehensive understanding of neuroscience requires a systematic way to study behavior. Machine learning models, such as the Mouse Action Recognition System (MARS), enable scientists to study behavior at scale. While MARS is already useful in practice for this purpose, we explore methods to improve data-efficiency and accuracy of MARS so this tool can be more easily used by scientists.Towards more data-efficient models, we study how to best allocate a fixed annotation budget as well as how to choose informative examples for annotation with active learning. We vary annotation aggregation strategy and image diversity in datasets used to train our models, finding that detectors favor aggregated annotations while pose estimators perform well either way. We learn that labeling images the models are uncertain about does not outperform randomly labeling images in either detection or pose estimation. For improving accuracy of MARS, we study using state-of-the-art pose estimators (HRNet) in place of existing modules and combining multi-view information to improve pose estimation from different views. Results demonstrate that using HRNet in MARS archives better performance than the existing module, and that using multi-view information is a promising future direction.

Gauging the Electric-Magnetic Duality in the 4+1d Toric Code
Ananth Malladi
Mentors: Xie Chen and Arpit Dua

Gauge theory is a fundamental in theoretical physics in which global symmetries are converted into local symmetries. In condensed matter physics, it can be used to understand and characterize topological phases of matter. Anyonic symmetries are symmetries of the system in which the labels of quasiparticle excitations can be changed without changing the properties of the system. Gauging anyonic symmetries in 2+1d generally leads to nonabelian topological order in the form of twist liquids, which can be fully understood through category theory. However, there is no such complete theory in higher dimensions, and little is known about gauging anyonic symmetries in such settings. Similar to the 2+1d toric code on a square lattice, the lattice/dual lattice symmetry of the 4+1d toric code on a hypercubic lattice leads to a Z_2 electric/magnetic duality. However, this symmetry extends further into an S_3 symmetry. In this project, we gauge the symmetry group/subgroups of this S_3 symmetry and investigate its structure. We hope that this work gives insight into the general structure of higher-dimensional gauge theories.

Comet NEOWISE Spectra Data Reduction
Tyler Mapes
Mentors: Geoffrey Blake and Maria Camarca

Comets are well-preserved remnants of the solar nebula, and the materials trapped within the comet's ice serve as an uncontaminated chemical snapshot. High precision spectrographs can gather a spectrum of the starlight that passes through the comet's coma, and these spectra can be analyzed to provide further insights into what materials were present in the early solar system. In this SURF, I used data reduction and analysis programs to clean raw data from the NIRSPEC spectrograph to create spectra of the comet NEOWISE as it occluded the star HIP 70384.

Improving the Heat Transport Model for the Continuum Simulation of AP/HTPB Burn
Patrick Martinez
Mentors: Brandon Runnels and Joseph Shepherd

Ammonium perchlorate in a hydroxyl-terminated polybutadiene binder is a commonly used composite propellant with a complex burn scheme. As such, a robust computational model is needed to simulate the solid phase, gas phase, and interactions between the two burn phases in order to improve safety and reduce the need for physical testing. The heat transport model links the heat flux coming from the high temperature gas phase to the solid phase interactions like thermoelastic strains. In order to capture these effects a smoothed boundary model version of the heat equation was used. This means the diffusion of heat is not only dependent on the temperature but on the order parameter which describes the phase of the material as well as a Neumann boundary condition in the form of heat flux coming from the burned material. In addition, the formulation is species dependent and so different material conductivities and variable heat fluxes are captured accurately. Further work to be done would link the different effects of the temperature changes in the different materials to stress and strain fields at the material boundaries.

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.

Numerical Monte Carlo Simulation of Cryogenic Buffer Gas Beams
Gavin McCabe
Mentor: Nick Hutzler

Cryogenic buffer gas beams (CBGBs) have numerous applications in both physics and chemistry, including quantum computing, the study of fundamental symmetry, quantum and ultra-cold chemistry, among others. The internal complexities of molecules make it challenging to apply standard techniques for cooling atoms, such as laser cooling. CBGBs solve this issue by relying on collisions with a cold, inert gas such as cryogenic helium. CBGBs are created in a particular cryogenic "cell", which is able to vary the properties of the resulting beam. Currently, the result of various cell properties on the properties of the resulting CBGB are often found via pure experimentation. Recently, however, a monte carlo simulation of CBGBs have allowed for simulating various properties of CBGBs (allowing for simulating - rather than building and testing - the result of various cell properties on CBGB properties). To more efficiently and quickly test various experiments using CBGBs, a new Julia simulation is presented which allows researchers to easily, quickly, and efficiently run simulations of various experiments with CBGBs. The Julia simulation runs 1,000 times faster than previous simulations and can graphically display cell inputs, simulation results, and particle trajectories.

Fabrication of 3D-Printed Algae-Cellulose Composites
Robin McDonald
Mentors: Eleftheria Roumeli and Chiara Daraio

Using living organisms, we can create more sustainable materials that have minimal environmental impact during production and degradation. Living organisms produce a plethora of biopolymers that are currently being explored for their ability to serve as synthetic polymeric material alternatives. While most biopolymers have not been studied for their mechanical performance, cellulose fibers have demonstrated high tensile strength in 2D and nano applications. Here, we produce novel, 3D-printed bulk composites by combining α- and bacterial celluloses with algae powders. Specifically, we use spirulina and chlorella algae powders due to their wide availability as inexpensive and non-toxic dietary supplements that are rich in many biopolymers. We optimized the formulations, printing parameters, and drying methods to create bulk compression test samples. The results demonstrate the properties of 3D-printed algae-cellulose materials and inform further incorporation of algae into composite materials.

Classifying Decision Making Behavior in Psychiatric Disorders
Kyle McGraw
Mentors: John O'Doherty and Jeffrey Cockburn

Computational modeling is an important tool currently being used to understand the neural basis of decision-making and how it is altered in psychiatric disorders. Reinforcement learning (RL) models currently dominate the field due to their reward-based learning that is well suited to decision making tasks and their relatively easy to understand nature, but the more flexible recurrent neural networks (RNN) may be able to model the decision-making process more accurately. In this paper, we compare the performance of RL models and RNN models on patient data from a decision-making task. Additionally, we attempt to use the RNN models to uncover behavioral differences between patient populations and related these to clinical scores in order to better classify mental disorders.

Mirror: A Python Package to Simulate the Reflected-Light Detection Capability of the Keck Planet Finder
Thea McKenna
Mentors: Andrew Howard and Sarah Blunt

My project aims to simulate the performance capabilities of the Keck Planet Finder, a high resolution spectrometer, in order to determine what star-planet systems have the right characteristics for exoplanet detection using reflected light. The software tool is easy to use and publicly available. The user can input characteristics and capabilities of their instrumental setup and of the exoplanet that they are trying to detect, and the tool then returns the signal-to-noise (SNR) of that exoplanet's reflected light signature as a function of wavelength under these circumstances. This effectively tells the user the likelihood of detection given the capability of KPF and the characteristics of the planetary system under observation.

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.

Structural Characterization of the C-terminal Domain of Giardia Sgt2
Vanessa Mechem
Mentors: William Clemons and Alexandra Barbato

The Guided Entry of Tail-Anchored proteins (GET) pathway targets tail-anchored (TA) proteins – membrane proteins with a single transmembrane domain (TMD) near the C-terminus – to the Endoplasmic Reticulum (ER). Sgt2, one of the first proteins in the GET pathway, has been suggested as the molecule that selects ER-targeted TA proteins. The Sgt2 N-terminal domain and TPR domain have been structurally characterized and found to be responsible for homodimerization and heat-shock protein recruitment, respectively. However, the Sgt2 C-terminal domain (CTD) has yet to be structurally characterized, though it is expected to bind the TMD of TA proteins. The purpose of this project is to solve the structure of the Sgt2-CTD through X-ray crystallography.

We created a His_6-TEV tagged *Gi*Sgt2-TPR-CTD construct, expressed, and purified the Sgt2 protein to set crystal trays. However, a Western Blot indicated that the His_6-TEV tag was not cleaved during the purification process. As such, we are in the process of creating a His_8-SUMO-*Gi*Sgt2-TPR-CTD construct as we have had past success with the His_8-SUMO tag. We set crystal trays with the His_6-TEV-*Gi*Sgt2-TPR-CTD protein with a JCSG+ and PEG/Ion commercial screen but did not see any crystal formation. We will continue to optimize protein expression, purification, and screening conditions before using X-ray crystallography to collect diffraction data on the crystals to build a model of the *Gi*Sgt2-CTD.

Development and Evaluation of Machine Learning Object Detection Models for the Classification and Localization of Marine Animals in the Benthic Zone
Krish Mehta
Mentor: Kakani Katija

The Monterey Bay Aquarium Research Institute is developing an open source dataset called FathomNet that could represent more than 200,000 marine animals, which can be used by researchers to increase our understanding of the ocean and the variety of wildlife that inhabits it. Machine learning object detection models based on the yolov5 family of models were used to detect different species of Peniagone, Benthocodon and Scotoplanes on the ocean floor. The models were trained using 7000 annotations from MBARI's Video Annotation and Reference System (VARS), and evaluated on images from the underwater Station-M Observatory. The model was also used to detect trends in Benthocodon concentrations at the Station-M observatory over 10 years, and will be used to add annotations to FathomNet in the future.

Angular Sensing and Integrated Circuit Verification of the ATOMS Devices for High-Precision Localization
Hayward Melton
Mentor: Azita Emami

Fully integrated three-dimensional vector magnetometers are a crucial piece of many magnetic systems. A new inductive coil topology for integrated CMOS magnetometers is analyzed and simulated. This inductive sensor utilizes a space filling on-chip coil design, creating a robust, fully integrated magnetic sensor with inherent background field rejection. The sensor prototype explored combines this on-chip coil with a low noise analog to digital converter and a digital backend for communication, making an easy to use but precise magnetometer. These magnetometers are designed with the goal of biomedical contactless 3D positioning; by creating a well-known magnetic field around the sensor, both the position and orientation of the sensor can be determined. In this work, the performance of the inductive sensor is verified in low-frequency electromagnetic simulation, and the orientation sensing is developed.

3D Mesh Generation via Rotation
Isabella Mendoza
Mentor: Santiago Lombeyda

Creating objects rotationally from cross sections has many merits, including better design intuition and increased precision, as well as utilizing the natural aesthetic of symmetry. Currently several tools exist for object modelling in virtual reality (VR), with many of the most well-known applications using sculpture or CAD techniques. However, very few address creating objects via rotation. To address this, we developed a highly intuitive and versatile application in VR allowing the creation of 3D objects from a user defined curve rotated about an axis, with inspiration from glassblowing. The application was designed using Unity and SteamVR with scripts mathematically generating vertices and triangles from user input in order to generate a mesh surface. This was developed with the purpose of education, art, and prototyping designs in mind, and with a target audience of students, artists, and engineers looking to create objects in VR. Additionally, we have added tools from glass blowing as well as other fields to deform, twist, and edit the mesh in intuitive ways, and added UI elements to help the user navigate the experience. We have created a novel way to generate 3D objects with room to extend utility in the future.

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.

Gravitational Lensing and Neural Networks
Josiah Miller
Mentors: Matthew Graham and Leonidas Moustakas

Abstract: ZTF captures images of transients that can be studied in bulk to gain insight on cosmological structure and parameters. The immense amount of raw data calls for machine learning techniques such as convolutional neural networking to process the images at the rate needed for any significant statistical inferences to be made. The approach here modifies the braii real-bogus classifier, developed by Dmitry Duev for ZTF, for use on quasars, which are one such transient. Because they are so massive, focusing on images of them is one way to probe the nature of gravitational lensing, and furthermore gravity, which is still not entirely understood and is of extreme importance to the cosmological and general scientific community.

Modeling Ultrasound-Induced Buckling of Gas Vesicles
Ellen Min
Mentors: Mikhail Shapiro and Hossein Salahshoor Pirsoltan

Abstract withheld from publication at mentor’s request.

Simulating tri-Higgs Production at the LHC
Joseph Mina
Mentor: Maria Spiropulu, Irene Dutta, Nan Lu, Cristian Pena, and Si Xie

Since the 2012 discovery of the Higgs boson at the Large Hadron Collider, the Higgs particle has provided a means of probing for physics beyond the Standard Model of particle physics. While the observation of an individual Higgs boson is already quite unlikely even in modern detectors, the HL-LHC (High Luminosity Large Hadron Collider) will likely provide the needed significance to confirm even events that produce three Higgs bosons from a single proton-proton collision. Madgraph simulations will be used to confirm the workability of producing and detecting di- and tri-Higgs in the future collider. These simulations can also be used to place theoretical limits on the likelihood of such events based on a variety of parameters and variations of the bSM (beyond Standard Model) 2 Higgs Doublet Model. This model involves as-yet-undiscovered Higgs-like particles that would represent an expanded Higgs sector with a number of different properties. Further, simulations will be used to understand the feasibility of an actual LHC analysis to find tri-Higgs events.

Creating a Solid Model of the Hadron Calorimeter for the LDMX
Noah Moran
Mentors: David Hitlin and Bertrand Echenard

The proposed Light Dark Matter eXperiment (LDMX) is a search for light force carriers could connect hidden sector dark matter to normal matter. It will occur at SLAC National Accelerator Laboratory in an electron beam striking a fixed tungsten target. The byproducts of the collision are searched for a dark force carrier signature, by analyzing missing momentum and energy. The target is surrounded by an electromagnetic calorimeter and a large hadron calorimeter that keep track of byproduct particles with their corresponding momenta and energies. This experiment has an unparalleled sensitivity to dark forces carriers with masses as low as one MeV, whereas previous dark matter experiments typically had sensitivity only down to one GeV.

Since LDMX will be at SLAC it must be earthquake proof. Solid models will be developed to run earthquake simulations on the LDMX. Specifically, we are creating a solid model of the hadron calorimeter and running various structural analyses on it. These include designing structurally stable individual modules that can readily be transported up to SLAC. Earthquake simulations are conducted on the individual modules and the full constructed hardon calorimeter. These simulations ensure that the LDMX will be structurally stable even during an earthquake.

Structural Determination of the Binding Interaction of Kapα:NLS
Anna Mortari
Mentors: André Hoélz and George Mobbs

Nuclear pore complexes (NPCs) play an outsized role during gene expression and cellular homeostasis, where they regulate the selective transport of macromolecules in and out of the nucleus. Using X-ray crystallography, the structures of many nucleoporins (Nups), the protein constituents of the NPC, have been resolved at atomic resolution. The nuclear import factor karyopherin alpha (Kap-ɑ) binds the nuclear localization signal (NLS) of proteins, allowing large proteins to easily move across the NPC. To investigate Kap-ɑ:NLS binding, both proteins were expressed and harvested separately in bacterial *E. coli* growths. Subsequently, they were purified separately to high homogeneity using several chromatography columns. The purified proteins were combined and set up in vapor diffusion experiments across over 600+ different conditions, resulting in either phase separation, precipitation, or protein crystals. Future work includes analyzing the crystals via X-ray diffraction experiments, and processing using specific software such as XDS, COOT, and Phenix to resolve its structure. The Kap-ɑ:NLS model will be used to elucidate the molecular basis of how Kap-ɑ interacts with NLS sequences.

An Anaerobic Microbial Community Obtained From Whale-Fall Sediment and Its Response to Changes in Free Energy
Greg Moss
Mentors: Victoria Orphan and Sujung Lim

As the most-produced renewable biopolymer in the world's oceans (between 10^{10} and 10^{11} tons annually), chitin is a significant source of carbon and nitrogen for marine organisms. Chitin, however, is present in low concentrations within the water column due to rapid microbial degradation, without which an intractably large carbon and nitrogen sink would form. While aerobic degradation of chitin is well-represented in the scientific literature, anaerobic is not. To ameliorate this, an anaerobic community of microbes was obtained from whale-fall sediment in the Monterey Canyon for study. We suspect whale-fall sediment to be chitin-enriched because of the chitin-carrying scavengers whale fall attracts (e.g. crustaceans, molluscs, and polychaetes). Laboratory incubations of the sediment exposed the microbial community to varying free energy levels by changing the available terminal electron acceptor (nitrate, sulfate, or no electron acceptor); N-Acetylglucosamine, the monomer of chitin, served as the sole electron donor. By conducting cell counts of incubations, this SURF seeks to answer the hypothesis that biomass is commensurate with free energy levels. Additionally, fluorescence *in situ* hybridization will help identify key taxonomic differences between treatments.

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.

Emittance Modulative Device Using Polyaniline-based Electrochemical System
Ankita Nandi
Mentors: Po-Chun Hsu, Ting-Hsuan Chen, and Austin Minnich

Radiation is a passive form of heat dissipation dependent on large temperature differences between the source and another point in space. To help keep human core body temperature constant, the body releases heat, and thermal radiation from skin is responsible for a significant percentage of the body’s heat loss. Thus, by controlling the skin’s thermal radiation, we can better manage one’s skin temperature. Thermal radiation is in the form of infrared radiation, so by using materials with tunable infrared emissivity, or how much heat is given off by a material, we can control how much heat passes through the material.

The conductive polymer polyaniline has different oxidation states with different emissivities. By applying a voltage to a polyaniline-based electrochemical system, we can switch between these oxidation states and change the emissivity of the material, thus either suppressing or increasing the amount of radiation passing through the material. Large-scale implementation of the device has been accomplished with a significant observable temperature difference, and work is being done to increase the scale and lifecycle of the device

Homes: Habitat Orientable and Modular Electrodynamic Shield
Nathan Ng
Mentor: Soon-Jo Chung

The abrasive and electrostatic properties of lunar dust threaten any long-term human presence on the moon. Our modular approach to mitigating unwanted lunar dust relies on electrodynamic dust shields (EDS) to direct the charged lunar dust using fringing electric fields. By embedding an EDS and circuitry within a rotationally symmetric frame, a panel can be created that mechanically interlocks and electrically interfaces with other similar panels. An array of these panels can be combined to transport lunar dust in any direction along an airlock floor, a work surface, or a common area.

The mechanical design of our solution relies on a low-outgassing plastic housing surrounding the electronics. Having been validated using topology optimization and static simulations, the plastic housing is pocketed even further to minimize weight while maximizing compressive strength. As a thermal management system, the bottom of the panel has an aluminum plate spanning its entire width. This plate specifically contacts heat-generating electrical components and acts as a heat spreader. As a preliminary panel is manufactured, I will continue to further optimize both systems using simulation and aid testing efforts.

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.

Strain Engineering of Pseudo-Magnetic Fields in Monolayer Graphene
Mai Nguyen
Mentors: Nai-Chang Yeh and Duxing Hao

Graphene is a promising candidate for valleytronic applications, where the valley degrees of freedom in electrons are leveraged to encode and process information. When smooth mechanical strains are induced on graphene, a gauge field—whose vector potential mimics that of a magnetic field—arises. Because of global time-reversal symmetry conservation, the strain-induced pseudo-magnetic field has opposite signs for the carriers in the two valleys at the K and K’ Dirac points, which can be exploited for valley filtering. This project aims to study how a well-designed strain arrangement produces certain configurations of pseudo-magnetic fields. Notably, when nearly strain-free monolayer graphene grown by plasma-enhanced chemical vapor deposition is strained on top of a rectangular array of nanostructures with the appropriate aspect ratio and horizontal spacing, parallel graphene wrinkles form. These strain-induced wrinkles encapsulate parallel channels of relatively uniform pseudo-magnetic fields with alternating signs and are observed under an atomic force microscope. The distribution and strengths of the encapsulated pseudo-magnetic fields are derived from the topographic data. These adjacent, parallel channels of pseudo-magnetic fields can spatially split incident electrons that belong to different valleys, generating a valley-polarized current and paving the way towards realizing practical valleytronic devices.

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.

Searching for Astronomical Transients in High Time Resolution Optical Observations
Jemima O’Farrell
Mentors: Gregg Hallinan and Qicheng Zhang

Optical transient astronomical events span a broad range of potentially observable events, from stellar-mass black hole flares to gravitational microlensing events. We aim to implement a pipeline of python libraries and processes specifically programmed to search for good optical transient events in over 100 hours of 30Hz imagery observed of the globular cluster Messier-22, provided by the Caltech HIgh-speed Multi-color camERA; CHIMERA.

We developed a pipeline that is a compilation of python libraries such as astropy and photutils, which are photometry libraries that were used tangentially with the image subtraction process. Through rigorous testing to identify transient candidates, we found a combination of processes that allowed us to create a pipeline that was adaptable to the ongoing input data-dependent changes. This pipeline can also screen these candidates for false positives to optimize the number of suitable candidates that we get to investigate further. We also computed a table of flux values for each candidate in the final subtraction, which is then used to calculate the flux of optical transient events in the input frames compared to the subtraction. These data will be helpful in further investigating and classifying candidates.

Quasi-Periodic Oscillations in AGN Light Curves: The Case of 2131-021
Sandra O'Neill
Mentors: Anthony C. Readhead and Sebastian Kiehlmann

The central engine of an active galaxy, the active galactic nucleus (AGN), consists of a supermassive black hole, accretion disk, dust torus, and sometimes, relativistic jets. These jets may form AGN objects. Using three sources of radio light curve data, we detected a returning quasi-periodic oscillation (QPO) in the object 2131-021. The first appearance of the QPO is from 1976 to 1983, with period 1746.30 ± 38.73 days. This QPO disappears until 2008, when it returns with period 1724.96 ± 6.35 days. By performing a least-squares sine fit to the data, we found that the data points deviate less than 1% from a true sine wave, making this an excellent case for a QPO in an AGN object. We go on to perform a PSD and WWZ analysis. This case also allows us to specify a set of criteria for classifying an object as a bona-fide QPO. We apply this criteria to the 61 other AGN QPO candidates in the literature—43 of which we have additional OVRO data for—to judge how convincing each case is. The existence of AGN QPOs at different parts of the electromagnetic spectrum informs us about the underlying mechanisms and location of these processes.

Squeezed Light Measurement via Balanced Homodyne Detection
David Oliveira
Mentors: Amir Safavi-Naeini and Michael Roukes

Light can be regarded as a harmonic oscillator with two conjugate variables, much like the canonical position and momentum x, p of a physical oscillator. These two variables, called field *quadratures*, oscillate in time and exhibit uncertainty. This uncertainty manifests as fuzziness in the amplitude and phase of light, establishing the standard quantum limit (SQL) on precision in optical measurements. This limit can be exceeded along one quadrature or the other by preparing *squeezed states* of light. In order to measure and use squeezed states, special balanced homodyne detection (HD) schemes can be used. However, achieving the sensitivity needed to resolve these quantum effects is quite difficult. To that end, we prepared a custom-built, photodiode-based HD detector circuit. We found that parasitic circuit effects are important to account for in achieving a stable, low-noise circuit. After several iterations of improvements, we developed a detector capable of resolving large differences between squeezed light statistics and the SQL, useful for applications in extremely precise metrology, quantum computation, and beyond.

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).

The Job Conundrum: Exploring the Politics of Work Among African Americans in the Post-Civil Rights Era
Chidinma Onyekonwu
Mentor: Danielle Wiggins

In this project, we explore the politics of work among African Americans in the post-civil rights era (post-1970). Specifically, we examine how local elites have advanced particular job creation ideologies and employment legislation to address racial inequity among black communities and promote economic redistribution in Atlanta, Georgia. Further, we analyze how the working class and poor black Atlantans have challenged these work ideologies and job creation programs. We survey articles using search terms such as "workfare," "job creation," "full employment," and "working conditions" from the *Atlanta Voice*, *Ebony*, *Black Enterprise*, and the *Atlanta Journal-Constitution, published between approximately 1970 and 1990.* In examining these articles, we will consider the following questions: How did we get from publicly-funded full employment legislation to private sector-led job creation? What were the overall sentiments from the working class and black Altantas regarding job creation policies? What were these jobs like? What was the working class' critique of the work-as-end itself? Why work? Exploring these works and the following questions will help pinpoint the overall counter-narrative to job creation policies. We also parse through the secondary literature concerning neoliberalism, the history of job creation in the United States, and theories of work to contextualize these local politics in a broader historical and theoretical perspective. We hope to gain insight into how employment policies and work ideologies have manifested in black communities today and how they continue to be upheld as the pathway toward progress and social mobility in these communities and other disenfranchised groups.

Predicting FLiNaK Infiltration Into Graphite
Xin Hui Ooi
Mentors: Raluca Scarlat, Lorenzo Vergari, and Melany Hunt

Molten salt reactors (MSRs) are new generation nuclear reactors proposed for commercial use due to their intrinsic safety features. MSRs employ large amounts of graphite and molten salts in their core. Thus, to ensure structural and thermal integrity of graphite, it is important that molten salts do not infiltrate graphite. Direct studies of salt infiltration in graphite are complex because they require large amounts of salts and pressurized setups. Fortunately, salt infiltration can be predicted through the Washburn equation from the contact angle of salt on graphite and the surface tension of the salt, which are easier to measure. In this work, we measure these properties through the sessile drop method, where a droplet of salt is melted onto a graphite substrate in a controlled atmosphere. An edge detection Python script was developed to extract the contact angle and the droplet's geometrical parameters. The variability of the contact angle, surface tension, and predicted infiltration pressure was investigated by exploring combinations of salt chemistry and graphite properties. The experiment uses FLiNaK (a mixture of LiF, KF and NaF) salt (pure and with traces of transition metal fluorides), two grades of nuclear graphite (IG110, ET10), and A3 graphite matrix.

Computational Complexity of Uryson Width
Noah D. Ortiz
Mentors: Fedor Manin and Peter Smillie

Define the Uryson k-width of a metric space X by the smallest w so that every map from X to a simplicial complex of at most dimension k has fibres of diameter at most w. We conjecture and wish to demonstrate that k-width is NP-hard to approximate up to a function of the size of X. This conjecture is supported by the examples due to Balitskiy and Berdnikov of spaces with small local k-width but large global k-width, showing that Uryson width is not a local property. We study available literature on Uryson width, particularly these discrepancies between local and global width, in order to develop methods for reducing an NP-hard problem to the Uryson width problem, with the aim of eventually preforming a reduction.

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.

Investigating the Effect of Magma Ocean Solidification Rate on Early Atmosphere Formation
Vibha Padmanabhan
Mentor: Yoshinori Miyazaki

The magma ocean stage of terrestrial planets' evolution is closely related to the redox state of their early atmospheres. Previous work has assumed the existence of deep magma oceans which remained molten for timescales comparable to that of planetary accretion. However, the lifetime of a magma ocean is likely orders of magnitude shorter. The deep magma ocean assumption also does not definitively explain the oxidized nature of Earth's early atmosphere and could result in a mantle composition that differs from what is observed. Thus, in this work, we aim to quantify the effects of a rapidly solidifying magma ocean on the atmospheric redox state and on siderophile (iron-loving) element concentrations in the mantle. We do so by constructing a thermochemical model of the mantle and atmosphere of a planetary body under the assumption that its magma ocean solidifies relatively quickly. Testing the rapid solidification model would improve our understanding of the key processes affecting the redox evolution of terrestrial planets.

Evidence for Centrifugal Breakout Around the Young M Dwarf TIC 234284556
Elsa Palumbo
Mentors: Benjamin Montet and Lynne Hillenbrand

Magnetospheric clouds, plasma that accumulates in dense clumps at a star's corotation radius, have been proposed as an explanation for variable dips in the light curves of young stars such as σ Ori E and RIK-210. However, the stellar theory that first predicted magnetospheric clouds also anticipated centrifugal breakout, an associated mass-loss mechanism for which there has been limited empirical evidence. Based on data from TESS, Gaia, LCO, ASAS-SN, and Veloce, we propose that the 45-million-year-old M3.5 star TIC 234284556 is a candidate for a direct detection of centrifugal breakout. To assess this hypothesis, we examine changes in the dip parameters over three sectors of TESS data, analyze optical flaring as a proxy for magnetic activity, and interpret the presence of an anomalous brightening event that precedes the disappearance of the dip. We argue that TIC 234284556 and previously identified ``flux-dip" stars together give us compelling evidence that centrifugal breakout is an important mass-loss mechanism. Finally, we consider possible mass-accumulation mechanisms and discuss how future observations may help us constrain M dwarfs' wind mass loss rates or give us valuable data about extra-solar CMEs.

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.

Delineating a Sexually Dimorphic Role of piRNA Pathway in Guarding Animal Fertility
Katherine Pan
Mentors: Alexei Aravin and Peiwei Chen

Abstract withheld from publication at mentor's request.

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.

Examining the Impact of an Individual's Physical and Personal Proximity to COVID-19 on Mental Health
Eunice Park
Mentors: Ralph Adolphs, Damian Stanley, and Tessa Rusch

With the sudden onset of the COVID-19 pandemic, the world was pushed into a stressful and anxiety-inducing time. The COVID-Dynamic team was formed to track individuals' psychological and social responses to this unprecedented period of prolonged stress. In 16 waves over 10 months the study gathered responses from 1000+ U.S residents tracking psychological, emotional, attitudinal, and behavioral change of an individual living through the pandemic. My project utilizes some of this self-report data while at the same time expanding it with additional public data, such as COVID-19 cases, unemployment numbers, and restrictions in participants' specific local areas. Using this data I characterize the extent to which the pandemic has affected the area around the participant, and investigate how predictive this may be for their survey responses pertaining to their more personal life and mental and emotional wellbeing; the information about the pandemic based on each participants' location is likely quite predictive of their emotional wellbeing, and their self-reported pandemic experience even moreso, since the world has been severely impacted by the unexpected casualties and political and financial stress.

Mach, Einstein, and the Rejection of the Luminiferous Ether
John Parker
Mentor: Joshua Eisenthal

It is widely accepted that the philosopher Ernst Mach influenced Einstein as a student and that Einstein would diverge from Mach's philosophy later in his career. However, the extent to which Einstein and Mach were aligned during the development of Special Relativity has been thoroughly debated. One ostensible case of Einstein's alignment with Mach was his conclusion that the luminiferous ether is "superfluous". Mach applauded Einstein for his elimination of a dogmatic physical concept inaccessible to direct observation. However, in order to prove that the ether was unobservable, Einstein's theory was built upon two thematic postulates (the principle of relativity and constancy of the velocity of light) – postulates which in themselves violated Mach's requirement of direct verification. In this paper, I evaluate this conflicting aspect of Einstein's work and determine to what extent Einstein's motivation to reject the luminiferous ether was in alignment with Mach's philosophy.

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.

Mechanically Triggered Small Molecule Release in Crosslinked Polymer Networks
Jolly Patro
Mentors: Maxwell Robb, Tian Zeng, and Ross Barber

Polymer mechanochemistry is field of research where mechanical force, transduced by polymer chains, causes predictable chemical transformations in force-sensitive molecules known as mechanophores. Mechanophores have been developed that turn on color, switch electrical conductivity, and release small molecules under applied stress. Prior work in the Robb group identified a mechanophore design capable of mechanically triggered small molecule release via a retro-Diels-Alder reaction revealing a furfuryl carbonate that can decompose and release small molecules in a polar protic solvent. This platform has only been proved successful in solution-phase experiments using ultrasound, however, it has yet to be demonstrated in solid state materials. Here, we investigated mechanically triggered release of fluorescent small molecules in bulk polymeric materials using various modes of mechanical activation. Mechanically triggered release in bulk polymeric materials could have potential applications in drug delivery, mechanical lithography, and self-healing materials.

Fabrication of Silicon Particle Monolayers
Elijah Paul
Mentors: Harry Atwater and Parker Wray

Prior work has demonstrated the preservation of the single-particle Kerker effect in large 2-dimensional films of silicon nanoparticles with random spatial distributions. In order to experimentally reproduce these findings, we must first fabricate monolayer films. We explore two ways of fabricating monolayer films of silicon nanoparticles through spin-coating and Langmuir-Blodgett methods. These fabrications use polyvinylpyrrolidone coating and amine functionalization respectively to create the appropriate surface chemistry on the silicon nanoparticles. The assembled films can be characterized using UV-Visible ellipsometry and spectroscopy to compare to theoretical predictions. The preservation of single-particle scattering is also leveraged theoretically for the design of optical filters, presenting an approach to designing optical filters using a monolayer of randomly distributed particles with a particular random size distribution. Unlike traditional approaches, this uses only one layer of a single material rather than many layers of varying material, and this approach is also more resilient to fabrication variation.

A Phase-Field Model of Preferential Meltwater Flow Through Snowpack
Joshua Pawlak
Mentor: Ruby Fu

Glacier and snowpack meltwater provide the main water supply for more than 1.2 billion people, and the economic cost of losing these sources could be as much as $50 billion annually in the United States alone. Given these potential impacts, a deeper understanding of physical processes in snow will allow for better predictions of glacier mass balance and water resources. In this project, we focus on modeling isothermal meltwater percolation through porous snow, which is a complex but important process in cryosphere hydrology. Variability due to snow metamorphism leads to disparate hydraulic properties, forming capillary barriers which reduce local meltwater flow, cause liquid ponding, and enforce preferential flow pathways. Even in homogeneous snow, downward infiltration still forms preferential pathways due to a gravity fingering instability. Recent efforts to model infiltration based on the Richards equation do not fully explain these observations. Here, we attempt to address these complexities with a phase-field model of unstable infiltration. We find good agreement of the model simulations with existing laboratory measurements, reproducing observed ponding and preferential infiltration patterns, as well as the rate of infiltration. The agreement between simulations and the lab experiments suggests that the phase-field method is a promising direction forward for understanding the myriad thermomechanical processes occurring during snow melt.

Comparing Equivariant Graph Neural Network Implementations for Use With Cellular Point Clouds
Hazel Winter Pearson
Mentors: David Van Valen, Uriah Israel, and Yisong Yue

Microscope images of cells have become prolifically available in recent years, but analysis methods for the resultantly extensive data are still fledgling. Because transformations (i.e., rotations, reflections, translations, and permutations) of cells in these images are not the result of biological changes, they should not impact their analysis. Our work builds on particular neural network architectures to utilize the symmetry of this problem. Equivariant neural networks process data so that the resulting feature map changes predictably when transformations to the data occur. We determine if this creates more efficient and accurate results.

We explore three implementations: an E(2) equivariant graph neural network, an SE(2) harmonic network, and an SE(2) transformer. We present successful implementations of all three and initial results about their comparative efficacy, laying the groundwork for further experiments with larger data sets.

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.

Study of Reaction of HCl With U Metal in Molten NaCl-$CaCl_2$
Claire Perhach
Mentors: Michael Simpson and Harvey Newman

For the purpose of generating UCl_3 in fuel salt for a molten salt reactor (MSR), bubbling HCl into the molten salt in contact with U metal was investigated. The base salt used for this study was equimolar NaCl-$CaCl_2$. First the NaCl-$CaCl_2$ was purified via heating to 200°C and purified by bubbling 5% HCl gas balanced with argon. Effluent gas was fed into an auto-titrator which measured the consumption of HCl in real time and was used to determine when to stop the reaction. Then, a uranium rod (3" by 2.1mm) was inserted into salt while 160ccm of 5% HCl gas balanced with argon was bubbled in. Salt samples were analyzed using inductively coupled plasma mass spectrometry (ICP-MS) and found to contain 0.06 wt% U. Additionally, open circuit potential was used to verify that the U in the salt is essentially 100% UCl_3 and not UCl_4. Applicability of this process to an integrated MSR fuel processing scheme that includes actinide drawdown from waste salt and dechlorination of waste salt will be discussed.

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.

Modeling Diffuse Inelastic Scattering in Cu_2O With Molecular Dynamics and Machine Learning Potentials
Bannhat Phat
Mentors: Brent Fultz and Claire N. Saunders

Large anharmonicity has been observed in optical phonons in cuprite, Cu_2O, along with unexplained broad diffuse inelastic intensities in the measured phonon spectrum. These phonon dispersions were measured by inelastic neutron scattering (INS) at 700 and 900 K by rotating a single crystal of cuprite in the Wide Angular-Range Chopper Spectrometer (ARCS) at Oak Ridge National Laboratory (ORNL). Although quasiharmonic and anharmonic calculations with cubic intensities accounted for the majority of the temperature-dependent behavior seen, they did not explain the diffuseness in the intensity profile. In this research, I will perform a classical molecular dynamics simulation to reproduce the experimentally observed intensity profiles and ascertain the mechanisms for the diffuseness.

Measuring Strain in a Giant Single-Celled Organism to Explore Underlying Mechanisms of Morphogenesis
Faith Pinney
Mentors: Elliot Meyerowitz and Eldad Afik

Alga *Caulerpa* is a large single-celled algae that looks similar to a multicellular organism. This plant has a free flowing cytoplasm throughout. Thus, it is able to generate a new cell wall if the plant receives damage to any of its organs and regenerates from fragments of the blades or stolons. By developing methods to modify the internal stresses via an introduction of a cut to stolons and osmotic pressure changes, the strain field of the blades can be inferred as they deform using time-lapse wide-field imaging. This can be used to determine if a non-homogeneous deformation occurs, which would indicate variations in the stress-strain relationship along the blade which maycontribute to the mechanisms of morphogenesis.

Towards an Optical-Based Two-Way Cellular Control Loop for *In-Vivo* Use: A Microfluidic Focus
Krishna Pochana
Mentors: Azita Emami and Fatemeh Aghlmand

Current methods for the control of cellular processes are limited by their reliance on already existing cellular pathways for functions such as protein synthesis. While these pathways can be adapted for other uses, such as drug synthesis and targeted delivery, the complexity and cost of doing so increases rapidly as more complex logic is implemented, and they can have unintended side-effects. Thus, this project seeks to make a single chip silicon-based system capable of robust sensing and control of cellular functions, namely protein synthesis, for applications such as drug delivery or health condition monitoring, using two-way continuous optical signaling between cells and the silicon chip. The SURF portion of this project focuses on designing and manufacturing a microfluidic system to load, house, and grow cells to enable optical sensing and signaling while providing the necessary conditions for the cells to grow and quickly respond to signaling molecules from the external body. This system is designed and manufactured using a resin 3D-printing process and demonstrated to meet all system requirements. Future steps include integrating this device with the finished silicon chip and iterating on the device in the final ingestible system.

Coherent Diffraction Method for Imaging Dusty Plasma Water Ice Grains
Geoffrey Pomraning
Mentor: Paul M. Bellan

Water ice grains spontaneously form in the Caltech ice dusty plasma experiment [1] which involves cryogenic (~190 K) neutrals, water vapor, and weak (~10^{-6}) ionization. The ice grains have been imaged until now using a long-distance microscope lens—with a 3μm resolution limit—mounted on a camera. Reference [1] showed that ice grain size and ellipticity could be ascertained from diffraction patterns of a HeNe laser beam. Re-visiting diffraction methods, we aim to use the diffraction pattern to obtain a complete detailed image of the ice grains. This pattern on a screen is the absolute value of a 2D Fourier transform (FT) of the ice grain shape so phase information is lost. We will use the Fienup phase restoration method [2] where iterative numerical guesses restore the missing phase using the physical constraint that the image intensity is non-negative. By taking absolute values of FT's, we have demonstrated this method on synthetic diffraction patterns, first removing then recovering phase. Theoretical considerations indicate that this diffraction/Fienup restoration method should improve on the microscope lens resolution by an order of magnitude.

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.

Limits of High Density Probes for Chemical Detection in the Brain
Rafael Porto
Mentor: Jessica Arlett

Current technology for chemical detection in the brain is highly invasive and offers data with poor time resolution. Smaller, higher density probes would address these issues but pose significant engineering problems, one of which is increased chemical cross talk which makes signals from closely spaced sensor pads unreliable. We investigate the feasibility and effectiveness of applying a catalase coating to the region between sensors with the goal of reducing this cross talk. We find through both random walk simulations and experimental data that cross talk is indeed reduced, but that the 20$\mathrm{\mu m}$ spacing between our sensors is near the resolution limit of fluid dispensing using the SonoPlot Microplotter II.

Surgical Drain Fluid-Based DNA Analysis in Head and Neck Cancer Patients
Aditee Prabhutendolkar
Mentors: Aadel Chaudhuri and Sarkis Mazmanian

In human papillomavirus (HPV)-positive oropharyngeal squamous cell carcinoma (OPSCC) patients, viral infection drives tumor growth. These patients on average have higher chances of survival and lower rates of recurrence than HPV-negative OPSCC patients, implying that some patients are potentially being overtreated. It is thus important to identify precise biomarkers to guide adjuvant treatment. In this project, we studied surgical drain fluid as a potential such biomarker.

The Chaudhuri lab has obtained patient data with HPV copies found in surgical drain fluid samples. We sorted the samples by the patients' pathologic features (lymph node metastasis and extranodal extension) which are associated with cancer recurrence. We performed multiple statistical tests to identify a strong direct correlation between HPV copies and presence of pathologic features. Therefore, we believe higher viral burden in drain fluid indicates the presence of tumor cells and circulating tumor DNA; we predict that these patients are more likely to recur, making them our targets for adjuvant therapy, usually chemoradiation. Likewise, patients with lower viral burden have lower amounts of tumor DNA, and therefore they have a lower likelihood of recurring. These patients could potentially require less adjuvant treatment and still achieve the same outcome after surgery.

Origami-inspired Metamaterial With Tunable Permeability
Anvay Pradhan
Mentors: Chiara Daraio and Ke Liu

The permeability of a porous material depends on two characteristics: (1) pore density: the number of empty spaces per unit volume of the material and (2) pore shape: the orientation of the pores in the medium. This study sought to tune permeability by reorienting pore shape within a medium while maintaining global volume of medium. This was achieved by rotating alternate units of the well-known Miura origami tube 90° to form a modified Miura tube which could limit global, longitudinal strain while undergoing large cross-sectional deformation. When tessellated in 3D, the modified Miura tube formed a matrix that experienced plateauing global deformation in volume, but large local strain causing a reorientation of pore shape. The reconfiguration mode of the modified Miura tube matrix was analyzed mathematically and shown to undergo the aforementioned phenomena. Equations were developed to describe the deformation of each tube and relate the theoretical model to a physical prototype. A foldable computer simulation was also created to show strain and cross-sectional area changes of the matrix. Lastly, a functional prototype for the matrix was developed and tested. This work was able to create a metamaterial with tunable permeability and demonstrate its behavior during actuation.

Learning Cancer and Immune Cell Developmental Lineages to Predict Evolution of Metastatic Prostate Cancer
Elora Pradhan
Mentors: Vanessa Jonsson and Matt Thomson

Approximately one third of early stage prostate cancer cases progress to metastatic castration-resistant prostate cancer (CRPC) –– an advanced disease stage with no long-term effective treatment strategies. Incomplete understanding of the evolving transcriptomic heterogeneity of prostate tumors, especially what drives metastatic progression and immune escape, presents a major obstacle in treating patients and mitigating the transition to CRPC. Here, we integrated publicly available single-cell RNA sequencing prostate cancer datasets to provide a comprehensive pseudotemporal view of the evolving tumor-immune landscape, with 165,023 single-cell transcriptomic profiles spanning both the early and CRPC stages. Trajectory analysis revealed changes in activation of specific gene regulatory networks from early to metastatic cell lineages. As potential drivers of the transition to CRPC, these genes offer both predictive power in determining patient prognosis and therapeutic promise as potential drug targets.

Multiwavelength Coupling With Waveguide-Integrated Optical Metasurfaces
Olivers Pranis
Mentors: Harry Atwater and Claudio Hail

Optical metasurfaces are artificially engineered materials composed of nanoscopic structures with the aim of manipulating the propagation of light at subwavelength scale. These metasurfaces could prove to be instrumental in realizing holographic displays, next-generation optical elements, and in miniaturizing existing optical systems. While research in this field has mainly focused on manipulating light propagating in free-space, the coupling of guided waves to free-space is much less explored. Here, we show how waveguide-integrated metasurfaces can be designed to achieve independent multiwavelength free-space light coupling. First, we employ finite-difference time-domain simulations to design two independent metalenses, each for a different wavelength, and confirm their focusing ability. In a second step, using two different approaches, we generate combined multiwavelength metalenses by superimposing the previously obtained single-wavelength metalens structures. While our results show that independent multiwavelength focusing can be achieved, further strategies can be explored to improve the performance in the future.

Antagonistic Mechanisms of PU.1 Transcription Factor on Notch Signaling During T-lymphocyte Development
Christopher Pukszta
Mentors: Ellen Rothenberg and Jihyun Irizarry

Hematopoietic stem cells (HSCs) progress through one of several developmental paths to comprise the human immune system. Cells assume a lineage as a result of a complex web of time-dependent environmental signals. PU.1 transcription factor is vital to the early development of T-Cell progenitors, supporting stem-cell specific gene expression through the early stages of development. The Notch signaling pathway is also vital for commitment to a T-cell fate. Notch signaling is a highly conserved cell-to-cell signaling pathway that includes a known force between the signaling and receiving cells. PU.1 expression antagonizes the effects of Notch signaling and controls some cell adhesion molecules. We investigate if PU.1's downstream effects can reduce the amount of cellular force due to Notch signaling as a method of regulation. To do this, we perturbed the expression levels of PU.1 by over-expressing or knocking out PU.1 in developing HSCs and examining their lineage choices with flow cytometry. Our results indicate that PU.1 expression reduces, but does not silence, Notch signaling levels to slow development of HSCs. This impediment to development indicates that the method of regulation involved is slight and thus could be a limiting of the cell's abilities to move and induce Notch signaling.

Development of the High Voltage Circuitry of a Modular Electrodynamic Shield System for Lunar Exploration
Kemal Pulungan
Mentor: Soon-Jo Chung

As NASA and other spacefaring entities seek to return humans to the moon to establish a permanent presence, lunar dust poses the greatest challenge to surface operations. It is highly abrasive, and charged due to solar radiation. Due to its abrasiveness, lunar dust quickens the pace of mechanical failure of parts, and is very harmful to spacefarers' lungs. Because it is charged, lunar dust adheres to surfaces easily, making mechanical methods of getting rid of it, such as brushing, ineffective. A Caltech student team has been developing the Habitat Orientable and Modular Electrodynamic Shield (HOMES), a system of electrodynamic dust shield (EDS) panels that can be placed in different configurations with each other. EDS works by pushing lunar dust off of its surface by generating electric and dielectrophoretic forces from moving electric fields. The electronics of the system are paramount to the success of the project, requiring high voltage electrical pulses to move dust. The circuitry revolves around MOSFETs switching high voltages. The challenges of high voltages are heightened by the fact that the electronics must fit inside the small space of the panel. LTSpice was used to design and simulate the circuit. It was then built and tested, simulations verified experimentally. Iterations on the circuitry were made from these tests. The electronics were then integrated into the full system and tested for a proposed lifetime of 15 years.

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.

Learning Demonstrated Player Behavior in Video Games With Neural Networks
Daniel Quintana
Mentor: Yisong Yue

Many machine learning algorithms are tested and used in the context of games and game-like settings. These settings represent high-dimensional control problems and are a useful avenue to explore the limitations of such algorithms. While neural networks have been shown to be effective at becoming good at games, we are interested in investigating their applicability in learning player behavior through imitation learning. To this end, we have created a simple strategy game to act as the test environment, and we are developing a multi-headed neural network to predict player decisions and control other agents within the game while the human plays. We will use behavioral data, recording a series of game states and corresponding human decisions, to train and measure the accuracy of the network's predictions.

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.

Determining the Priority Queuing Mechanism From a Poverty Framework
Kavya Rajagopalan
Mentors: Colin Camerer and Marcos Gallo

In America and throughout the world, wealth inequality is a significant contributing factor in dictating how people behave. Individuals are described as making a sequence of decisions and bargains in order to reduce the strain of their daily demands in a process similar to that of an economic decision: Allocating limited resources such as energy, time, emotions, and goods (Goode, 1960) in different ways. The process of determining which tasks take precedence, known as Priority Queuing, is a phenomenon that we will study in regards to poverty. Experimentally we will be examining this topic by simulating an artificial priority queue, and inducing poverty-conditions by varying the time scarcity and urgency of different tasks. Likewise, we will develop a theoretical framework to assess the optimal decision-making protocol once a participant is given a set of tasks. We anticipate observing that high urgency, high effort and induced time scarcity will ultimately result in suboptimal decision-making and thus an increase of incomplete tasks. Our hope is that our research in the long-term will serve as the scaffolding for understanding how poverty traps come to be and how come conditions intrinsic to the poor are able to perpetuate this cycle of wealth inequality.

High-Level Optimization of SOFTS Devices for Synchrotron and Sunyaev-Zeldovich Effect Physics
Eitan Rapaport
Mentors: James Bock and Ritoban Basu Thakur

In thin film superconductors like NbTiN, DC current can be used to alter the kinetic inductance, therefore the transmission delay. Superconducting On-chip Fourier Transform Spectrometers (SOFTS) use such JPL fabricated current-controlled variable delay lines, a few mm’s in length to attain GHz resolution interferometers on-chip. SOFTS enables broadband submillimeter spectro-imaging with integral focal plane units, to study Sunyaev-Zeldovich effects in galaxy clusters and other cosmic microwave background spectral distortions.

We develop a computational framework to study how such SOFTS devices can image galaxy-clusters whilst simultaneously obtaining color information. Our simulation enables forecasting of how well these devices may perform at recovering Sunyaev-Zeldovich spectral distortion parameters of a galaxy cluster. To do this we make noisy voxels and apply MCMC analyses to recover cluster parameters such as the electron density, temperature and the optical depth. At its core, the simulations realize multiple versions of SOFTS focal planes, with choice of bandwidth, resolution and number of simultaneous imaging-spectrometers; it considers the photon noise penalties and then performs the MCMC analyses. Guided by the results of the simulation, we extract specific configurations of SOFTSs that perform best in recovering aforementioned cluster physics.

Explaining the Formation of Planet 9 With a Theoretical Early Solar Binary

Dennis Raush
Mentor: Konstantin Batygin

With the development of better telescopes and sky surveys throughout the 2000s, astronomers noticed peculiar trends in the orbits of extreme trans-Neptunian objects (eTNOs), or rocky bodies that orbit at a distance in excess of 250 times that of the Earth. The culmination of these observations came with Batygin and Brown (2016), which proposed a hypothetical "Planet 9" (P9), a planet 5-10 times the mass of the Earth orbiting in the outer reaches of the Solar System. The gravitational influence of P9 would explain the clustering observed in orbital parameters of the eTNOs, but since the development of this theory, there has been no observational evidence of the existence of P9. Additionally, El-Badry et al. (2021) shows, using new observational data from the Gaia space observatory, that around half of Sun-sized stars form with a binary companion. In this work, we shed light on theories of the formation of P9 through astrophysical N-body simulations of the early Solar System in the presence and absence of a solar binary companion. In both simulations, we observe test particles scattered from the inner Solar System (a = 4.5 AU – 12 AU) into the Kuiper belt and inner Oort cloud. In the presence of a solar binary, however, the eccentricity of orbits of some scattered particles decreases and stabilizes. We conclude that P9 could have been scattered from the inner Solar System and stabilized into its current orbit by a binary companion.

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.

Investigating the Effects of Microbial Metabolites on Mitochondrial and Immune Functions of BV-2 Microglial Cells

Bruna Lopes Resende
Mentors: Sarkis Mazmanian, Reem Abdel-Haq, and Livia Hecke Morais

Throughout human evolutionary history, an intimate symbiotic relationship with a consortium of gut bacteria has given rise to an extensive bi-modulatory system between those bacteria and the host's organism. This interconnection occurs through distinct mechanisms, including direct and indirect pathways, and modulates body functions in physiological and pathological conditions. In the past years, increasing evidence from animal models suggests a microbiome role in the pathogenesis of many diseases, such as Parkinson's Disease. In this study, we investigate the interaction between microbial metabolites and a brain-resident immune cell – the microglia. Specifically, we evaluate if these metabolites modulate microglia's mitochondrial and immune functions, both significant aspects of PD pathophysiology. For this, we stimulate BV-2 cells, a microglial cell line, with Butyrate, Acetate, Propionate (microbial metabolites), o a mixture of all three, and assess proinflammatory cytokines profile, oxidative stress, ATP concentration, and phagocytic activity. To date, our results indicate that, while there isn't an effect of any metabolite in preventing proinflammatory profile, butyrate might be acting as a stimulator of phagocytosis. Our results provide insights into microglial responsiveness to microbial metabolites, and future steps include further investigation of microglial phagocytic and autophagic functions.

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.

Evaluating Algorithmic Approaches to the K-Coloring Problem Using Well-Mixed Stochastic CRNs
Philippa Richter
Mentor: Erik Winfree

Graph K-Coloring is one of the most well-known and well-studied problems in the field of computer science. It is extremely difficult, falling into the NP-complete complexity class. One approach to solving the K-Coloring problem is termed stochastic local search (SLS), which involves randomly resolving vertex coloring conflicts until a valid coloring is achieved. This strategy can be naturally implemented using well-mixed stochastic chemical reaction networks (CRNs). In this exploration, four classifications of SLS-based CRNs were evaluated: Walk-SAT, Direct-Conflict, Walk-Coloring, and Stochastic-Tabu. It was found that, for k=3 the Walk-Coloring CRN construct was able to solve difficult K-Coloring problems more quickly, and with greater consistency, than the other types of CRN.

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.

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.

Impact of Premature Bcl11b Expression on T cell Development

Makena Rodriguez
Mentors: Ellen Rothenberg and Tom Sidwell

Thymic T cell progenitors have the potential to differentiate into cells of diverse roles important to the proper functioning of the immune system. While much progress has been made in elucidating the diverse mechanisms behind thymic and post-thymic specification to these cell fates, questions remain regarding why committed T cells develop from multipotent hematopoietic stem cells the way they do. Commitment of progenitor cells to the T cell lineage is dependent on the upregulation of the transcription factor Bcl11b, normally occurring only after more than ten rounds of division in the thymic microenvironment. In this project, we aimed to elucidate why Bcl11b expression and resultant T-lineage commitment occurs only after progenitor cells have dwelled in the thymus for so long. To address this question, we investigated the impact premature upregulation of Bcl11b has on key transitions in T cell development. Having analyzed the timing of key developmental transitions of bone marrow cells cultured in conditions mimicking the thymus, we transduced these cells with a Bcl11b overexpression vector at a timepoint prior to endogenous Bcl11b expression. These cells were then cultured in T- and non-T lineage promoting conditions and analyzed using flow cytometry at two subsequent timepoints to assess their developmental phenotypes relative to empty vector transduced controls. Preliminary results indicate that premature Bcl11b expression insulates T cell progenitors from diverting from the T cell developmental trajectory, but slows down the rate at which they progress along the pathway. Notably, provision of the exogenous Bcl11b repressed the expression of the endogenous allele. Further work will be to repeat this experiment, and to characterize the impact of the closely-related Bcl11b paralog Bcl11a in the same context.

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.

Structural Identification of Karyopherin-α Binding Interactions During Nuclear Pore Complex Assembly
Asha Rollins
Mentors: André Hoelz and George Mobbs

The nuclear pore complex is an essential protein mega-structure that regulates nucleocytoplasmic transport within cells. The pore is made up of approximately 1000 proteins, termed nucleoporins, and includes a nuclear basket, cytoplasmic filaments, and a central symmetric-core, forming a large and intricate 110 MDa structure with distinctive eight-fold symmetry. Due to its importance and structural complexity, understanding how the nuclear pore complex is assembled during the cell cycle is an important objective for current research. In this project, we aim to determine the structure through which the NLS sequences of certain proteins of interest bind to the adaptor protein Karyopherin-α (Kap-α) during the process of nuclear pore assembly. In order to complete this work for a first protein of interest, we expressed the necessary proteins and purified them through a series of chromatography columns. By extensive screening over 600 different crystallization conditions and multiple protein concentrations, we obtained several Kap-α crystal samples for analysis. Future steps for these crystals include x-ray diffraction experiments conducted at the synchrotron and structure solution. Additionally, we used prior x-ray diffraction data to solve a Kap-α binding structure with a second protein of interest through iterative model building and refinement.

Comparing N_2 Reduction on Ruthenium Catalysts
Michael Rose
Mentor: William A. Goddard, III

The Haber-Bosch process is the primary means of artificial ammonia production. Without this ammonia for fertilizers, modern agricultural methods would be unable to sustain the current global population. However, this process requires intense temperature (400 - 500 ℃) and pressure (100 - 200 atm), making it highly energy intensive and requiring large, expensive infrastructure. An electrochemical alternative would potentially solve these problems; however, currently the catalysts for such an alternative are not competitive. To this end, improving a ruthenium catalyst was investigated by modeling reduction on different crystal surfaces: (0001), (1-100), and (2-1-10). The energetics for these cases were calculated using Vienna Ab initio Simulation Package (VASP). JDFTx was used to determine the effect of an electric potential on these energetics, and Nudge Elastic Band method was used to describe the kinetics. The competitive reduction of hydrogen was also investigated on these surfaces. The hope is by better understanding nitrogen's reduction on these three surfaces to gain insight into improved catalysts that will enable an electrochemical alternative to become a reality.

A Non-Invasive and Targeted Approach to Studying the Role of Intrinsically Photosensitive Retinal Ganglion Cells in Human Neural Response
Iyla Rossi
Mentors: Shin Shimojo and Daw-An Wu

Intrinsically photosensitive retinal ganglion cells (ipRGCs) are photoreceptors contained within the outer retina. They respond to light alongside rods and cones, mediate non-visual light responses, and relay information via two pathways: the rod-cone pathway, and a melanopsin-driven pathway. Prior studies have implicated ipRGCs in several important neural functions, such as attention, visual awareness, and circadian rhythm. Thus, by studying ipRGCs, we can gain greater insight into how ipRGCs participate in visual perception (or "sight").

It is difficult to accurately and precisely study ipRGCs in humans due to the requirement for non-invasive and targeted experiments. We aim to develop a method for studying ipRGCs in humans which will utilize the SONY Compact Retinal Scan Near-Eye Display prototype; we will safely and precisely project images directly onto the retina to investigate the ipRGCs in the blind spot.

We have successfully designed experiments to locate the blind spot and investigate the neural response to blind spot stimulation using PsychoPy, an open-source package for running neuroscience experiments in Python. Further research should continue optimizing and expanding upon the current experimental designs. Additionally, further research should perform the experiments on human participants using the SONY Compact Retinal Scan Near-Eye Display prototype.

Validating Model of Thermo-Diffusive Instabilities in Hydrogen Gas Combustion
Perry Samimy
Mentors: Guillaume Blanquart and Matthew Yao

The combustion of hydrogen gas has been widely considered as an alternative to traditional means of energy production and storage due to its lower emissions and higher efficiency. High-fidelity simulations of hydrogen combustion are necessary to take full advantage of these properties. Large Eddy Simulations (LES) have emerged as a powerful method of simulating turbulent flows, but are conducted under low resolution and rely on a subgrid-scale model (SGS) to model the unresolved physics. Thus, the SGS model needs to capture all relevant turbulent and chemical phenomena, including thermo-diffusive instabilities present during hydrogen gas combustion. Jason Schlup has developed a new, reduced thermal diffusion model that accounts for such instabilities within DNS. It also reduces simulation cost by decreasing the number of tracked chemical species from nine to two. The current work involves validating said model by comparing the simulated flow of hydrogen and methane gas to experimental data, as well as results obtained using more traditional SGS models. To do this, a grid was created in MATLAB using the combustion chamber geometry and the chemistry was tabulated for use in the LES. The flow of hydrogen and methane gas were then simulated using the NGA code on the Hoth cluster at Caltech. The simulated results have not yet been compared to experimental data nor other simulations, but the implementation of Schlup's model in SGS is expected to yield substantial predictive improvements.

Optimizing Reference Frame Selection to Improve Exoplanet Detection Limits With the Keck/NIRC2 High-Contrast Imager
Aniket Sanghi
Mentors: Dimitri Mawet, Jason Wang, and Jerry Xuan

High-contrast imaging has probed exoplanets at separations ~10-100 au and masses >2 Jupiter masses. The direct detection and characterization of lower mass planets at smaller separations from their stars presents a unique challenge that requires state-of-the-art adaptive optics systems and coronagraphs combined with optimized observing and post-processing strategies. Reference star differential imaging (RDI) is a powerful observing strategy that enables direct imaging of exoplanets at small separations. It uses reference stars distinct from the science target to model the target star's point spread function (PSF) for subtraction. The primary challenge in implementing RDI is the construction of a high-quality reference library for PSF subtraction. We aim to optimize the RDI strategy through statistical pre-frame selection of reference stars. We leverage ~10000 archival PSF observations by the Keck/NIRC2 vortex coronagraph to develop a suite of metrics to rank reference frames by their similarity to the science observations. By computing contrast curves and performing fake planet injection-recovery tests, we demonstrate significant improvements in detection sensitivity levels achieved with this technique, compared to the default strategy of using a single night of reference star observations. This work will enable the uniform reprocessing of archival Keck/NIRC2 observations with RDI to uncover previously undetected exoplanets.

Comparing Canonical Machine Learning Models With 3D Computer Vision for Molecular Property Prediction
Megan Santhumayor
Mentors: Sarah Reisman and Michael Maser

In this project, we predict properties of molecules such as the HOMO-LUMO gap given the 3D representation of the molecules. Published architectures which utilize convolutional neural networks for 3D object recognition were tested in an experiment. Higher capacity models performed best, achieving regression errors as low as 0.40 eV. We created our own model which combines the benefits of each architecture and contains inception modules with carefully selected kernels. Expanding the inception modules improved the performance of this model, as it was initially significantly smaller than the published architectures. Then, we created baseline models that use ensemble machine learning techniques including random forest, gradient boosting, and deep neural networks. These baselines were built for the purpose of comparing the computer vision models and were tested on molecular descriptors and fingerprints. After training and testing these baseline models, we observed that they were surprisingly effective for this task. The R^2 value was as high as 0.86 and the errors were significantly lower than those of the more complex computer vision models, as low as 0.26 eV. Next, we implemented a model with message passing graph neural networks consisting of nodes and edges for each molecule. We believe graph convolutional networks can be very useful for this task. These models are interesting tools for the field for predicting orbital energy levels. In the future, more work can be done to use these models to predict the results of a reaction from 3D representations of molecules, which will be helpful for labs working with large molecules.

Optimizing Cell Extracts by Testing Deletions of Metabolic Pathways to Inform Model Building
Pranay Satya
Mentor: Richard Murray

A major question in synthetic biology is how organisms can be engineered and altered to produce a desired product in the most efficient way possible. Cell-free systems provide a way to separate an organism's need to grow and reproduce from its other functions like protein synthesis. Cell extracts obtained from organisms like *E.coli* contain a vastly intricate metabolism which is difficult to predict and change in terms of directing the production of a protein or chemical. While computational modelling using chemical reaction networks (CRNs) can help quantify chemical reactions of metabolism and make predictions about chemical species, there is a disconnect between physical data and modelling predictions. We aimed to reconcile the two by using data from metabolic engineering experiments to direct modelling work which would in turn provide further insight for further physical experiments. We started with using the pORTMAGE protocol to insert mutations into *E.coli* BL21DE3 strains to disrupt the synthesis of amino acids like glutamate, ornithine, lysine, and arginine. Data from these disruption in cell free extract would be used to direct the parameterization of a model being simultaneously developed by another SURF student in the Murray Lab. The goal is to demonstrate that a model informed by physical experiments can reliably predict metabolite concentrations over time and also inform one on what disruptions to cell-free metabolism would optimize cell extract for the specific cell free protein synthesis.

Nitrogenase Identification and Activity in *Azotobacter vinelandii*
Cameron Scantlin
Mentors: Douglas Rees and Rebeccah Warmack

Fixed nitrogen is essential to living organisms, but artificial nitrogen fixation is energy expensive and outputs massive amounts of carbon dioxide. This prompts scientists to explore organisms that fix nitrogen naturally. Nitrogenase, the enzyme that fixes nitrogen in diazotrophs, has been studied extensively *in vitro,* but has yet to be visualized *in vivo*. In this paper, we set the groundwork to image *in vivo* nitrogenase. Most notably, we found sub tomogram averaging to be a suitable method to reconstruct a representative model of nitrogenase. Such models could be used to computationally select nitrogenase in cellular tomograms. We found preliminary data for nitrogenase expression and activity against *A. vinelandii* growth to determine the optimal time for imaging and to be used as a baseline for alternate growth 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.

Simulated Selection Effects for Fast Radio Burst Localizations
Jerome Seebeck
Mentor: Vikram Ravi

With the rise of Fast Radio Burst (FRB) observations localizations and host galaxy properties are beginning to play a vital role in discovering the mysteries of FRB progenitors through comparisons to other transient populations. We examine selection effects on current samples of Fast Radio Bursts (FRBs) through in-depth simulations and associations of these transients in a wide population of galaxies. We used a galaxy catalog created by the Henriques 2015a L-galaxy model from the semi-analytical Millennium Simulation. Based on different population models, galaxies, and the location within them, were chosen for each FRB to allow for accurate calculations of characteristic properties such as dispersion measure (DM) and scattering timescale. We then applied selection functions in DM and scattering from the Canadian Hydrogen Intensity Mapping Experiment (CHIME) and associated each FRB with a host galaxy using Probabilistic Association of Transients to their Hosts (PATH) a Bayesian method for host association with a magnitude limited galaxy sample cutoff by the PANSTARRS limit $m_r \leq 23.2$. We find that selection effects cause a +1.3 $M_{sun}\,yr^{-1}$ change in SFR and a +2.2 kpc change in the projected physical offset of the FRBs. Radio selection effects have larger effects on offset distributions while optical selections have a greater impact on SFR. In our use of PATH, we have found that for a m_r = 25 limited host galaxy sample a P(U) = 0.6 would be the most effective choice.

Satellite Glial Cell Response to Peripheral Nerve Damage
Aditi Seetharaman
Mentors: Valeria Cavalli, Oshri Avraham, and Marianne Bronner

Sensory axons within dorsal root ganglia (DRG) diverge into peripheral and central branches, projecting towards musculoskeletal organs and the spinal cord, respectively. Peripheral nerve injury elicits a pro-regenerative response in peripheral sensory neurons, enabling axon regeneration. Spinal cord injury, however, does not induce regenerative processes. Single cell transcriptional profiling of DRG three days after peripheral nerve injury revealed that satellite glial cells (SGC), which envelop the neuronal soma, promote axon regeneration in peripheral nerves by regulating the expression of genes related to fatty acid synthesis and peroxisome proliferator-activated receptor (PPARα) signaling. This response failed to occur after injury to the central axon branch. We found that the SGC clustering changed due to injury. t-SNE clustering and trajectory analysis suggest that at least four SGC subtypes exist in naive conditions and a distinct cluster appears after nerve injury. To further understand the contribution of SGC to the regenerative response, single-cell RNA-seq of DRG was performed at various time points along the regenerative process following sciatic nerve crush injury, from one day to 28 days post injury. Current analysis is focused on determining how SGC clustering and communication with other cells in the DRG evolves during the regenerative process. This will allow us to better define the role of SGC and the environment of DRG neurons in axon regeneration.

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.

Column Generation of Power Cones for Signomial Optimization
Anish Senapati
Mentors: Adam Wierman and Riley Murray

Certifying function nonnegativity is a prevalent problem in applied mathematics with applications in optimization and engineering. A new method for the certification of polynomial and signomial nonnegativity has been proposed that uses the sums of arithmetic-geometric exponentials or "SAGE" decompositions for verification. SAGE-based optimization techniques are traditionally done with a type of convex optimization called relative entropy programming. Recent research shows those same optimization problems can be approximated by power cone programming, a different convex optimization approach. While the power cone reformulation searches a subspace of SAGE certificates, its standard usage across solvers makes it an appealing alternative to resolve the numerical issues in SAGE decompositions. We proposed and optimized an efficient column generation approach to identify and add power cones into the nonnegativity cone of interest. This generation approach numerically exhibits sublinear convergence to the SAGE bound. The convergence of this method is seen to have no dependence on the number of variables in the signomial. Additionally, assuming certain uniqueness conditions of the constraints generated, we proved that the constraints are defined by so-called "X-circuits". Further outlooks of this research aim to look at the identification of X-circuits for polyhedral X where such uniqueness conditions can be verified.

Modeling the Effects of Planetary Engulfment on Stellar Lithium Abundance
Jason Sevilla
Mentors: Jim Fuller and Aida Behmard

The effect of planetary engulfment on a star's surface lithium abundance is unclear. Although the addition of lithium from the planet may cause lithium enrichment, it will also result in increased mixing which can cause lithium depletion. Mixing pushes lithium into hotter portions of the star where it is burned in nuclear fusion. In particular, the presence of heavy elements in the outermost layers of the star facilitates thermohaline mixing. This project will shed light on the outcome of these competing effects using MESA stellar models. My project will simulate stars ranging from 0.5 to 1.4 solar masses and accretion of a 10 Earth mass planet with an Earth-like composition. We will evolve the star through the main sequence, considering processes such as diffusion, thermohaline mixing, and overshoot mixing. We find that any surface lithium abundance gained from accretion is depleted on timescales of about 10^8 years. At the upper end of our stellar mass range, this depletion is pronounced. Thus, depleted lithium could be used as a signature of a planetary engulfment event. Planetary engulfment and these mixing processes can explain the pattern of lithium depletion over a star's lifetime that has been observed in solar-type stellar populations.

Exploration of Full Binary Alternating Max-Average Arithmetic Circuits
Yakov Shalunov
Mentor: Chris Umans

Games against Nature (i.e. against a random opponent) serve as a classification of IP=PSPACE and as a model of decision making under uncertainty, making them interesting to consider. For a specific formulation of games against Nature, where each turn consists of one bit and Nature moves with equal probability, we can evaluate the n-move game as a full binary tree formula of depth n with alternating layers of max and average gates (an MA- formula/tree). We consider the properties of MA-trees, and specifically the query complexity (number of input leaves known) of estimating them. We look at the value of games with random payoff functions and at a more limited promise-gap case where it is known that the value is either 1 or $\leq\delta$ and the algorithm's goal is to distinguish which case it is. We show that without randomness, adaptive algorithms offer no worst-case advantage and for both cases, we look for separation between simple adaptive and non-adaptive algorithms.

The Structural Incidence Problem for Cartesian Products
Junxuan Shen
Mentors: Adam Sheffer and Nets Katz

We prove new structural results for point-line incidences. An incidence is a pair of one point and one line, where the point is on the line. The Szemer´edi-Trotter theorem states that n points and n lines form $O(n^{4/3})$ incidences. This bound has been used to obtain many results in combinatorics, number theory, harmonic analysis, and more. While the Szemer´edi-Trotter bound has been known for several decades, the structural problem remains wide-open. This problem asks to characterize the point-line configurations with $\Theta(n^{4/3})$ incidences. We completely characterize the case where the point set is a lattice.*Theorem.* Let $1/3 < \alpha < 2/3$. Let P be a lattice of size $n^\alpha \times n^{1-\alpha}$ and L be a set of n lines, such that P and L form $\Theta(n^{4/3})$ incidences. Then L contains $\Omega(n^{1/3}/\log n)$ families of $\Theta(n^{2/3})$ parallel lines. The y-intercepts of each family of parallel lines form an arithmetic progression.When $\alpha < 1/3$ or $\alpha >$ 2/3, it is impossible to have $\Theta(n^{4/3})$ incidences. We also obtain similar results where P = $A \times B$ where only one of A,B is an arithmetic progression. That is, in the case where only one axis of the Cartesian product P behaves like a lattice.

Integration of Lie Algebras: Homotopical Methods
Ze'ev Shirazi
Mentor: Anton Kapustin

Lie's third theorem states that any finite dimensional Lie algebra $\mathfrak{g}$ can be integrated to a simply connected Lie group G such that Lie(G)=$\mathfrak{g}$. Traditionally this has been viewed as a hard result, obtained by gluing together 'chunks' of the group obtained using a power series motivated by the exponential map. We look at new homotopical methods at proving Lie III, including generalisations to structures with higher homotopy terms such as L-infinity algebras. We do this to try to investigate methods for which Lie integration can be generalised to infinite-dimensional Lie algebras, specifically a Lie-Frechét algebra, where smooth paths of locally generated automorphisms exist. The basic method in the finite dimensional case involves dualisation to its Chevalley-Eilenberg algebra, and using dga-homomorphisms to de Rham forms on the n-simplex to define a simplicial structure. The spatial realisation of this simplicial structure has fundamental group G and its higher homotopy groups are the homotopy groups of G.

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
Mentors: Andrew Howard and Nets Katz

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.

Structural Szémeredi-Trotter Theorem for Lattices
Olivine Silier
Mentors: Larry Guth and Nets Katz

The study of point line-incidences was initiated by Erdős. A point and a line form an *incidence* if the point is on the line. For |P| = n and |L| = m, the Szemerédi-Trotter theorem states that the number of incidences between points from the set P and lines from the set L is $O(n^{2/3}m^{2/3})$. Though the Szemerédi--Trotter theorem has been known for four decades, hardly anything is known about the *structural problem*: characterizing configurations with $\Theta(n^{2/3}m^{2/3})$ incidences. So far only configurations with an underlying lattice structure have been known to have a maximal number of incidences. In this work we use a number theoretic approach to construct a family of configurations where the point set is not a lattice, but rather a Cartesian product of a generalized arithmetic progression, and the number of incidences is maximal.

The Induction of Neuroprotective Pathways as a Means of Ischemic Stroke Recovery
Liam Silvera
Mentors: Alastair Buchan, Anna Schneider, Yvonne Couch, and Sarkis Mazmanian

The fatality rate of stroke ranks just behind cancer and cardiac disease. The need for acute stroke recovery methods is paramount. During an ischemic stroke, the core area consists of dead tissue, however, the surrounding penumbra has the potential to be viable. One proposed means of stroke mitigation is the induction of the energy sensing pathway, PI3K, in particular, the component, mTOR. Under certain cellular conditions, this pathway can signal for energy-preserving processes such as productive autophagy and limited protein synthesis, ultimately protecting cells from further damage. Augmentation of the cell-preserving effects of mTOR is an intriguing target for neuroprotection. Both rapamycin and nutritional intake have significant impacts on the mTOR signaling cascade, as a result, they are of particular interest. To study these components, ischemic stroke was induced in mouse models and various treatments were administered. Using IgG immunohistochemistry and blood sampling, the efficacy of each method was compared and measures of stroke volume and inflammation were correlated. The effects of rapamycin and fasting on stroke recovery were investigated providing new insights into the mechanisms of neuroprotection with potential clinical applications.

Algorithms for Rearrangement of Two-Dimensional Defect-Free Atom Arrays
Jacob Sims
Mentor: Manuel Endres

We recreate an algorithm for rearrangement of two-dimensional optical tweezer arrays, stochastically filled with neutral atoms. Starting with the description of this algorithm in Ebadi et al. (2020), we write a program which will be used in future experiments to create defect-free arrays of record-breaking size. We introduce average rearrangement time as a new metric to demonstrate that this algorithm is much more efficient than many others found in the literature, especially as array size increases. Finally, we present a plan to use reinforcement learning to develop new rearrangement techniques, starting with one-dimensional arrays and expanding to stochastically loaded two-dimensional arrays.

Simulation and Observation of Disconnection-Mediated Triple Junction Grain Boundary Migration
Parul R. Singh
Mentors: Brandon Runnels and Gil Refael

A grain boundary triple junction is a line defect where three polycrystalline grains and the grain boundaries between them meet. Triple junctions can affect the properties of materials in many ways, including their finite formation energy that affects the thermodynamics of microstructure evolution, drag on grain boundary motion, and the probability of a fracture. We aim to simulate a triple junction and introduce nucleation sites in the boundaries, to observe and validate that triple junctions are effective nucleation sites of disconnections that cause grain boundary migration. We calculate the energy of the grain boundaries throughout the simulation, as well as their stress-strain relationship, and the location of the triple junction after the energy minimization and GB migration. These results will provide insight into the nature and properties of grain boundary migration at triple junctions, which is important for predicting the behavior of materials used in engineering.

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.

Generalization of *p*-Adic AdS/CFT Correspondence
Aditya Sivakumar
Mentor: Sarthak Parikh

In mathematical physics, an anti-de Sitter/conformal field theory correspondence (AdS/CFT) is the name for a special type of mathematical relationship between two different kinds of physical theories: the quantum theories of gravity (which are often based in asymptotic *anti-de Sitter spaces* (AdS)), and the *conformal field theories* (CFT) (which are quantum field theories). One AdS/CFT correspondence (called *p-adic AdS/CFT*) has already been made, which mathematically relates the *Bruhat-Tits tree*—a non-Euclidean space with a "tree" structure, to the *p-adic numbers*—a totally disconnected non-Archimedean number system. The goal of this SURF project is to attempt to generalize the AdS-CFT correspondence to field extensions of the *p*-adic numbers—that is, for a field extension of the *p*-adic numbers, find an AdS-CFT correspondence that relates this field extension to some suitable extension of the Bruhat-Tits tree, such that the correspondence reduces to the original AdS-CFT correspondence when the field extension is restricted to the *p*-adic numbers. We first attempt this generalization for the simplest case—namely the unramified finite-degree extensions (of the *p*-adic numbers)—by mirroring the sequence of steps (formally called *coarse-graining*) used to derive the AdS-CFT correspondence for *p*-adic numbers. The final goal will be to generalize the correspondence to infinite-degree extensions such as the *complex p-adic numbers*—i.e., the completion of the algebraic closure of the *p*-adic numbers. This will most likely require some non-trivial modifications to the coarse graining procedure used for *p*-adic numbers.

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.

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.

Data-driven Spacecraft Mission Design
Shiva Sreeram
Mentors: Yisong Yue, Shreyansh Daftry, Yashwanth Nakka, and Jialin Song

For every interplanetary mission, the scientists as NASA and JPL must spend exorbitant amounts of time planning the flight path from Earth to their destination. Scientists can use search algorithms and account for constraints to create an optimization problem whose solution is the optimal flight path. However, this problem is intractable (computationally expensive) due to the large dimensionality of the search space. The complexity of the optimization problem can be reduced by decomposing the problem into multiple three-body problems and by placing appropriate intermediate waypoints. We select the waypoints by using search-based algorithms that are often done offline. One way to improve search speed is to use data-driven techniques where we simulate realistic flight paths (namely ones employing gravity-assist) in three-body scenarios. Therefore, when applying machine learning, we can train a model on data we generate to optimally place waypoints. The project builds off of existing hierarchical planning work in a graph scenario and applies it to a three-body problem. These models will then be tested and compared to standard search algorithms.

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.

A High Throughput Method to Evaluate X-chromosome Counting With a Fluorescent “Calico” Cell Line
Aubrey Stevens
Mentors: Mitchell Guttman and Drew Honson

Non-coding regions of the genome account for 95% of DNA, with a large portion of this region encoding for long non-coding RNAs (lncRNAs). lncRNAs are involved in multiple regulatory and structural functions. They are often studied through the model of X-chromosome inactivation (XCI), wherein one X-chromosome is randomly silenced in female mammalian cells. The ability to differentiate between active and silenced X-chromosomes is essential to understanding XCI; however, current methods for X-chromosome detection, such as RNA FISH have low throughput. Producing a cell line of fluorescent mouse embryonic stem cells (mESCs) to count the number of active X-chromosomes would help automate data collection through flow cytometry. mESCs were transfected with an eGFP and coRFP construct using CRISPR-Cas9, with each construct being inserted into different X-chromosomes. Prior to XCI, both fluorescent proteins are expressed, allowing cells to be screened for containing two X-chromosomes. After dox induction, cells in different stages of XCI display different fluorescent patterns. They can be sorted through flow cytometry to easily quantify the patterns of inactivation, greatly expediting data collection.

Test Design for Extremely Resilient System
Christian Stromberger
Mentors: Richard Murray and Josefine Graebener

Typically, machines increase their resilience by adding redundant parts, the idea being that if something breaks, a spare can take over. "Extreme resilience" is the idea that this extra layer of protection can be implemented into a robot without increasing the number of parts. For example, a CPU could take over for a broken heating system by performing a long and safe calculation, causing it to heat up nearby components. This is a very powerful idea, since implementing such resiliency can dramatically increase a robot's operational lifespan without requiring the addition of the weight and extra cost that redundant parts bring with them. To demonstrate an extremely resilient system, the PhantomX robotic pincher arm has been placed on a Turtlebot. A simulated failure is then injected into the Turtlebot in the form of a wheel failure, and the arm takes over and pushes the Turtlebot toward the original objective. To determine when and how to push, a variation of the NEAT (NeuroEvolution of Augmenting Topologies) algorithm is used, and in order to help this algorithm evolve, thousands of tests are run in a Gazebo simulation.

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.

Audiovisual Illusions in the Late Blind and Those With Low Vision
Katelyn Sulett
Mentors: Shinsuke Shimojo, Armand R. Tanguay, Jr., and Noelle R.B. Stiles

The Illusory Audiovisual Rabbit illusion, first discovered by the Shimojo Lab in 2018, was one of the first to demonstrate that audition can influence vision *postdictively*. Postdiction occurs when a stimulus presented later in time affects the perception of a second stimulus presented earlier. In the Illusory Audiovisual Rabbit illusion, the participant is presented with a flash-beep pair, then a beep, followed by a second flash-beep pair, with the two visual flashes spatially separated, but with the auditory beeps centrally located. An illusory flash is perceived to accompany the second beep. The location of the illusory flash is perceived to occur *between* the two spatially separated flashes, clear evidence of a postdictive influence from the location of the second flash.

This illusion has been previously observed in sighted participants with a fixed separation between flashes. The Audiovisual Rabbit illusion can potentially be used in those with low vision to study how the brain reorganizes audiovisual integration as vision loss progresses, particularly in disorders such as Age-Related Macular Degeneration. In this experiment, the Audiovisual Rabbit illusion will be tested on participants with a monocular scotoma (a region of vision loss) to determine whether the illusory flash can be perceived in this region. Preliminary results with sighted subjects suggest that the Audiovisual Rabbit illusion extends over flash-to-flash separations that are significantly larger than in the original experiment, thus potentially allowing those with significant regions of vision loss to participate in forthcoming low-vision trials.

Understanding the Infrared Spectroscopic Signature of Water Ice in Lunar PSRs
Andy Sun
Mentor: Bethany Ehlmann

The NASA Lunar Trailblazer Mission led by Prof. Ehlmann aims to better understand water ice on the lunar surface, including in lunar permanently shadowed regions. For the various quantities and structures of water ice which the HVM3 imaging spectrometer on Lunar Trailblazer might encounter, the thresholds of detectability and spectral properties are affected in ways that have not been fully quantified. We examine how infrared spectroscopic signatures of water ice are expressed for three possible lunar geologic scenarios of occurrence: coatings of ice on regolith, areal mixing where regolith and ice combine linearly, and intimate mixtures where spectral signatures combine non-linearly via a Hapke radiative transfer model as a function of grain size and mixture proportions. We then analyze trends in water detectability at different absorption bands as a function of illumination level and also compare the results of our simplified radiative transfer model to laboratory ice mineral mixtures.

Standalone Search for Quirk Pair Production
Nathan Suri
Mentors: Maria Spiropulu, Cristian Pena, Christina Wang, Michele Papucci, and Si Xie

Quirks are a class of heavy stable charged particles (vector-like fermions). Existing within a dark confinement scale significantly larger than Standard Model QCD, quirks are most easily identified by their oscillating trajectories resulting from the coupling of the quirks via a flux tube of dark gluons. This study seeks to identify and utilize key features that may allow for quirk signals to be most easily identifiable from Standard Model background. Since quirks are theorized to traverse the detector via oscillating non-helical (planar) tracks, two discriminants tested were the time delay and plane-fitting efficiency of the quirk hits. These discriminants proved powerful in initial tests, retaining high signal efficiencies on account of the exotic signature of the quirks. While the initial tests focused on assessing the power of the aforementioned discriminants, future work will be done to identify Standard Model background processes with similar signatures and determine if these discriminants are effective in rejecting these events.

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.

Applications of the Cooperative DNA Catalyst
Dallas Taylor
Mentors: Lulu Qian and Sam Davidson

Our previously developed cooperative DNA catalyst has demonstrable potential for applications in various strand-displacement motifs. Many of these implementations require introducing a threshold, allowing for our cooperative catalyst to process input signals in the presence of noise. Two methods of thresholding, sequential and competitive, have been developed to produce near-zero output production with low, non-zero input signals. Cooperative catalysis with competitive thresholding allows for a simplified implementation of two-input logic AND gates: one double stranded gate species, two double stranded threshold species, and one single stranded fuel species. We show near-complete output production when both input signals are above specified threshold concentrations and near-zero output production when below. The simplicity and composability of this modified AND gate provides an intriguing development of strand-displacement based DNA logic circuits. Additionally, we introduce a new method of one-input thresholding that we call an activator-creating threshold (ACT): one double-stranded threshold species, one double stranded gate species, and one single stranded fuel species. The ACT similarly displays near-complete output production when input signal is above a specified threshold concentration and near-zero output production when below. The sensitivity and speed of this activator-creating threshold shows an exciting new mechanism for thresholding.

Modeling Photonic Quantum Information Processing Experiments Using Gaussian Characteristic Functions
Kaden Taylor
Mentors: Maria Spiropulu and Nikolai Lauk

Single optical photons are currently the best possible candidates for long distance quantum information exchange due to low interactions with each other and with the environment. In practice, single photon states are difficult to create, meaning that often in experiments more accessible states are used to approximate single photon states, such as weak coherent states or two mode squeezed vacuum states. Since these states are Gaussian and all underlying operations, including experimental imperfections and measurements, can be described as Gaussian processes, phase space methods can be used to model photonic quantum information processes. In particular, we use the characteristic function approach to model the effects of using photon number resolving detectors (PNR's) to improve the purity of heralded single photon sources based on spontaneous parametric down conversion (SPDC). We further use this approach to examine the possible improvements of using PNR's in the Hong-Ou-Mandel interference experiment that can be used to estimate photon indistinguishability. Current results suggest significant improvements in purity for low losses and few improvements in purity for high losses. In addition to PNR related models, we also extend the previous teleportation model to include entanglement swapping protocols so we can estimate the fidelity of the process.

Thermoresponsive Interpenetrating Networks for Atmospheric Water Harvesting
Zane Taylor
Mentors: Julia R. Greer and Amylynn Chen

Humidity in the atmosphere makes up ~10% of the world's freshwater supply, accessible over much of the world, including otherwise water-scarce regions. However, few methods exist which can extract water from low-to-moderate humidity air and simultaneously release it again at low energetic cost. Interpenetrating networks (IPNs) of poly(N-isopropylacrylamide) (PNIPAM), polyacrylic acid, polyacrylamide, and their copolymers were studied in the context of their water uptake and energy-efficient thermoresponsive release. Both conventional IPNs made by swell-in method and microporous IPNs fabricated through cononsolvency techniques were explored. These approaches aimed to maximize water uptake capacity and preserve thermoresponsive deswelling induced by heating above the lower critical solution temperature of the PNIPAM network. These materials were designed to be additively manufactured, allowing optimal architectures to be coupled with the desired material properties such as liquid water release. Preliminary results have shown as much as 20% mass loss of liquid water in swollen IPNs without optimization. Further research will continue to improve these energy efficient desorption mechanisms and enhance the water affinity / collection capacity, as well as begin to introduce architecture driven performance enhancement.

An Alternative Model for Flocculation in Freshwater Channels
Kenny Thai
Mentors: Michael Lamb and Gerard Salter

Flocculation, or the aggregation of small suspended sediment particles (of order 10 -5 m in diameter and smaller) to form composite structures (flocs) during transport, is an underexplored area of study, especially in its applications to freshwater channels. Flocculation is believed to be the reason for the effective settling velocity of certain grain sizes greatly deviating from theoretical estimates. It is commonly assumed in research on this topic that all suspended sediment of small enough size aggregate to form flocs. This paper explores an alternative model of flocculation that does not assume a 100% flocculation rate in particles of the appropriate size. Cursory tests of the alternative model have produced better fits for sediment concentration profiles taken in the Mississippi River's Wax Lake Delta than the more commonly used initial model.

Investigation and Modeling of CO_2 Uptake in Concrete
Kathryn Thompson
Mentor: Melany Hunt

Concrete is produced from a series of chemical reactions that generates large amounts of carbon dioxide and as a result has become a leading source of greenhouse gas emissions. In an effort to combat said emissions, researchers have looked into various methods both natural and synthetic to boost the elimination of carbon dioxide from the atmosphere. Concrete carbonation produces a natural solution with the potential for additional benefits. The reabsorption of carbon dioxide in concrete is a slow process that requires many factors to be in alignment for success including humidity, the composition of the cement, years exposed to carbon dioxide, water-cement ratio, etc. The purpose of the research we are conducting is to model the process of concrete carbonation at a basic level. We want to track and match experimental results from previous studies to a simple model. Given this fundamental model, future changes can be used to bring various, more complex environmental conditions into the equation to allow for further, more in-depth exploration into concrete carbonation.

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

Abstract withheld from publication at mentor’s request.

HOMES: Rigorous Verification and Validation Program Ensuring Lunar Artemis Mission Readiness
Malcolm Tisdale
Mentor: Soon-Jo Chung

NASA has deemed it critical that scalable Lunar dust mitigation solutions are developed to ensure success of the Artemis Program and sustained habitation of the Moon. In addition to threatening astronaut health, Lunar dust has also caused the degradation or failure of mechanical, thermal, electrical, and optical systems. The Habitat Orientable and Modular Electrodynamic Shield (HOMES) is a state-of-the-art technology developed by an agile team of 25 Caltech students that directly addresses the gap of Lunar dust mitigation in airlocks and habitable volumes. HOMES is a collection of 10” x 10” x 1” modular and rotationally symmetric square panels that utilize Electrodynamic Dust Shielding to locomote Lunar dust along any planar configuration through the generation of periodic electric fields. Astronauts will be able to cover airlock floors with a custom layout of HOMES panels to transport dust that has fallen to the floor and collect the material for easy disposal. To assure NASA that HOMES can operate for 30 years in the periodically high vacuum and cryogenic environment of a Lunar airlock, a rigorous verification and validation program must be developed and implemented. This paper discusses the methods and results of the initial subsystem validation and the ongoing flight-readiness verification program.

Towards Scalable Object-Centric Learning and Reasoning
Megan Tjandrasuwita
Mentors: Jure Leskovec and Yisong Yue

Object-centric learning is a subfield of machine learning that attempts to endow algorithms with the ability to recognize object representations from raw pixels, which are useful for downstream tasks. However, prior works are limited to detecting a fixed number of objects per image or requiring spatiotemporal data with numerous frames of interacting objects. This is a far cry from humans' natural ability to recognize objects and theorize about common patterns given only a few examples. To push machines towards human-like recognition and reasoning, we develop an unsupervised framework that discovers objects and relations without the aforementioned limitations. We first pretrain energy-based models (EBM) for detecting individual concepts, relations, and operators, and subsequently train a reinforcement learning agent to find a composition of EBM's that appropriately describe any number of images. Future work will involve testing our framework on 2D images involving shape and color concepts, in addition to 3D scenes with various shapes, colors, and materials. We aim to show that our method is agnostic to the scale of objects and relations present in different inputs.

EEG Analysis of Time Frequency Data With Principal Component Analysis (PCA) and Neural Network
Sasha Tolstoff
Mentors: Joseph Kirschvink, Daw-An Wu, Isaac Hilburn, and Kyongsik Yun

Extensive behavioral evidence gained over the past 70 years demonstrates that many organisms ranging from bacteria to higher animals respond to the geomagnetic field, so the Kirschvink & Shimojo groups here at Caltech designed an experiment to test this in humans. They reported the construction of an experimental chamber designed to apply a controlled magnetic field, and then used 64-channel electroencephalography (EEG) to analyze brain activity in response to the stimulus.

To discover the implications that the data has for human magnetoreception, machine learning was applied to the Kirschvink lab’s EEG data sets. The Brainstorm electrophysiology software was used in coordination with MATLAB for the foundation of the EEG analysis, and the scikit-learn software for Python was used for the machine learning aspect of the project. Principal Component Analysis (PCA) was conducted to see if the radio frequency (RF) statuses of a magnetoreception experiment can be predicted. Once the meaning of each principal component is determined, the PCA may be used to implement a neural network that can further extrapolate the data to predict the RF statuses of a magnetoreception experiment, as well as offer further insight into understanding human magnetoreception.

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.

Spatial Distribution of Gas and Dust Surrounding KIC-8462852
Angelina J. Torres
Mentors: Josh Simon and Lynne Hillenbrand

In 2016, KIC-8462852, also known as Boyajian's star, was observed to have aperiodic dips in flux which are inconsistent in depth. These dips can range from 0.2% to 22% of the star's overall brightness. This star, however, is a completely normal, main-sequence F3V type star. There is no observed infrared excess indicating the presence of circumstellar material or signs of youth that might explain these irregularities in brightness. Boyajian's Star is the only star of 150,000 monitored by the Kepler Space Telescope with changes in flux that do not have any reasonable explanations in terms of stellar astrophysics. A possible explanation for this behavior is a cloud of gas and dust passing between Kepler and Boyajian's Star. Through this project, we determine the spatial extent of this cloud. We use spectra collected by the Gemini Telescope of Boyajian's Star and five nearby stars to determine the velocities of gas and dust clouds along the line of sight to each star. If the velocity of the gas along the line of sight to Boyajian's Star differs from that seen toward any of the neighboring stars, then the absorbing material is likely local to Boyajian's Star. However, if the velocities are all the same, the absorbing gas must span across the interstellar medium. Through this research, we can further understand the mysterious behavior of Boyajian's Star.

Partitions and the Generalized von Mangoldt Function
Justin Toyota
Mentor: Alexander Dunn

The classical partition function $p(n)$ satisfies the equation $\sum_{n=0}^{\infty} p(n)x^n = \prod_{m=1}^{\infty}(1-x^m)^{-1}$. In a 2000 paper, Yang analyzed a variant $p_1(n)$ of the partition function, defined by the equation $\sum_{n=0}^{\infty} p_1(n)x^n = \prod_{m=1}^{\infty}(1-x^m)^{-\Lambda(m)}$, deriving an asymptotic formula for $\log p_1(n)$. We generalize Yang's methods to derive an asymptotic formula for $\log p_k(n)$, where $p_k(n)$ is defined by the equation $\sum_{n=0}^{\infty} p_1(n)x^n = \prod_{m=1}^{\infty}(1-x^m)^{-\Lambda_k(m)}$; here $\Lambda_k(m)$ denotes the generalized von Mangoldt function.

Characterizing Long-Period Variable Stars With Palomar Gattini-IR
Kayton Truong
Mentors: Mansi Kasliwal and Viraj Karambelkar

Asymptotic giant branch (AGB) stars represent the late stage of evolution in stars of intermediate mass. They make up a large proportion of long-period variables and are characterized by periodic oscillations in their luminosity (where their period is at least 200 days). Studying them is useful because: (1) the linear relationship between their log(luminosity) and log(period) makes them standard candles, and (2) their evolutionary stage and chemical compositions can shed light on stellar atmospheric and evolutionary processes. AGB stars, due to their variable nature, slowly lose their mass to stellar winds and mass ejections. This creates cosmic dust, enshrouding the AGBs and making them invisible to optical time-domain surveys, which are common astronomical surveys.

Using Palomar Gattini-IR, we use the astronomical J-band to see through the dust and collect time-domain data on various objects in the northern sky. This data can be programmatically sifted to yield a catalog of long-period variables, which is the goal of this project. This project also aims to study period-luminosity relationships, classify objects as O-rich or C-rich, identify objects with periods greater than 1000 days, and cross-match our catalog with other surveys (2MASS, ZTF, PanSTARRS, Gaia) to extract more data on these objects.

A Statistical Modelling Approach Towards Discovering Transition and Development of Behavioral States During Social Interactions
Tat Hei Dexter Tsin
Mentors: David Anderson, Tomomi Karigo, and Adi Nair

One of the central problems of system neuroscience is understanding interactions between animal social behavior. The key idea which has allowed us to make strides in this space is that of an 'internal state', unique sensory-transformations that govern an animal's interaction with its conspecific. Identifying such internal states has been historically challenging due to the reliance on manual observation of annotation of behaviors. My project focuses on applying a novel statistical learning framework GLM-HMM on social behaviors, with the goal to improve model performance in predicting animal behavior and describe unique internal states that regulate both aggressive and mating behavior. The project also involves collecting a new dataset of animal social behaviors during different stages of maturity and applying them to the same framework. Through this novel approach, we hope to discover and categorize the dynamical transitions between internal emotional states and emergence of internal states behind aggressive behaviors during development.

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.

Using Deep Learning to Automate Vessel Segmentation and Cardiac Blood Flow Measurement on 4D Flow MR Images
Arielle Tycko
Mentors: Albert Hsiao, Evan Masutani, and Thanos Siapas

4D Flow MRI is an important tool for measuring cardiovascular blood flow, providing key diagnostic information for a variety of congenital heart diseases. However, performing these measurements using 4D Flow software requires skill and expertise. To reduce the need for this expertise, we propose using convolutional neural networks (CNNs) to automate vessel segmentation. Flow measurements were performed manually using 4D Flow MRI on 278 patients. U-Net CNNs were then trained using several strategies: use of anatomic images alone or with flow velocity data, inclusion of multiple adjacent time points, variable use of augmentation (mirroring, magnification, and rotation); these methods were compared via Dice similarity coefficient (DSC). Greater performance was achieved when training the CNN with inclusion of flow data with (DSC 0.89 ± 0.06), compared to without flow data (DSC 0.82 ± 0.23).

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.

Magnetic Measurements in a Cryogen Free Cryostat
Aditi Venkatesh
Mentor: Joseph Falson

The Falson Lab at Caltech focuses on the synthesis of new materials through thin film epitaxy and the characterization and study of new physics in these thin films. One specific area of research the lab focuses on is the synthesis and characterization of 2D magnetic materials. The anisotropies of these materials are measured in order to study their properties. This is done by first bringing these samples to ultra low temperatures around the single Kelvin to milliKelvin range. This can be accomplished through the use of a cryostat. This summer, secondary resistance thermometry was done on ruthenium oxide thick film resistors with the use of the Physical Properties Measurement System (PPMS) in order to develop calibration curves in anticipation of the arrival of the cryostat in the fall. To conduct different kinds of measurements on samples, such as torque magnetometry, a sample rod with a rotating stage was designed and built.

Design of a Modular and Orientable Electrodynamic Shield for Dust Mitigation: Optimization and Verification
Polina Verkhovodova
Mentor: Soon-Jo Chung

As humans seek to establish a permanent presence on the moon, the effects of lunar dust must be addressed. During the Apollo missions, equipment and astronauts were affected by dust adhesion and abrasion, leading to mechanical failure and adverse health effects due to the ingress of dust. To address these issues, we are developing the Habitat Orientable and Modular Electrodynamic Shield (HOMES), a unique design of scalable and modular panels embedded with an electrodynamic shield (EDS) which can be easily assembled in any configuration to create a flat and dust-free work surface for any application. The EDS system within HOMES is a series of four-phase wire electrodes that generate a moving electric field that can push parties in a specified direction. The EDS produces electrostatic and dielectrophoretic forces to attract and transport particles, taking advantage of the charged nature of lunar dust. This project focuses on the optimization the EDS system and the verification to a high technology readiness level of the full panel system for applications in future lunar missions.

Intelligent Exploration for Safely Learning Unstable Robotic Systems
Yasmin Veys
Mentors: Yisong Yue, Ugo Rosolia, and Ivan Jimenez Rodriguez

In this work, we explore learning the dynamics models of unstable robotic systems. We use Gaussian processes (GP) to model the uncertain dynamics probabilistically. Through this approach we can characterize the model uncertainty to plan a robust trajectory using model predictive control (MPC). The Gaussian process' kernel function measures the distance between the collected data and the controller's predicted trajectory. When the model is used in regions of the state space where no data is available, this distance is high, indicating the model is inaccurate. We design a model predictive controller that plans a trajectory which is "close" to the collected data. Our contribution is to rigorously define the notion of closeness using the covariance of the Gaussian process. The effectiveness of the approach is tested on inverted pendulum and segway environments.

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

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.

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.

X-Ray Properties of Dynamically Disturbed Galaxy Groups
Jenny T. Wan
Mentors: Christine Jones, Marie Machacek, and Sunil Golwala

Galaxy group and cluster mergers are important lenses through which we can test cosmological models and learn about the formation of large-scale structure in the Universe. We use *Chandra* observations of early-type galaxies NGC 7618 and NGC 5353 to study the structure of the hot gas in these two merger systems. NGC 7618, the central elliptical galaxy of a nearby galaxy group (z = 0.017), and its host group are undergoing a merger with a neighboring group, at the center of which resides UGC 12491. Arc-shaped slingshot tails exhibited by NGC 7618 and UGC 12491 indicate that the groups are near apogee in their orbits. By contrast, NGC 5353 is a lenticular galaxy (z = 0.0077) in the HCG 68 group and is in the process of merging with the other dominant galaxy in the group, NGC 5354. The more relaxed appearance of the surrounding gas suggests the galaxies are at an earlier stage of the merging process, perhaps near the point of closest approach. Through analyzing and comparing the spectra derived from these two systems' X-ray features (e.g., edges, extended emission features, etc.), as well as profile fits modeling gas density and thermodynamical properties of the hot group gas, we can craft a deeper understanding of the physics behind these mergers.

Continuous Authentication in Mobile Devices
Alexis Wang
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.

Causal Discovery in Physical Reasoning Benchmark
Jianxin Wang
Mentors: Anima Anandkumar and Huaizu Jiang

Understanding and reasoning the physics are the critical components of human intelligence. Generalization and counterfactual reasoning are the key aspects of physical reasoning. Humans can understand the abstract physical concept, like gravity, mass, inertia, and friction and figure out the relationships between different objects. Therefore, humans can quickly solve new tasks with the generalized knowledge. Many machine learning algorithms in physical reasoning aren't generalized well to unseen tasks. Causal discovery is shown to have good generalizability. We propose using causal discovery model to solve physical reasoning tasks. In particular, we test the model on PHYRE (PHYsical REasoning) Benchmark. The model is able to infer graph representations, including objects relationship type, such as ball to ball interaction or ball to cup interaction. Then, it will make future predictions based on the graph. As of now, the model is performing at the same level as the state-of-the-art results in PHYsical REasoning benchmark. We are experimenting different types of causal model to see which one works the best.

Characterizing the Genetic Interactions of SARS-CoV-2 Nsp14
Megan Wang
Mentors: Rodney Rothstein and Judith Campbell

To characterize the genetic interactions of SARS-CoV-2 proteins, we performed Selective Ploidy Ablation (SPA) in *S. cerevisiae* expressing individual viral proteins to identify synthetic dosage lethal (SDL) and suppressor-like interactions. Both interaction categories help elucidate the role of viral proteins in host cells. SDL interactions identify genetic pathways that are stressed in the presence of viral proteins, and suppressor-like interactions suggest host cell functions that are compensated by viral protein expression. Nonstructural protein 14 (nsp14) functions as both an exoribonuclease and an S-adenosylmethionine (SAM)-dependent methyltransferase. In *S. cerevisiae*, the activity of the methyltransferase domain of nsp14 confers a growth defect, and the severity of the growth reduction was not compatible with our SPA screening system. However, co-expression of nsp14 with nsp10 (viral replication complex stabilizer) attenuated the methyltransferase domain growth defect allowing us to uncover methyltransferase-dependent SDL interactions between pathways involved in the kinetochore-microtubule interface and mitochondrial functions. Additionally, nsp14 suppressor-like interactions were discovered in the SAM recycling pathway, specifically with proteins involved with the build-up of the SAM precursor S-adenosylhomocysteine (SAH). We hope that elucidating viral interactions in a model organism will provide insights on how to leverage our findings to develop a drug discovery platform for nsp14.

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.

Modeling the Absorption Spectra of Galaxy Simulations to Gain Insight Into the Properties of Faint Galaxies
Amelia Whitworth
Mentors: Lise Christensen and Omer Tamuz

For some galaxies too faint to be observed in emission, the study of absorption spectra from a background quasar can provide unique insight into their properties. However, researchers studying these absorption spectra are restricted by a limited sample size of galaxies and a limited number of lines of sight through each galaxy. For my SURF project, I worked with Lise Christensen at the Cosmic Dawn Center in Copenhagen to use code from the Trident project to digitally model the absorption lines of galaxies from the IllustrisTNG simulation. The advantage of analyzing a simulated galaxy, is it is possible to control the parameters of our models, and observe the corresponding changes in the absorption spectra. This summer, we primarily focused changing the position of a background quasar, and identifying how the Delta-v90 of particular absorption lines change as distance from the galaxy center increases. However, our research has laid the groundwork further investigation into other faint galaxy properties and their correlations to absorption spectra.

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.

Spectral Variability of 3C273 Using NuSTAR
Lena Wu
Mentors: Fiona Harrison and Murray Brightman

The results obtained from ten X-ray observations spanning 2015-2021 on the quasar 3C273 performed by NuSTAR are presented here. The combined spectrum, when fit with an absorbed power-law model over the 3-78 keV band reveals significant deviations from the power-law above 25 keV. The spectrum is better described by an exponentially cutoff power-law which self-consistently includes the iron line and a weak reflection component from cold, dense material(pexmon). By comparing each NuSTAR observation when fit with the pexmon model, we can investigate the spectral variability of 3C273. Evidence of complex spectral features such as soft excess, Fe K emission line, flux and spectral correlated variability are presented. We explain these features as arising from the structure of the accretion disk and coronal emission. Correlation studies on the source also reveal a direct relationship between the cutoff energy and photon index as well as an inverse correlation between the flux and photon index.

Reconstruction of Bacterial Transposons for Stochastic Genome Minimization
George Wythes
Mentors: Kaihang Wang and Charles Sanfiorenzo

Transposons are a powerful yet underutilized genetic engineering tool due their ability to mobilize and randomly integrate any desired cargo. Currently, there are only two transposon species used in bacterial engineering so this project aims to expand the number of functional transposon species with the goal of using multiple species for stochastic genome minimization using Cas3 targeted deletions. Wild type hyperactive transposons sequences were found using frequency based reconstruction of transposon homologs across many bacterial genomes. These transposon sequences were then tested for functional excision and integration using a number of reporter plasmids. Out of the four sequences screened, one transposon has the ability to excise and integrate but its efficiency is hindered by its extreme toxicity when expressed. This transposon also has many copies already in the E. coli genome meaning it could be very valuable for transposon mutagenesis and minimization studies.

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.

Producing Flat-Top Beams With Digital Micromirror Device
Keqin Yan
Mentors: Manuel Endres and Xin Xie

Optical tweezer experiments have introduced many new possibilities to AMO experiments, quantum computer constructions, and many other fields by neatly configuring atoms in different shapes of arrays. Flat-top beams therefore can be very desirable to address the target atoms uniformly. The most commonly used light source, lasers, however, are usually in a TEM_{00} mode; that is to say, they usually have a Gaussian spatial distribution. In order to shape the Gaussian beams in a customizable and fast-responding fashion, we propose the implementation of Digital Micromirror Devices (DMD). Each DMD is composed of a large amount of micromirrors arranged in a 2D array, and each of the mirrors can be programmed to either an on or off state, corresponding to two physical angles the mirrors can point at, which eventually allows the DMD to serve as an amplitude mask and spatially shape the incoming beam to a flat-top one.

Dynamic International Networks for the Large Hadron Collider and Other Data Intensive Science Programs
Brian Yang
Mentors: Harvey Newman and Carlyn-Ann Lee

Today's Data Intensive Science Programs, like the Large Hadron Collider, are generating and analyzing unprecedented volumes of data. With their expected exponential growth within the next few years, their datasets will exceed the affordable capacity of the world's R&E networks. Hence, we develop a new network paradigm with intelligent control and data planes capable of supporting wide area topologies encompassing up to transoceanic distances to meet the demands of these Data Intensive Science Programs. We use Reservoir Labs GradientGraph® (G2) analytics, a network optimization platform for high-resolution traffic engineering, to identify impactful flows and alternate path recommendations over the Pacific Research Platform virtual network testbed. After diverting the impactful flow groups onto the selected alternate paths, we validate that the impact of redirecting the flows is as predicted utilizing ESnet's NetPredict AI-based traffic prediction model, thus relieving congestion. Real time traffic engineering operations are enabled and facilitated by the P4 programming language for packet processing. Our experimentation demonstrates that this new networking paradigm is significantly more effective at real-time traffic engineering in more data-intensive settings than traditional networking protocols. Future work will consist of developing more precise traffic engineering success metrics and applying Reinforcement Learning to fine-tune networking policies.

Engineering Differential Signaling and Sensing Genetic Circuits Within Synthetic Cells
Bridget Yang
Mentor: Richard Murray

Synthetic cells are artificially engineered semipermeable compartments that are made from phospholipid bilayers and consist of numerous subsystems such as metabolism, sensing and signaling, regulation/computation, actuation, and export/communications. The principal objective of my project is to create a synthetic cell that will differentially respond to two separate signals, meaning that it will trigger two distinct biological responses, to study the crosstalk between different sensing and signaling genetic circuits and demonstrate that synthetic cells may be used to explore paramount biological phenomena such as morphological development. I have created four linear genetic circuits: one that produces Superfolder Cyan Fluorescent Protein (sfCFP), one that produces Superfolder Yellow Fluorescent Protein (sfYFP), and two that repress these circuits. I am then going to put these circuits into vesicles with cell-free transcription-translation (TX-TL) and α-hemolysin channels to study and quantify how membrane impermeable doxycycline (Dox) and Isopropyl β- d-1-thiogalactopyranoside (IPTG) can trigger two distinct responses in the form of sfYFP and sfCFP.

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.

Dual-Channel qSR: A Software to Characterize the Correlation Between Pol II Clusters and Their Transcriptional Output

Zitian Ye
Mentors: Ibrahim Cissé and Manyu Du

The spatial and temporal organization of proteins in the nucleus of eukaryotic cells plays an important role in genetic processes. RNA Pol II has been found to form clusters in eukaryotic cells, yet how they are associated with transcriptional output remains elusive. To study this, the dynamics of Pol II clustering is measured using super resolution microscopy in one channel and compared with its functional output, labeled as mRNA intensity, in another channel. A software package qSR has been previously designed for quantitative analysis of the super-resolution data acquired from imaging clusters of a single type of protein, but analyzing two channels of data via qSR requires constantly switching between qSR and ImageJ as well as manually determining the correspondence between regions in two images. Hence, based on qSR, we developed a MATLAB app to facilitate the upload and display of two channels of data: one is a pre-processed single-molecule localization dataset of Pol II clusters, while the other is a raw image of cell highlighting the gene locus. The program then allows users to adjust image contrast, export gene locus intensity and location, compute clusters size, lifetime and distance from gene locus, and potentially bulk processing of data from multiple cells.

Design and Development of CS 22: Data Structures and Parallelism

Steven Yee
Mentor: Adam Blank

The primary objective of CS 22: Data Structures and Parallelism is to teach students the importance of algorithmic correctness, implementation, and parallelism and serve as a transition from CS 2: Introduction to Programming Methods to CS 38: Algorithms. However, as a novel course, most, if not all, foundational infrastructure must be created from scratch. In this work, we design and develop all necessary materials, including the course timeline, testing environment, and problem sets. More importantly, a complexity decider utilizing abstract analysis is created to assist students in writing proper code and to provide a consistent method for grading assignments.

CS 22 will be offered during the Winter 2022 term to students who have either completed CS 2 or have the instructor's approval. As a result, the course should balance covering concepts from both CS 2 and CS 38 with great extent without being skewed too far in either direction. We create the course with this in mind, but without testing the effectiveness of the material in an active setting it will be difficult to truly gauge how balanced CS 22 is. As a result, further work on course design is recommended through the Fall 2021 term.

Engineering Macrophages as Cellular Cancer Sensors With Mammalian Acoustic Reporter (mARG) Gene Expression

Mei Yi You
Mentors: Mikhail Shapiro and Justin Lee

Abstract withheld from publication at mentor's request.

Discrete Fourier Transform Over Schurian Schemes

Hantao Yu
Mentor: Chris Umans

Association scheme is a combinatorial object generalized from groups that is being studied recently by mathematicians. The schurian scheme, isomorphic to the double coset algebra G//H for some group G and its subgroup H, is a special type of association scheme with nice properties. We extend Hsu and Umans' work on Discrete Fourier Transform (DFT) over groups to schurian schemes, and propose two ways of doing DFT over association schemes, using $O(|G//H|^{\omega/2}|N_G(H)\backslash G/H|)$ or $O\left(|G//H|^{\omega/2}(\sum_{i=1}^{n-1} c_i)\right)$ time given a subgroup chain $H < G_n < \cdots < G_0 = G$ with $|G_i/G_{i+1}| = c_i$ for all $0 \leq i \leq n-1$, respectively. Here ω is the matrix multiplication exponent and $N_G(H)$ is the normalizer of H in G.

Smartphone-based Eye-tracking for Assessing Autism Spectrum Disorder

Jennifer Yu
Mentor: Ralph Adolphs

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder that affects an individual's ability to communicate in and understand social contexts. Early detection of ASD and subsequent intervention is hypothesized to help guide a child's social abilities back towards a normal developmental trajectory. However, barriers to diagnosis and an imbalance in access to resources persists within underserved communities. On average, the age of ASD diagnosis for white children is 6.3 years of age, compared to 7.9 years for African American children and 8.8 years for Latinx children. These disparities are significant considering that early intervention is critical for maximizing treatment of ASD. These statistics make it even more imperative for scientists to develop tools for rapid and scalable detection of ASD. In this project, we use eye-tracking technology

to help overcome these barriers, capitalizing on the fact that smartphones and other personal devices have become more ubiquitous. The project leverages the accessibility of smartphones to collect eye-tracking data from historically excluded communities and has found group differences between participants with and without ASD. Including underserved communities can better inform our analyses and future machine learning diagnostic tools, reducing bias in this technology and making it more meaningful for all users.

Broad-band Spectral-Timing Analysis of the Black Hole X-ray Binary MAXI J1820+070 With *Insight*-HXMT Data

Zhibo Yu

Mentors: Javier A. García, Guglielmo Mastroserio, and Riley M. Connors

Low-frequency Quasi-Periodic Oscillations (LFQPOs) are commonly observed in black hole binaries while their physical origin is still unclear. However, observations have revealed that LFQPOs are strongly correlated with spectral properties. Studying such correlations could allow us to probe into the physics near the innermost region of the accreting system. In this work, We perform detailed broad-band spectral-timing analyses of the black hole binary MAXI J1820+070 observed by Hard X-ray Modulation Telescope (*Insight*-HXMT) through its entire 2018 outburst. LFQPOs are detected up to 200 keV during the initial Bright-Hard State (BHS), which suggests the signals directly come from the hot corona; the QPO frequencies are below 0.5 Hz, and do not present any energy dependence, in contrast with observations in a number of other observations. The energy spectra in the 2-150 keV band are analyzed through X-ray reflection spectroscopy. We show that the sources can be classified into different phases in the BHS as traced on the Hardness-Intensity Diagram. We find a strong correlation between the QPO frequency and powerlaw photon index, and the trend differs between phases. We plan to implement more sophisticated reflection model to account for the spectral features and provide a more physical description of the source.

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.

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.

Determining Systematic Bias in the Organ Allocation Algorithm
Theresa Zhang
Mentor: Federico Echenique

There exists the possibility of bias in the organ allocation algorithm that can cause it to discriminate against patients from certain demographic groups. The outcome test of bias is a method for determining bias that accounts for the nuances in the algorithm decision process. Assuming that the algorithm is optimizing a certain outcome variable/measure (e.g. survival rate, quality of life, etc.), the outcome test observes how the algorithm treats patients from different demographic groups with regard to that measure. This project aims to use many years' worth of data from allocations and patients to determine where there may exist bias in the allocation algorithm. By observing how different outcome measures vary across patients with respect to certain demographic characteristics (e.g. race, insurance status, etc.), we can identify trends that may indicate unequal treatment of different groups. Results have indicated two points of interest: (1) the relatively low survival rate of black patients compared to other racial groups and (2) the consistently higher survival rates of patients with private insurance compared to that of patients with public insurance. Further research should investigate whether these trends result from systematic bias or from inherent biological characteristics of these demographic groups.

Progress Toward Symmetric Pd-Catalyzed Conjugate Addition of Arylboronic Acids to β-substituted α,β-Uunsaturated 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.

Structural and Biochemical Characterization of the Kap-α:NLS Binding Interaction
Wentao Zhang
Mentors: André Hoelz and George Mobbs

Within eukaryotic cells, massive transport complexes (~110 MDa) called nuclear pore complexes (NPCs) facilitate macromolecular transport across the nuclear envelope. In humans, the NPC is comprised of multiple copies of 34 different proteins, called nucleoporins (nups), arranged in an eight-fold symmetric ring. Through the efforts of labs including the Hoelz group, the assembled symmetric core of the NPC has largely been characterized to near-atomic resolution. The nuclear import factor karyopherin alpha (Kap-α) binds the nuclear localization signal (NLS) of proteins, facilitating transport of proteins larger than 40kDa across the NPC. To investigate

Kap-ɑ:NLS binding, Kap-ɑ and an NLS construct were expressed in *E.coli* and purified using standard affinity, ion exchange, and gel filtration chromatography. The purified Kap-ɑ and NLS construct were screened across over 600 different conditions and allowed to crystallize through vapor diffusion techniques. Future work will consist of screening additional crystallization conditions, refining and generating X-ray crystallography-viable crystals, sending optimized Kap-ɑ:NLS crystals to a synchrotron, and using the data obtained to build an atomic-resolution model of Kap-ɑ:NLS. The Kap-ɑ:NLS model will be used to elucidate the molecular basis of how Kap-ɑ interacts with NLS sequences.

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.

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.

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.

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.

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 García, 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.

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.

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.

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.).

X-Ray Bright Versus Faint Active Galactic Nuclei (AGN): Using the Structure Function to Compare AGN Variability
Milo Brown
Mentors: Matthew Graham and Daniel Stern

We refer to supermassive black holes with accreting matter as Active Galactic Nuclei (AGN). Accreting matter near the center of the AGN emits shorter wavelength light (e.g. X-rays), while matter farther from the center emits light with longer wavelengths (e.g. visible light, infrared light). The magnitude of this light varies over time at all wavelengths, but the interaction between variability in different wavelengths is not well explored. We measure optical AGN variability using the Zwicky Transient Facility (ZTF). ZTF searches for exotic transients with high volumetric survey speed. We are analyzing and comparing data at visible wavelengths from ZTF on X-ray bright and X-ray faint AGN using scale-dependent variability measures, such as the structure function.

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.

Locating Leaks in Water Distribution Networks Using a Computational Sensor Selection (Cosense) Strategy
Hugo Chacon
Mentors: Yisong Yue, Katie Bouman, He Sun, and Hao Liu

In the U.S., water distribution networks at the city-scale experience 12% water loss on average due to leakage. Thus, leakage reduction in distribution networks is desirable from a cost, resource management, and conservation perspective. However, current methods for locating leaks are inefficient due to network size, complexity, and often-buried infrastructure. To more efficiently locate leaks, we are developing a deep neural net framework to predict leak locations. Specifically, we utilize a computational sensor selection (cosense) strategy targeting sparse measurement of water network attributes with the goal of locating leaks down to the pipe. Cosense has thus far been applied to sensor selection in image reconstruction tasks; porting cosense to water network sensor selection proved non-trivial. To simplify the problem, we pre-train the decoder half of the cosense autoencoder and constrain the possible leak locations to a fixed set of ten non-adjacent pipes. This approach allows us to identify the more informative network attributes and control complexity as we prepare to incorporate the encoder, which will include a trainable, probabilistic, attribute mask sampler. Current decoder implementations return up to 87.3% test accuracy using a single-layer, ten-class, classifier with flow rate measurements as input. Next steps for increasing model generality include increasing input variability, constraining attribute measurement count per sample, and combining network attributes (e.g. hydraulic head and flow rate) to use as model input.

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.

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.

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.

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 CO_2 Reduction Reactions (CO_2RR) 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 CO_2 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 CO_2RR, 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 CO_2. 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 CO_2RR 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.

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.

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.

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.

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.

FIS1 and Regulation of Mammalian Mitochondrial Dynamics
Ameneh Gharabi
Mentors: David Chan and Yogaditya Chakrabarty

Mitochondrial dynamics (fission and fusion) and mitophagy are fundamental to a healthy mitochondrial population and regulating cell function. In yeast, Mitochondrial fission 1 protein (FIS1), a mitochondrial outer membrane protein, has been shown to recruit Drp1 during yeast mitochondrial fission. However, little is known about mitochondrial fission and the exact role of FIS1 in mammalian cells. Studies have shown knockdown of FIS1 in mammalian cells leads to fundamental developmental defects. Our primary focus is on unraveling the function of FIS1 in mammalian mitochondrial fission. We will perform co-immunoprecipitation studies to identify the proteins associated with FIS1 and regulate its function. Our findings will provide more insight into the role of FIS1 in mammalian mitochondrial fission.

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.

Structural and Vibrational Investigation of Römerite Under Icy Satellite Conditions
Nina Gilkyson
Mentor: Jennifer Jackson

In their spectral investigations of the surface and interior compositions of Jupiter's icy satellites, researchers have proposed hydrated salts as a principal constituent. Römerite, $Fe^{2+}Fe^{3+}_2(SO_4)_4 \cdot 14H_2O$, is a mixed valency hydrated sulfate salt, a natural sample of which was obtained from the Caltech Mineral Collection. Here, single crystal X-ray diffraction and synchrotron infrared spectroscopy are used to characterize römerite in low temperature, high pressure icy satellite conditions. Single crystal X-ray diffraction measurements were done in 20K temperature intervals from 300-100K, including a reverse temperature series. Römerite's crystal structure was refined at each temperature to an agreement factor $0.030043 \leq R_1 \leq 0.036565$ and a goodness of fit $1.00956 \leq S \leq 1.02128$ on the basis of 2747-2942 reflections ($F_o \geq 4\sigma_F$). The evolution of römerite's unit cell parameters, atomic positions, and bond properties with temperature were quantified. Low temperature and high pressure synchrotron infrared spectroscopy measurements in the diamond anvil cell were performed ranging from 20-300K and 0-8 GPa. Bonding environments of the H_2O and SO_4 groups were characterized with temperature and pressure. These results are compared with other hydrated sulfate phases relevant to icy satellite surfaces and interiors.

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.

Robotic Arm Control Through Algorithmic Neural Decoding and Augmented Reality Object Detection
Sydney Hunt
Mentors: Richard Andersen and Jorge Gamez de Leon

A brain-machine interface (BMI) is a device that uses neurally implanted sensors to translate brain neuron activity into commands capable of controlling external software or hardware, such as a computer or robotic arm. BMIs are often used as assistive living devices for individuals with motor, sensory, and/or verbal impairments. They can also restore more independence than voice-controlled prosthetics by eliminating the social anxiety induced by announcing everything one wants to do. The Andersen Lab's previous BMIs used brain signals of paralyzed individuals to control only the speed of a robotic arm as it moved a predefined object between predefined locations.

This project's BMI incorporated Microsoft's HoloLens2 augmented reality headset, allowing users to select an object, its start/end location, and action to be executed on it by a JACO robotic arm. HoloLens2's eye-tracking, image recognition, object detection, AR object positioning, spatial awareness, and pixel to real-world coordinates training features determined the robotic arm's trajectory. The desired action (grasp, drink, drop) and execution speed on the object were identified by neural decoding a paralyzed individual's thoughts. Data analysis of tasks created to analyze possible control signals for action selection demonstrated higher neuron firing rates in motor imagery than nonverbal commands.

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.

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.

Creating the Wide Field Infrared Camera (WIRC) Exoplanet Transit Software Package Version 1.0
Winnie Wei Jeng
Mentors: Heather Knutson, Michael Greklek-McKeon, and Shreyas Vissapragada

The Knutson Group has developed software that convert images taken by the WIRC instrument on the 200” Hale Telescope at Palomar Observatory into transit light curves that can be used to study the formation, evolution, and habitability of transiting exoplanets. Processing high-resolution infrared images of transiting exoplanets with the existing software pipeline is a slow process, as the existing software scripts are neither unit tested, fully documented, nor designed with optimization. Many errors can occur during the calibration process, throttling the performance of analyzing astronomy data and making it difficult to resolve bugs without a coherent set of documentation.

To reduce information bottlenecking, the existing software scripts were documented for readability, tested for accuracy, benchmarked for performance, optimized for efficiency, and finally packaged into an installable python library exowirc. The open-source exowirc package is hosted on Github, ready for installation by scientists who are interested in utilizing the pipeline with the WIRC instrument to study exoplanets. Documentation for exowirc version 1.0 is also made publicly available on readthedocs, a popular scientific research community for hosting documentations of software packages. Installation guides and tutorials are added to the readthedocs website to increase the ease of use for the exowirc package.

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.

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.

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.

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.

CRISPR Interference Interrogation of Key Genes and Regulatory Genomic Elements in Early T-Cell Development
Alicia Mercado
Mentor: Ellen Rothenberg

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.

Performance of Interaction Network on the Analysis of the Boosted $HH \rightarrow b\underline{b}\tau^+\tau^-$ Decay Mode
Cameron Moffett-Smith
Mentors: Harvey Newman and Nan Lu

With the discovery of the Higgs boson in 2012 at the Large Hadron Collider(LHC), its properties are still trying to be understood. One such way is the search of Di-Higgs productions at the LHC, in order to study more properties and even look for physics beyond the Standard Model. With billions of events occurring, it is important to be able to pick out events we are looking for and suppress background noise. The goal of this project is investigating the effectiveness of an interaction network to identify boosted $HH \rightarrow b\underline{b}\tau^+\tau^-$ decays at the LHC. The interaction network does this by using points on a graph to represent charged particles, and the connections modeling their interactions. The algorithm takes various input variables such as transverse momentum of decay jets, and gives a probability that such a jet was produced by a Higgs decay by using multiple neural networks. If the interaction network proves to be effective, it can be applied to other decay channels.

Analyzing Genes Linked With Autism Spectrum Disorder (ASD) Utilizing a Zebrafish Model
Nathan Nadler
Mentors: David Prober and Jin Xu

Autism Spectrum Disorder (ASD) affects 1.85% of Americans and is associated with difficulty in social interaction. However; the broad nature of ASD leads to diverse phenotypes with varying severity, making it difficult to study. In an effort to better understand the underlying mechanisms of ASD, researchers have identified 60 genes possibly linked to ASD. Zebrafish have proven an ideal model to study these genetic components, as they have a comparable genome to humans, are easily handleable, and are well suited for molecular screens. After identifying several genes of interest, different Zebrafish mutant lines were created using CRISPR-Cas9. Once these lines were established, the offspring were then subjected to two different analyses: behavioral and neuronal. As many behavioral related symptoms of ASD are unique to humans, the behavioral assay involved analyzing the sleeping patterns of Zebrafish, as ASD is largely associated with insomnia and hyperactivity during the night. The neuronal assay involved bleaching and staining neurons of the mutant larvae. Once these larvae were stained, they were imaged using a confocal microscope in order to identify which neurons were firing.

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.

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.

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.

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.

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.

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.

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.

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.

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

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.

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.

Longitudinal Impacts of Discrimination on Depressive Symptomatology in Racial/Ethnic Minorities During the COVID-19 Pandemic
Jada Russell
Mentor: Ralph Adolphs

There is no shortage of historical reasons why the topics of discrimination and racial injustice are extremely relevant. Attention to this issue was significantly renewed in the summer of 2020 when the deaths of George Floyd and Breonna Taylor sparked protests and invigorated the Black Lives Matter movement. Over the past year, Caltech conducted a large longitudinal study with the goal of quantifying the impact of the COVID-19 pandemic and other events of 2020 upon the mental health of the US population. While 2020 was an extremely stressful and traumatic year for the entire US population, including job loss, family loss, disparate health outcomes, and more, a critical thinking point is understanding how the combined effects of discrimination and stress may have impacted the mental health of the minority population. To investigate this, we examined the relationship between experienced discrimination and mental health outcomes, specifically depression, by probing the role of experienced discrimination in shaping depression trajectories of minority individuals in the face of the unprecedented stressors of 2020. In particular, we will test the prediction of the Minority Stress Model, that increased experiences of discrimination by minoritized individuals will be associated with depressive symptoms.

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.

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.

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.

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 63rd order exceptional point. Although implementing the Hamiltonian for a 63rd 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.

Entanglement Renormalization of the Z_N Checkerboard Model
Juan Pablo Speer
Mentors: Xie Chen and Arpit Dua

Topologically ordered quantum models are exactly solvable systems that exhibit a finite ground state degeneracy that is dependent on the topology of their manifold. The Z_N checkerboard model is one such system that also exhibits fracton order which is characterized by quasiparticle excitations with constrained mobility and a ground state degeneracy that scales exponentially with system size. We seek equivalence relations between the Z_N checkerboard model and other models with fracton order through entanglement renormalization transformations. The renormalization procedure consists of applying local unitary quantum gates to a system's Hamiltonian. If the resulting Hamiltonian is equivalent up to the addition of decoupled degrees of freedom in a way that preserves the ground state of the initial model the systems are phase equivalent. Through this work we aim to improve the classification of fracton models and the relations between them.

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.

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.

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.

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.

Investigating the Product Distribution of Reactions Between Resonance Stabilized Radicals
Megan Woods
Mentors: Mitchio Okumura, Charles Markus, Greg Jones, and Wen Chao

Resonance stabilized radicals (RSRs) species play a critical role in hydrocarbon reactions in combustion chemistry, planetary atmospheres, and the interstellar medium. RSRs possess conjugated π-systems, leading them to be less reactive than other radicals. RSR reactions are believed to be the primary precursors for aromatic and heterocyclic compounds in low temperature environments such as Titan's atmosphere, and in more extreme environments found in combustion. Previous studies have identified primary products of self-reactions of the RSR propargyl radical (C_3H_3) and reported the formation of C_6H_6 isomers: benzene, 1,5-hexadiyne, 1,2-hexadien-5-yne, dimethylenecyclobutene (DMCB) and fulvene. However, these reactions have not yet been observed at low temperatures relevant to Titan's atmosphere which could significantly impact atmospheric models. Additionally, there is minimal investigation of the formation of heterocyclic compounds through reactions involving RSRs at pertinent temperatures. To bridge this knowledge gap, propargyl radicals were produced through photolysis of propargyl bromide within a flow cell and a static reactor. This allows for the investigation of propargyl recombination and the reaction with reactive nitrogen-bearing molecules such as isopropyl isocyanide at and below room temperature. Product channels of the self-reaction of propargyl-radical, and cyano-radical reactions with propargyl radicals, were analyzed through GC-MS. Product analysis of the radical reactions may provide evidence of the formation of C_6H_6 isomers and heterocyclic compounds at low temperatures.

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.

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).

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.

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.

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.

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.

Analysis of Local Field Potentials During Zebra Finch Song Production After Viral Induced HVC Neuronal Circuit Degradation
Sabrina Jones
Mentors: Carlos Lois and Zsofia Torok

Neural circuits, upon exposure to trauma, have an ability to recover lost function, a concept termed neural resilience. Previous studies of Zebra Finch song production have shown that the characteristic motif of a zebra finch song is represented by stereotypical local field potential (LFP) traces in HVC. Thus, the goal of this study was to determine if, after viral induced degradation of HVC neurons, a stable LFP trace would be present immediately after degradation, during recovery, and after full recovery of the song. To this end, template search algorithms were utilized to identify motif renditions in both degraded and undegraded audio data collected from viral infected zebra finches. The simultaneously recorded LFP data was then averaged over template matches that exhibited high similarity. Further analysis is needed to elucidate the structure and stability of these LFP traces. The results of this study will aid in determining the processes that allow for neural circuit recovery and define the resiliency of these networks within Zebra Finch HVC, as this information is pertinent to both further understanding of the functioning of the brain and to potential translational studies that exploit these mechanisms as the basis for treatment of neurological diseases and injuries.

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.

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.

Studying the Detectability of High Mass Black Hole Binary Mergers With Future Gravitational Wave Detectors
Sabrina Barbaro
Mentors: Alan Weinstein and Richard Udall

In this work we will determine the distances to which gravitational waves from Intermediate Mass Black Hole Binary (IMBHB) mergers can be detected by ground based gravitational wave detector network in observing run four (O4), and beyond. Binary black hole mergers between 65 and 150 $M_\odot$ are predicted to be rare as a result of pair instability in the final stages of their progenitor stars, so future observations of IMBHB mergers will help us to understand formation processes. Therefore this study seeks to calculate the detectability of IMBHB mergers for future runs of the detector network. We aim to determine the sensitive luminosity distance of merger events within the IMBH mass range, averaged over other astrophysical parameters. Optimal sensitivity distances will be given for several detector network configurations, including predictions for future detectors. Additionally we will present detection efficiency predictions as a function of red-shift, and distance horizon value for various high mass mergers. We will present the sensitive volume of the detector network, and predict the number of IMBHB merger events we expect to observe in future runs.

Refining the Search for Sub-threshold Lensed Gravitational Waves
Storm Colloms
Mentor: Alvin Li

Gravitational waves, theorised over 100 years ago, open up a new window with which to study the universe. Since their first detection with LIGO (Laser Interferometer Gravitational-wave Observatory) in 2015, properties of gravitational waves such as their speed, polarisation, and weak interaction with matter have been observed,and many properties of their sources investigated. Like the gravitational lensing of light due to curved space-time caused by massive bodies, gravitational waves can also be lensed. Gravitational lensing would produce multiple events of the gravitational waves which are magnified or de-magnitfied and time-delayed compared to what would be the unlensed wave. De-magnified lensed counterparts may be present in data from recent LIGO observing runs but could be undetectable with current signal analysis methods due to the high noise back-ground. In this work, we describe efforts to make improvements to targeted sub-threshold lensed gravitational wave search pipeline, which would include investigating the waveform approximant used in the pipeline, as well as imposing conditions on the sky location of the lensed images.

Red Pitaya Digital Laser Controller
Osama Elgabori
Mentor: Francisco Salces

This report details using the Red Pitaya (125 MHz 14 bit) electronic board as a digital feedback controller for laser frequency stabilization. There is an exploration of various digital signal processing functionalities of a python interface to the onboard FPGA. Through a plant model approach, we attempt to validate the performance of Red Pitaya for feedback control. This is achieved by configuring the board to perform system identification and fitting frequency response data to a pole-residue model. The aim is to develop an automated device capable of determining the frequency response of some unknown plant and cancelling undesirable features (e.g. resonances) to produce a flat response.

Investigating Data Quality Metrics for Stochastic Gravitational-Wave Detection
Makenzi Fischbach
Mentor: Derek Davis

The detection of gravitational waves has created the opportunity for many new discoveries. One such potential discovery is the stochastic gravitational wave background. In order to detect it, stochastic data must be properly monitored and analysed. Stochmon, a low latency stochastic data monitoring pipeline, works to monitor the quality of stochastic data. Stochmon has not been recently updated and is not well integrated with current gravitational wave data analysis tools. The goal of this project is to identify potential improvements to make to Stochmon's analysis functions, implement said changes, and integrate the system with existing analysis tools so that it can be used during the next observing run. A new feature of Stochmon, the stochastic detector sensitivity (SDS) has been implemented which calculates the energy density at which a detector can detect a stochastic signal.}

Bayesian Analysis of Low Latency LIGO Alerts
Nicholas-Tyler Howard
Mentor: Shreya Anand

LIGO (Laser Interferometer Gravitational Wave Observatory) detectors are capable of detecting gravitational wavescreated by collisions of massive stellar remnants moving at high accelerations (The IPAC Communications andEducation team 2021). Collisions of massive stellar remnants create electromagnetic waves that can reveal manyaspects of the remnants that collided. The EM community is attempting to use data from the LIGO instruments toinfer the location of the sources and view the sources across all electromagnetic wavelengths as shown from the effortsfrom (LIGO Scientific Collaboration 2021). Gravitational wave detectors are poor at localizing mergers, making thediscovery of counterparts a challenging task. We will compare the Bayes factor and the Terrestrial probability ofalerts as metrics of classifying sources as astrophysical in low latency. We will improve the low latency data productsthat are provided to EM observers in order to aid in the discovery more counterparts in the futureABSTRACTLIGO (Laser Interferometer Gravitational Wave Observatory) detectors are capable of detecting gravitational wavescreated by collisions of massive stellar remnants moving at high accelerations (The IPAC Communications andEducation team 2021). Collisions of massive stellar remnants create electromagnetic waves that can reveal manyaspects of the remnants that collided. The EM community is attempting to use data from the LIGO instruments toinfer the location of the sources and view the sources across all electromagnetic wavelengths as shown from the effortsfrom (LIGO Scientific Collaboration 2021). Gravitational wave detectors are poor at localizing mergers, making thediscovery of counterparts a challenging task. We will compare the Bayes factor and the Terrestrial probability ofalerts as metrics of classifying sources as astrophysical in low latency. We will improve the low latency data productsthat are provided to EM observers in order to aid in the discovery more counterparts in the future

Mitigating the Effects of Instrumental Artifacts on Source Localizations
Maggie Huber
Mentor: Derek Davis

Instrumental artifacts which materialize as glitches in strain data can overlap with gravitational wave detections and significantly impair the accuracy of sky localizations of compact binary coalescence (CBC) signals. To mitigate the effect of glitches, we are developing a method that applies a reweighting formula to the signal-to-noise ratio (SNR) of a signal. From tests on ~1500 simulated signals, we determined that reweighting the SNR timeseries is able to improve the accuracy over zeroing out bad data. When we repeated this process for raw data with a simulated glitch, the reweighting formula likewise improves upon removing the data alone. In this report we discuss our results and future goals for the development of our new method to handle instrumental artifacts.

Simulating Scattered Light for Development of Beam Tracking System
Bobby King
Mentors: Rana Adhikari, Yehonathan Drori, and Tega Edo

The goal of this project is to develop a physically representative simulation of scattered light as the laser beam moves on the surface of the mirror. This simulation will be used in the training of a convolutional neural network that will eventually track the location of the beam on optics in real video footage of the measurements, in an effort to monitor the possible angular rotation of the optics that contributes to angular noise. Due to imperfections in the mirror surface such as surface roughness and point defects, as well as imaging nonlinearities in the video data, such as saturation and poisson (shot) noise, classical centroid tracking approaches are not robust enough to locate the beam on the mirror with sufficient accuracy. Using simulated images additionally allows us to generate a robust body of labeled data with which to train the network. Starting with a light propagation model, and considering angular spectrum propagation, we will build layers of complexity so that the network can be trained on these modularly, if necessary, to identify when and why the network fails.

Non-Linear Noise Subtraction for Low Frequency
Yuka Lin
Mentor: Gabriele Vajente

The amplitude of the noise in laser interferometric data limits the astrophysical information that can be extracted from it. LIGO has a strong history in reducing the linear and stationary noise at different frequencies by monitoring auxiliary sensors and the correlation with the estimated strain at a given time. Recently, it was shown that nonlinear correlations could be used to reduce the noise even further for the case of the noise spectral density around 60 Hz in laser interferometers. The approach involved utilizing two types of auxiliary channels, each with different spectral content. In this project, a similar methodology will be investigated for the lower part of the LIGO spectrum (around and below 10 HZ) where the gravitational wave memory from Core Collapse Supernovae and pre-merger binary star signals have significant energy.

Optimal State-Space Estimation of Interferometer Mode-Matching
Mark Nguyen
Mentors: Rana Adhikari, Aidan Brooks, and Jon Richardson

LIGO's current detectors rely on a system of adaptive optics to carry out highly sensitive measurements, but they lack an optimal control system. In response, we have adopted the Kalman filter formalism to systematically derive a more optimal estimate of the state of the resonant spatial mode of each of the optical cavities by allowing this formalism to statistically weigh both measurement data and predicted state parameters. The filter is capable of accessing the plethora of information that is considered inaccessible by the current suboptimal control system, and then using that information to narrow down the location of the actual state in relation to the desired state. Python simulations are being run on a simple one arm cavity housing two mirrors being lazed by an input beam of an arbitrary mode. Our goal is to eventually be able to integrate this new control system within LIGO's current and future adaptive optics systems to calculate real time estimates of the state of the interferometer.

Marginalizing Over Noise Properties in Gravitational-Wave Parameter Estimation
Cailin Plunkett
Mentors: Katerina Chatziioannou and Sophie Hourihane

The traditional gravitational wave (GW) parameter estimation process relies on sequential estimation of noise properties and binary parameters. Using new capabilities of the BayesWave algorithm and recent developments in noise uncertainty modeling, we simultaneously estimate the noise and binary properties, which mitigates the assumption that the noise variance is known during the fitting process. We do so using both the wavelet- and template-based models available in BayesWave. Initial results on GW150914 and injected signals suggest the methods produce signal reconstructions and posterior parameter distributions that agree to within uncertainty. Future work intends to repeat the analyses on more injected signals and all real events in the second Gravitational-Wave Transient Catalog (GWTC-2) to identify whether the method used to handle the noise systematically impacts GW inference.

Facilitating Multi-Messenger Astronomy With Early Warning Gravitational Wave Detection
Anna Tosolini
Mentor: Ryan Magee

Early warning gravitational wave detection pipelines are extremely important tools that could alert astronomers to a gravitational wave event before the event has occurred, facilitating a new frontier for multi-messenger astronomy. The aims of this project are to study the early warning pipeline, specifically GstLAL, and run the pipeline using data from Advanced LIGO and Advanced Virgo's third observing run colored to projected O4 sensitivities. I am varying this data by the upper frequency bound, since early warning detections are concentrated in the lower frequency bands, and comparing the background plots for various frequencies. Once this goal has been completed, I will work on testing various methods for optimizing the pipeline. Specifically, I plan to split the inspiral waveform by time and test to see how the background changes for the full waveform as opposed to various time slices of the waveform. The results of this project will give us insight into how many false alarm events we could detect in O4 and will contribute to making more accurate localization estimates of the events to come.

Optimal Settings for Fast Low-Latency Skymaps of Neutron Star Binaries
Celine Wang
Mentors: Katerina Chatziioannou and Isaac Legred

The detection of gravitational waves is instrumental to our understanding of astrophysical processes and the fate and evolution of the sources of such waves. One source of gravitational waves is compact binary coalescences (CBC's)--binary systems which consist of black holes, neutron stars, or both. Specifically for this project, we are focusing on neutron star binary systems and how to optimize data intake to improve localization of such systems. Longer signal durations increase typical computing effects but maximize relevant information we can extract from the signals. For analyses where prompt results are essential, such as for multimessenger followup, we present the ideal conditions for fast and accurate analysis.

Data Folding for the LIGO Stochastic Directional Analysis Pipeline
Eli Wiston
Mentors: Arianna Renzini and Colm Talbot

While a growing number of individual gravitational-wave events have been observed, researchers are still searching for a stochastic gravitational-wave background. This superposition of weak, unresolved gravitational-wave signals could hold a wealth of both astrophysical and cosmological information. Studying both the isotropic and anisotropic components of the background at current detector sensitives could provide a measure of matter distributions and large-scale structure in the Universe. Eventually these searches may provide concrete evidence of inflation and act as a primordial analog to the Cosmic Microwave Background. This paper will detail the development of a data folding algorithm for the stochastic gravitational wave background analysis pipeline. Taking advantage of the fact that detector response is periodic with the rotation of the Earth, we develop an algorithm to condense long stretches of time series data to the size of one sidereal day. We implement this algorithm in both simulated and real data and verify it's efficacy through direct comparison to calculations with unfolded data. With the implementation of data folding, anisotropic directional searches can be carried out far more efficiently. Data folding only needs to be applied once, but brings orders of magnitude improvements in speed and data size, with negligible loss of information.

Testing General Relativity With Gravitational Wave Signals Using Hybrid Sampling
Noah Wolfe
Mentor: Colm Talbot

The population of observed gravitational wave transients continues to grow, and with it, our ability to further constrain deviations from our current understanding of gravity. However, our current procedures for computing these constraints will not successfully scale with future transient catalogs. Thus, we leverage modern statistical methods, like ensemble Monte Carlo Markov Chain sampling, to provide more efficient and more complete investigations of the parameter space of deviations from general relativity given gravitational wave observations of binary black hole mergers.

Backaction Evasion for PT-Symmetric Interferometer
Kagan Yanik
Mentors: Rana Adhikari, Yanbei Chen, Xiang Li, and Shruti Jose Maliakal

In gravitational wave research, one of the challenges for conventional detectors is that we need to sacrifice peak sensitivity to obtain a larger bandwidth in the noise spectrum. White Light Cavities (WLC) enable us to improve the bandwidth without sacrificing the peak sensitivity. In our project, we consider a PT-symmetric interferometer consisting of an arm cavity, a test mass attached to the arm cavity, a filter cavity, and a mechanical oscillator which is the end mirror of the filter cavity. This interferometer with coherent quantum feedback yields a stabilized WLC (sWLC). However, the backaction noise due to radiation pressure on the test mass reduces the sensitivity of the system in the lower frequency range. In this project, we introduce an effective negative mass to cancel the backaction noise and obtain a larger bandwidth by sacrificing less of the sensitivity compared to a conventional detector. We achieve the negative mass by attaching an optical mode to the mechanical oscillator of the system and applying blue-detuned pumping, red-detuned pumping, and detuning.

Low-Noise Nonlinear Cavity for Cryogenic Interferometers
Rahaf Youssef
Mentors: Rana Adhikari, Francisco Salces-Carcoba, and Anchal Gupta

First detected by LIGO, gravitational waves (GW) introduced new methods to study and characterize many astronomical phenomena. To achieve a higher detection range, the noise introduced by thermal fluctuations in the test masses needs to be reduced. To that end, the test masses will be made of crystalline silicon rather than fused silica, and they will be kept at 123 K. The change of the test masses material will necessitate a change in the laser's frequency from 1064 nm to 2128 nm, which can be achieved through a Degenerate Optical Parametric Oscillator (DOPO). In this project, we are investigating the sources of frequency noise in DOPO as well as methods to detect it and mitigate it if necessary. The frequency noise detection scheme will involve mirrors whose substrate is made of fused silica and coating consists of layers of silica and tantala. Calculating the frequency noise introduced by these mirrors showed that their contributions are negligible compared to other sources closer to the DOPO cavity itself. Therefore, our current focus is characterizing the noise sources that contribute to the frequency noise of DOPO in the downconversion process itself. Subsequently, we can develop methods to mitigate this noise.