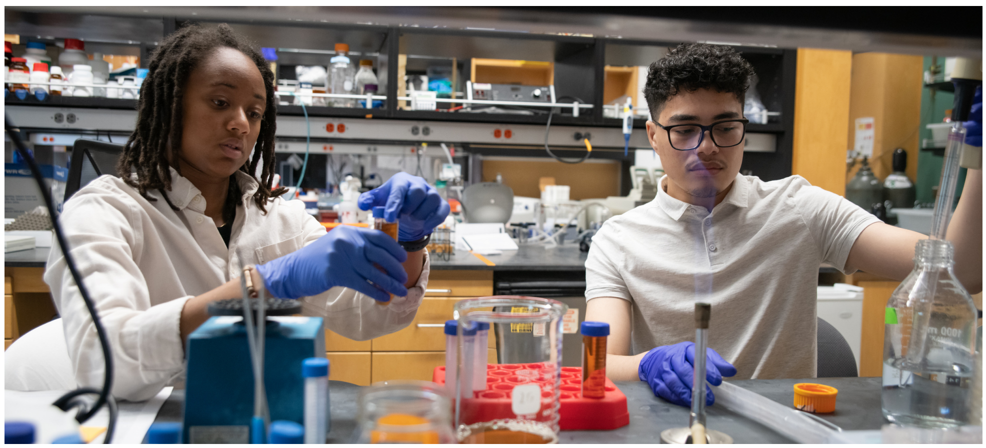
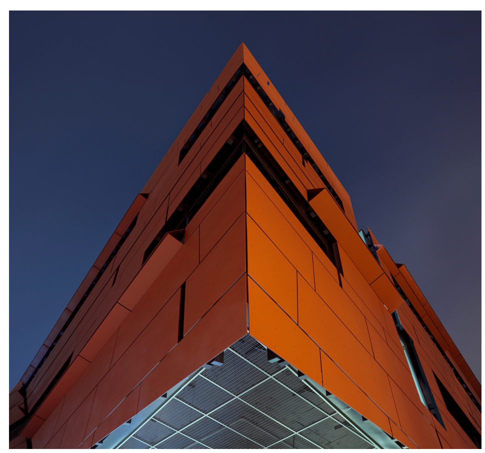
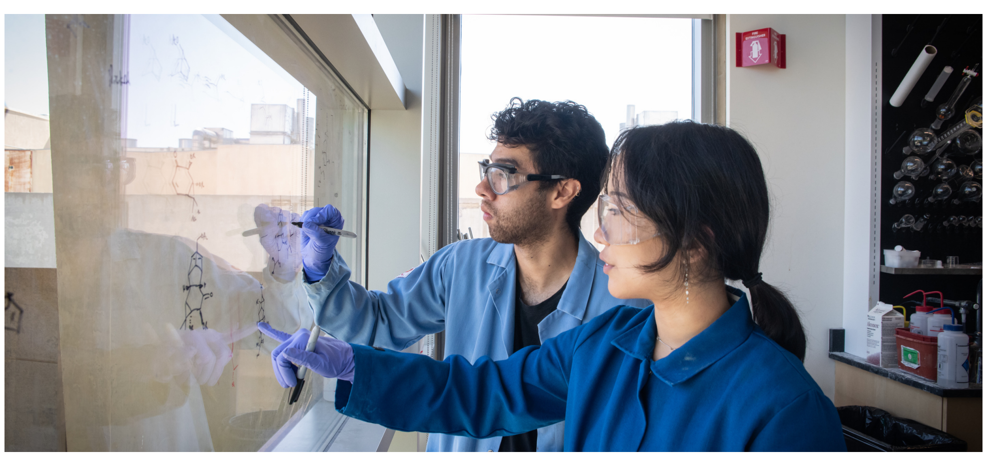
Caltech
Student-Faculty Programs
sfp.caltech.edu

2023 Abstract Book







STUDENT-FACULTY PROGRAMS

2023 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 2023.

Table of Contents

Investigations on Hamiltonicity and Cycle Spectra of 3 and 4-connected Almost-Planar Graphs
Santiago Adams
Mentors: Sandra Kingan and David Conlon

A Hamiltonian cycle is a cycle that crosses every vertex of a graph and a Hamiltonian path is a path that crosses every vertex. An almost-planar graph is a non-planar graph G where for each edge e, either G/e or G\e is planar. In this project, we studied 3- and 4-connected almost planar graphs to relate their properties with known results on 3- and 4-connected planar graphs. We used Gubser's 1990 classification of 3-connected almost-planar graphs to develop algorithms that show that all 3-connected almost-planar graphs are Hamiltonian. Moreover, all 4-connected almost-planar graphs are pancyclic, which means they contain cycles of all possible lengths and Hamiltonian-connected, which means they have a Hamiltonian path between every pair of vertices. We aim to further these results to resolve conjectures that we made on the Hamiltonian-connectedness and pancyclicity of 3-connected almost-planar graphs.

Quality Testing Optically Contacted Bonds
Sophia Adams
Mentors: Rana Adhikari and Christopher Wipf

Optical contacting is a type of bonding that can be achieved when flat, polished surfaces are brought into close contact. When used as a replacement for fused silica, optically contacted silicon has the potential to increase the sensitivity of LIGO Voyager to gravitational waves. This project is aimed at determining the quality factor of optically contacted silicon bonds in order to quantify their potential to reduce the noise in LIGO Voyager. By maximizing the energy contribution from the bond and oscillating a silicon cantilever, the quality factor of the bond can be estimated. The eventual goal is to create an ideal optically contacted bond which minimizes damping and energy loss.

Variational Discretization Methods for Curvature Flows on Riemannian Manifolds
Zofia Adamska
Mentors: Yakov Berchenko-Kogan and Nets H. Katz

The study of geometric flows has many interesting applications that span a wide variety of scientific disciplines. In this project, we focus on analysing the evolution of curves in Riemannian manifolds under curve-shortening and curve-straightening flows. They can be viewed as gradient flows of the length and elastic energy functionals, respectively.

Previous research focuses on manifolds with Riemannian metrics that are conformally flat. Our approach is to use variational discretizations with the expectation of obtaining a simple computational method that is capable of producing results for any arbitrary Riemannian metric. Furthermore, we developed an algorithm that uses partitions of unity to evolve curves in manifolds covered by multiple charts. Using our method, we evolved curves according to curve-shortening and curve-straightening flows on manifolds with several metrics, and verified convergence to expected theoretical results. The methods developed in this project could have the potential to deepen our understanding of the geometry of non-trivial Riemannian manifolds, such as their geodesics and minimal submanifolds. These insights can open new avenues of investigation and inspire further developments in the field of discrete differential geometry.

Deep Mutational Scanning to Characterise Differences in Binding Epitopes of IgG1 and IgG2 Antibodies Elicited by Vaccination
Yusuf Adia
Mentors: Pamela J. Bjorkman and Alexander A. Cohen

Vaccine efficacy is limited by viral evolution and the bias of the immune response upon reinfection towards its memory. Therefore, newer SARS-CoV-2 variants, such as Omicron, aren't as affected by vaccination as older variants. Immunisation with a nanoparticle presenting diverse SARS-like viral antigens ("Mosaic-8b") generates broader neutralising antibodies compared to single antigen display ("Homotypic SARS-2"), and so is a promising development in vaccine design. We performed Deep Mutational Scanning to study binding differences of IgG1 and IgG2 antibodies after vaccination. Antibodies target the receptor binding domain (RBD) of the viral antigen, which mediates entry into host cells. By generating a library of yeast cells, each expressing a mutant RBD, one can identify which mutants "escape" antibody binding, thereby identifying the epitope for the antibody. IgG1 and IgG2a binding appears to be protocol dependent. Following Mosaic-8b immunisation, IgG1 binds to conserved aspects of the antigen while IgG2a is less broad, binding to epitopes known to exhibit antigenic variability. Conversely, IgG2a binding following Homotypic SARS-2 immunisation targets conserved parts of the antigen, while IgG1 appears less broad compared to those elicited following Mosaic-8b immunisation. Exploiting nuances in antibody binding may prove an effective mechanism for directing host immune responses.

Quantum Perceptrons on Rydberg Array Quantum Simulator: Implementation and Exploration
Ishita Agarwal
Mentors: Anima Anandkumar and Taylor L. Patti

Quantum neuromorphic computing (QNC) is a subfield of quantum machine learning (QML) that exploits system dynamics and is capable of operating on modern, chaotic quantum hardware. Building these neuronal models can be done in part through the use of perceptrons, where the dynamics of a single neuron are represented by each perceptron.

A quantum perceptron (QP) based on the analogue dynamics of interacting qubits with tunable coupling along with tunable single-qubit rotations is capable of universal quantum computation, in stark contrast to the limited computational complexity of a single classical perceptron. Architectures built out of QPs promise to be noise-resilient and find applications in measuring inner state product, entanglement detection, quantum metrology and can be used in variational circuits for machine learning tasks.

QPs can be realized in highly controllable and pulse-equipped quantum hardware but the realization of fully controlled, coherent many body systems is a formidable scientific and technological obstacle. Neutral atoms have been considered for gate-based quantum computations using interactions between the Rydberg atoms as they exhibit long coherence times, controllable and scalable geometries, and increasing levels of single-atom control. Thus, in this project I would like to show how the mechanisms required for the quantum perceptron can be carried out using the dynamics of the Rydberg array as well as demonstrate that the quantum perceptron on the Rydberg array can detect and report information on many body dynamics like phase classification.

Cryogenic Packaging for Transmon Qubits: Sample Holder and PCB Design
Ali Ahmad
Mentors: Mohammad Mirhosseini, Parth Shah, and Chaitali Joshi

Superconducting qubits provide a scalable framework for quantum computing and a testbed investigating many-body physics. For experiments involving multiple qubits, it is essential to have a means of delivering and reading classical control signals from an on-chip device, while maintaining a clean, low-loss electromagnetic environment. In practice, this is achieved by designing a metal packaging entailing the measurement chip and a printed circuit board (PCB) that includes microwave waveguides. This project aims to design a packaging capable of accommodating the control signals for five qubits, for future experiments in Mirhosseini's lab.
To do this, we initially model the existing packaging in the lab using electromagnetic simulation tools (COMSOL) to map out any possible spurious box modes near the superconducting qubits' operational frequency. The packaging is subsequently modified using Pogo pins, which are used to ensure adequate grounding of the PCB and adjust the boundary conditions to increase the frequencies of the spurious modes well above the measurement operating range (4-8 GHz). In the second part of this project, we design a new PCB to support a larger number of control and readout lines. To do this, we employ KiCAD to substitute coplanar waveguides (CPWs) with buried striplines, a variant that effectively minimize crosstalk and provides a more compact footprint. Furthermore, we redesign the packaging to accommodate the new PCB and cable connectors, and the Pogo pins. Future work in the lab will focus on the fabrication and experimental validation of the designed packaging.

Identifying FRBs From Known Pulsar Wind Nebula VT 1137-0337
Ethan Alderete
Mentors: Gregg Hallinan and Walid Majid

Fast radio bursts (FRBs) are highly energetic transient radio signals whose origins are yet to be fully understood. In 2020, multiple fast radio bursts were detected from magnetar SGR 1935+2154, establishing magnetars as at least one source of such bursts. We have found several potential fast radio bursts appearing to originate from the extragalactic pulsar wind nebula VT 1137-0337, which we now present as another source of FRBs. Using Heimdall, we searched through observational data taken by the Deep Space Network (DSN) for potential fast radio bursts and narrowed our search down using the physical properties of VT 1137-0337. Due to the extragalactic nature of this source, we had to correct for dispersion smearing through incoherent dedispersion techniques before running the data through Heimdall. Our detection of these bursts originating from VT 1137-0337 will provide more insight into potential sources for fast radio bursts, allowing for more refined strategies of finding sources and upper limits on the physical processes that create fast radio bursts.

Spin-lattice Relaxation Mechanisms in Nitroxide Free Radicals
Kevin Alexander
Mentors: Ryan Hadt, Nathanael Kazmierczak, and Katie Luedecke

Spin-lattice (T_1) relaxation constitutes a key limiting factor for scaling up room temperature qubit devices. To better understand the mechanisms leading to T_1 relaxation in molecular qubits, we studied the dependence of T_1 relaxation on molecular orientation in nitroxide free radicals, a widely used class of paramagnetic spin labels. Our experimental techniques included continuous wave electron paramagnetic resonance (EPR), pulsed EPR, UV-vis spectroscopy, magnetic circular dichroism, and Raman spectroscopy. On the theoretical side, we used quantum chemical calculations to obtain additional information such as spin-phonon coupling coefficients and vibrational frequencies. Taking our experiment and theory together we have ruled out a g-tensor driven T_1 anisotropy in nitroxides and have made progress in constructing a model for T_1 relaxation that is dependent on hyperfine anisotropy.

Investigating Greenwashing in Energy Industry Communications Using Natural Language Processing
Jena Alsup
Mentors: R. Michael Alvarez and Danny Ebanks

The propagation of misinformation related to climate change through corporate rhetoric constitutes a pressing issue that demands further exploration. Greenwashing involves intentionally misleading consumers about a corporation's own environmental practices, often to appear more eco-friendly or socially responsible than the company actually is. However, there is yet to exist a quantifiable definition of what specifically constitutes greenwashing. We leverage a diverse array of media such as SEC filings, corporate sustainability reports, and tweets from the 15 most influential energy and renewable energy companies. We analyze this cross-sectional time series text data using structural topic modeling — a modern natural language processing technique based on unsupervised learning — that tests language distances between renewable energy companies and oil companies. This ultimately allows us to investigate the role of rhetoric in shaping public opinion on climate change.

Realizing Photonic Integrated Circuits on Thin Film Lithium Niobate
Parthorn Ammawat
Mentors: Alireza Marandi and Ryoto Sekine

Integrated photonics based on thin film lithium niobate (TFLN) has been a promising all-optical solution for low-cost and energy-efficient communication, sensing, and computing. Due to its strong nonlinearity, TFLN has emerged as a promising foundation for modern systems including photonic computing. However, all computers require a combination of linear and nonlinear operations. While these elements have been demonstrated individually on TFLN, they have yet to be combined on the same chip to implement a full computer. To do so requires further optimization of both components to make them compatible with each other. One vital component of the circuits is optical couplers. This project optimized several types of couplers and performed fabrication sensitivity tests on them. These were done by using commercial software, then the results were verified by using different simulation methods, including MODE, EME, and FDTD. The real devices were then fabricated, and the results were measured.

Investigating the Effects of Different p97 Inhibitors on CML
Chelsea An
Mentors: Tsui-Fen Chou, Vivian Lai, Baiyi Quan, and Shyue-Fang Battaglia

Chronic myelogenous leukemia is a deadly hematologic cancer mostly impacting older adults. In recent years, both competitive and allosteric p97 inhibitors, such as CB-5339 and NMS-873 respectively, have shown great potential in treating various types of cancer, including leukemia. p97, or Transitional Endoplasmic Reticulum ATPase, is an integral component of the ubiquitin proteasome system, processing substrates that have been ubiquitinated for degradation by the proteasome by removing them from the membrane of the endoplasmic reticulum as part of the Endoplasmic-reticulum-associated protein degradation pathway. Using liquid chromatography-mass spectrometry, we analyzed the differences between competitive and allosteric inhibition on p97 and the effects of p97 inhibition on various cellular processes. Further experimentation is necessary to confirm the effects of the inhibitors and compare proteins of interest.

Uncovering Structure in Vision-Language Embeddings
Sahithi Ankireddy
Mentors: Pietro Perona and Laure Delisle

As the popularity of multimodal learning rises, vision-language models like CLIP gain wider adoption. CLIP demonstrates remarkable transferability to various computer vision tasks, showing competitive performance even on novel datasets. However, the structure of the model's embeddings remains largely unknown, particularly in terms of how latent representations capture and organize concepts and semantics within the embedding space. To investigate the naturally emerging structure of CLIP's embeddings, we propose a method combining dimensionality reduction, spectral clustering, and latent vector similarity analysis. Using this method, we perform a cross-modal, inter- and intra-class examination of captioned ImageNet images. Our results reveal intuitive by-class grouping and uncover previously unknown hierarchical clustering following the semantic structure of the embedded data, both interclass and intraclass. We also uncover that themed or specialized datasets, like ImageNet object-centric natural images, occupy distinct subspaces within the embedding space. This work introduces a novel method to compare vision-language embeddings across models and provides valuable latent structure mapping for future representation learning techniques.

Using Machine Learning to Classify Trees
Mohammad Arbab
Mentors: Mory Gharib and Julian Humml

As climates change to become warmer and drier, forest fires are becoming substantially more frequent. Utilizing the diverse applications of machine learning, this project has the objective of applying a deep learning model to a drone to classify trees and theoretically the type of tree to predict the path of forest fires. However, this project is mainly focused on whether or not a deep learning model can successfully do binary classification of trees. In order to achieve this, we're attempting to use an existing model to do transfer learning and image segmentation to isolate the subjects of the image. We're then using live video to apply this segmentation, where new and unique images will be shown to the model and it will create an inference. There are various factors that play a role in a learning model's performance such as dataset size, hyperparameters, weight decay, and linear layers. Because of this, we haven't had a model that works yet, but one can be trained to do so with a sufficient dataset and possibly be able to identify species of trees in the long run. At the present stage, we are working on incorporating a camera for this image pipeline.

Modeling and Experimentation of Cement-based Products for Enhanced Carbon Capture
Mars Arechavala
Mentors: Melany Hunt and Ricardo Hernandez

Carbon capture can be performed using granules that absorb the CO_2 emitted from point-sources like industrial plants. These granules can then be regenerated by increasing their temperature, providing reusable sources of carbon capture. Similarly, the reactions that occur during CO2 diffusion into cement-based products can act as large sources for carbon capture. This carbon sequestration can be modeled mathematically based on the environmental conditions and formulation of the cement, which can help understand its role in global carbon uptake. The accuracy of carbon sequestration done by cement is crucial to the understanding of the carbon imbalance caused by humans. This understanding can be applied to the granules which use components of cement like calcium hydroxide that can help with the binding of the granules while improving its CO2 absorption ability. The most promising formula for enhanced CO2 capture ability includes a high proportion of K_2CO_3 which has high absorption capability and some combination of $CaCO_3$ to improve granule shape, size distribution, and strength. The focus is to improve this formulation by introducing different binders and pore-formers to increase its regeneration and carbon capture capabilities.

Interaction-aware Trajectory Planning Using Linear Quadratic Regulator
Nishka Arora
Mentors: Daniela Rus, Xiao Li, Johnson Wang, Yutong Ban, and Soon-Jo Chung

When we drive, the past behavior of vehicles surrounding us helps us forecast their future interaction with our vehicle. For an autonomous vehicle (AV), predicting the behavior of other road agents and planning around these predictions is a pressing challenge and one that poses many safety concerns. A previous project (ConceptNet) executes multi-agent interaction-aware trajectory prediction using a graph neural network. This project aims to use the predicted trajectories to create scenario-specific emissions that form the cost functions of a Linear Quadratic Regulator (LQR) to be used as the planner. The cost function of the LQR is set up the maximize the distance from (predicted trajectories of) neighboring cars while minimizing the distance from a reference trajectory. Results show that different scenarios benefit from varying parameters of the LQR cost functions. Further work can be done in training a neural network to emit these parameters given an input scenario.

Lab-Scale Demonstration of a Reflector Assembled in Space
Diego Attra
Mentors: Sergio Pellegrino and Jongeun Suh

Due to the demands of future space missions, building large-scale structures on the order of hundreds of meters in space has become of interest. Current deployable design approaches are limited by the stowed size of these designs. A new design approach of an in-space assembled reflector has been studied and is being developed as an alternative to deployable designs. The multifaceted nature of this concept has required different modules to be developed simultaneously. The "Truss Builder" is one of the modules, and it is responsible for the storage of structural components as well as the autonomous fabrication of the structure itself. This work details the development and initial testing of a lab-scale demonstration of the "Truss Builder" system.

Segmentation of Volumetric Cell Images With Segment Anything Model
Angel Rodrigo Avelar Menendez
Mentors: Yisong Yue, Uriah Israel, and Markus Marks

Qualitative measurements of volumetric biomedical images achieve a better understanding of biomedical systems such as diseases. Segmentation is a method to take these qualitative measurements. Existing models that perform segmentation are not generalizable, as they need to be trained for specific datasets and tasks, and are mostly designed for 2D images. This project aims to develop a novel 3D segmentation model by building upon Meta's Segment Anything Model (SAM). SAM was trained on millions of images to perform 2D segmentation. Through transfer learning, we extract relevant information on 2D slices of cell images and aggregate their encodings to perform 3D segmentation. We also compare how existing models perform on segmentation of various 3D cell images.

Examining Trends Between Supermassive Black Hole Growth and Star Formation in IllustrisTNG Cosmological Simulation
Diana Citlali Avila Padilla
Mentors: Fiona Harrison and Joanna Piotrowska-Karpov

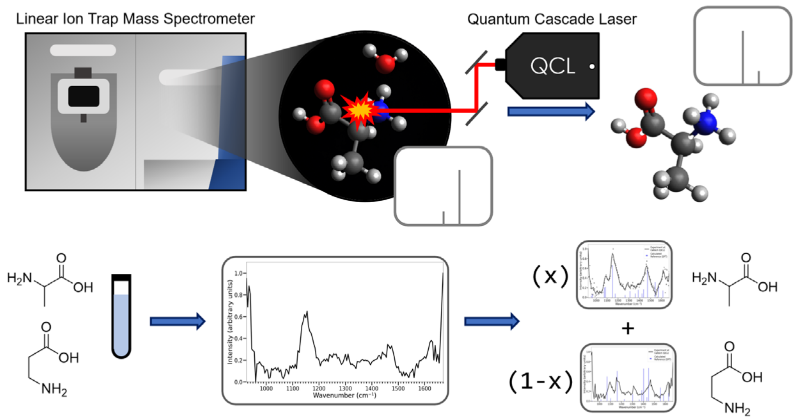
Supermassive Black Holes (SBH) surrounded by discs of accreting matter, known as Active Galactic Nuclei (AGN), have long been suggested as the primary cause for preventing star formation within galaxies. However, due to the variable nature of the AGN and long timescales associated with galactic star formation, the exact nature of long-term black hole impact on host galaxies still remains an open question in the field of galaxy evolution. We address this problem by investigating potential connections between SMBH accretion histories and the present-day star formation state of their host galaxies in IllustrisTNG cosmological simulation. We divide galaxies into two categories based on their star formation activity and analyze statistical properties of their SMBH populations.We also characterize individual growth histories of black holes, searching for statistically significant relationships between time-resolved accretion and star formation in large galaxy samples. By combining conventional analysis techniques with machine learning algorithms, we aim to learn how time-dependent energy deposition from the AGN into its surrounding galaxy bears influence on star formation activity, hence shedding new light on the role of supermassive black holes in galaxy evolution.

Investigation, Modeling, and Control of Quantum Optoelectronic Circuits and Systems
Pablo Backer-Peral
Mentors: Ali Hajimiri and Volkan Gurses

Optoelectronic circuits leverage the advantages of both photonics and electronics to enhance the performance of sensing, communications, and computing systems. Quantum photonics is an emerging field that leverages the quantum mechanical nature of light to create systems beyond the limit of classical photonics. Quantum optoelectronic circuits expand the scope of quantum photonics by enabling a holistic integration of quantum photonic and electronic functions, offloading some of the functional requirements from optical circuits to radio-frequency circuits. To this end, this project aims to develop quantum optoelectronic circuits and their control systems to demonstrate novel functionalities and improved performance. Some of the contributions of this work will be, but are not limited to, building prototype and printed circuit boards for quantum optoelectronic circuits, developing scripts to automate the readout and control of the experiments, and programming FPGAs for real-time processing of measured quantum signals.

Simple Room-Temperature Photodissociation Action Spectroscopy of Water-Tagged Biomolecule Ions
Aadarsh Balaji
Mentors: Mitchio Okumura and Tyler Nguyen

Identification of biomolecules is important both in the astrobiological search for extraterrestrial life as well as in standard analytical laboratories. However, ambiguity in identification and distinguishment of isomers make this task challenging. Here, we report on modifications to a commercial linear ion trap mass spectrometer that allow the usage of infrared photodissociation spectroscopy to overcome these challenges. Our apparatus traps water-tagged biomolecule ions and uses mid-IR quantum cascade lasers to dissociate the tag. The laser is scanned across a range of irradiation wavelengths, a photodissociation yield is obtained from a mass spectrum collected at each wavelength, and the yield is then plotted as a function of wavelength to obtain an infrared spectrum of the molecule. Together, the usage of the ion trap to select by mass, and the lasers to obtain a spectrum, allow for the acquisition of orthogonal spectroscopic information with just a single experimental apparatus. We confirm the reasonableness of experimental spectra through comparison with density functional theory (DFT)-calculated spectra, and demonstrate the capabilities of our apparatus to quantify the relative abundance of isomers in complex mixtures. This approach has potentials in improving analytical workflows, overcoming challenges of small molecule identification, and aiding in compound identification in future planetary science missions.



Electrochemical and Thermochemical Testing of Cobalt and Copper Oxides for Electrochemical Hydroformylation
Þorfinnur Ari Herrmann Baldvinsson
Mentors: Karthish Manthiram and Emma Cosner

Hydroformylation (thermo-HFN) is an industrially relevant reaction performed at a scale of 10 million tons/year. It is a reaction where olefins are coupled with high pressure carbon monoxide and hydrogen, in the presence of a catalyst at high temperatures to form aldehydes. Electrifying thermo-HFN (electro-HFN) to use protons and electrons instead of hydrogen gas could mitigate the need for elevated temperature and pressure and the use of H_2 gas as a reactant. Zeng and coworkers proved that electro-HFN is possible using a rhodium catalyst. However, rhodium is rare and expensive, therefore finding catalysts that are more abundant is necessary for making electro-HFN sustainable. Cobalt and copper could be good candidates as they are more abundant and cobalt has literature thermo-HFN precedent while copper catalyzes C-C bond forming reactions. Several Cu and Co materials were tested i.e., Cu, Cu_2O/C, CuO, Co/C, CoO, Co_2O_3 and Co_3O_4. All the oxides were commercially available except Cu_2O/C, it was synthesized and characterized by X-ray diffraction, scanning electron microscopy and energy-dispersive X-ray spectroscopy. The Cu and Co materials were screened for reactivity by constant current experiments at –500 μA for 2 hours, none showed reactivity. Future work should focus on making other rhodium nanoparticles on graphene and phosphorus-based supports.

The Effect of Tree Canopy Coverage on Residential Temperature
Meher Banik
Mentor: Julie Kornfield

This research project studies the relationship between tree canopy coverage and residential temperature, with a specific emphasis on addressing urban heat islands. Urban heat islands refer to the marked temperature differences between urban areas and their surrounding rural counterparts. Recent studies have revealed a significant correlation between urban temperature disparities and the extent of tree canopy coverage in urban areas, highlighting the critical role of vegetation in mediating local microclimates.

The overarching objective of this study is to explore the relationship between tree canopy coverage and residential temperatures within the context of environmental justice. The research is expected to have far-reaching social and environmental implications, as it may inform strategies for mitigating urban heat disparities, reducing greenhouse gas emissions, and fostering more sustainable urban ecosystems.

The research methodology involves the strategic placement of temperature sensors in selected sites, enabling the collection of data that will help elucidate the impact of tree canopy coverage on indoor temperatures. Preliminary experiments aim to characterize temperature variations under different conditions, laying the foundation for more extensive data collection and analysis.

Effect Of Porosity in Vortex Ring Formation Time Scales
Sebastian Banuelos
Mentors: Mory Gharib and Scott Bollt

Vortex rings are a commonly studied phenomenon in fluid mechanics due to their large presence in turbulent flow. They are flow structures generated when a body of water is forced through an outlet, causing a separation in the boundary layer at the opening, resulting in a rotating column of air. Gharib et al. proposed that vortex rings achieve a maximum circulation at a universal formation number. Using a piston-cylinder experimental setup, he described this characteristic number to be a stroke-to-diameter ratio of approximately 4.

In this project, the effect of porosity in formation time scales of vortex rings is studied experimentally. By allowing smaller streams to flow across its surface, porous bodies display different aerodynamic properties than a conventional solid plate. These jets interact with wake flow affecting the formation of vortex structures.

Thus, we will utilize perforated plates with industry-standard porosity ratios. By accelerating these plates through a water tank, we obtain velocity and vortex flow fields using Particle Image Velocimetry. By varying the porosity of such plate, we seek to identify the critical ratio at which flow transitions from wake to trailing jet behavior. Ultimately, porosity could serve as a potential parameter space to model the formation time scale of vortex rings.

Using Webcam-based Eye Tracking Technology to Probe Atypical Gaze Behavior in Autism
Ava Barbano
Mentors: Ralph Adolphs, Na Yeon Kim, and Qianying Wu

Autism spectrum disorder (ASD) is a neurodevelopmental disorder that is commonly associated with social and communicative difficulties. The complex and heterogeneous nature of ASD symptoms has placed challenges in establishing an objective and quantifiable behavioral marker that provides a foundation for further research on the genetic and biological basis. Eye tracking has revealed atypical gaze patterns in ASD; however, conventional desktop-based eye trackers require specialized equipment and in-lab testing. This study instead utilizes Webgazer, a webcam-based eye tracking technology, to study gaze behavior in a large-scale subject population recruited from Prolific, an online study platform. The pilot implementation of this study (N = 96) featured ASD and non-ASD groups viewing naturalistic Zoom conversations featuring human actors and physical objects. All participants completed Autism Quotient and Social Responsiveness Score questionnaires, as measures of autistic traits. Preliminary analysis of the pilot data will be used to inform the final experimental design and implementation of the study, with a focus on the comparison of gaze data, self-reported engagement,demographic information, and questionnaire reports between the ASD and non-ASD groups.

Using Variability of Emission to Determine Presence of Black Holes in Galaxies
Diego F. Barcenas
Mentors: George Helou and Frank John Masci

The AGN (Active Galactic Nuclei) refers to the torus shaped region at the center of a galaxy. Observing instruments of AGNs such as telescopes NEOWISE/WISE (NASA's Near-Earth Object Wide-field Infrared Survey Explorer) and ZTF (Zwicky Transient Facility) perform a survey of the night sky, crossing the ecliptic poles. We categorize the information from a given galaxy collected by ZTF and WISE/NEOWISE, to determine the probability of a black hole being present in the galaxy's center. The measurements of luminosity were studied to estimate the variation, or fluctuation of the significant source of light. Fluctuations strongly correlate with the pretense of an accreting black hole in the center of a galaxy, being the source of energy or radiation from the galaxy. From there, given data from an arbitrary galaxy, a categorization can be made if a black hole is present or not.

Studying the Effects of CB5339 as a p97 Pathway Inhibitor on Proteins in the Ubiquitin Pathway of IMR90 Fibroblast Cells
Karina Bender
Mentors: Tsui-Fen Chou, Shyue-Fang Battaglia, and Lai Chai Foong

The p97 gene regulates the ubiquitin pathway, which is responsible for the degradation of waste products and proteins in the cell. This gene pathway is regulated differently in younger cell cultures compared to older cell cultures. In older cells, p97 and the ubiquitin pathway are not expressed as frequently as in younger cells, leading to a buildup of waste products that are harmful to the cell and ultimately leads to apoptosis and cell death. In this project, we determined how the inhibition of p97 with the reagent CB5339 affected the proteins in the p97 pathway in both younger and older generations of the cell line IMR90, a fibroblast cell line, to determine their effects on the aging process. This allowed us to gain a better understanding of the role of p97 in fibroblast aging, and specifically how its inhibition can be used to limit aging in cells. This knowledge can then potentially be used to combat neurological disorders by reprogramming the fibroblast cells into neurons, allowing us to further study potential ways to inhibit rapid aging in brain cells and treat conditions such as Alzheimer's or Parkinson's.

Effect of Bathymetry on the Dynamics of Southern Ocean Subpolar Gyres
Emma Beniston
Mentors: Andrew Thompson, Scott Conn, and Ruth Moorman

The subpolar gyres of the Southern Ocean are large cyclonic ocean circulations which lie between the Antarctic Circumpolar Current (ACC) and the Antarctic coastline. The subpolar gyres are important circulation features playing a role in the transport of heat, sea-ice and carbon within the region. Understanding the governing dynamics of the subpolar gyres is thus crucial to developing a comprehensive understanding of the Southern Ocean and its interaction with the global climate. Though gyres in general are well-studied features of the global ocean, traditional theories rely on gyres being bound by continents on both their eastern and western edges. By contrast, the Weddell and Ross gyres of the subpolar Southern Ocean have no eastern land boundaries and have either partially or fully submerged western and northern boundaries. To investigate the governing dynamics in these nonstandard geometries, we carried out a series of numerical simulations with idealised bathymetry (seafloor depth) constructed to represent the Weddell and Ross gyres. We assess how changes to the bathymetry affect the shape, strength, and extent of the gyres, particularly where the eastern limb of the gyre separates from the ridge and the ACC. We also analyse how a vorticity balance is achieved in each configuration.

Correcting Phonon and Quasiparticle Dynamics in Geant4 Simulation of Kinetic Inductance Detectors
Ruth Berkun
Mentors: Sunil Golwala and Karthik Ramanathan

Kinetic Inductance Detectors (KIDs) can be used to detect low-mass dark matter candidates. When dark matter interacts with KIDs, it creates a pulse of phonons and quasiparticles, the latter of which can be used to characterize the energy of the dark matter. However, the physics behind phonon propagation and interaction with quasiparticles is not well understood. To gain more insight into these interactions, we modify a previous Geant4 (GEometry ANd Tracking) simulation created by a previous lab member (Erik Lindeman) and compare it to experimental data of a lab wafer of KIDs. We analyze the phonon and quasiparticle physics separately, modifying different parameters affecting propagation to see if they help the simulated pulse shapes have more similar rise and decay features to the experimental pulses. Parameters such as total internal reflection and absorption parameter were both found to affect quasiparticle decay time; however, more work needs to be done to change the relative rate of decays for KIDs at different distances from the detectors. Understanding what other parameters affect phonon and quasiparticle creation and decay can help aid the development of more sensitive detectors.

Modeling Non-terminal Cloud Droplets in PySDM
Brady Bhalla
Mentors: Tapio Schneider and Emily de Jong

Cloud microphysics, which describes the interaction of microscopic particles in the atmosphere such as water droplets, ice crystals, and aerosol particles, is a major source of uncertainty in current climate models. One simplification made when modeling microphysics is treating all droplets as moving at their terminal velocity. However, this is not always true, especially when there is a high frequency of collisions. Immediately after two droplets coalesce, the resulting droplet will be moving slower than its terminal velocity, and immediately after a droplet breaks into smaller droplets, the resulting droplets will be moving faster than their terminal velocities. This work explores the importance of non-terminal droplets through a pythonic implementation of the super-droplet method, PySDM, which is a high-fidelity tool for modeling cloud microphysics. We create a new dynamic which allows droplet velocity to relax towards the terminal velocity instead of instantly updating. Simulations using this non-terminal velocity in the context of coalescence and droplet breakup are used to explore the importance of non-terminal droplets, which improves our understanding of microphysics and furthers the goal of reducing uncertainty in climate modeling.

Molecular Qubits for Enhanced Quantum Sensing
Nachiket Bhanushali
Mentors: Norman Yao, Nicholas Hutzler, Emily Davis, Weijie Wu, and Zilin Wang

Recent efforts in quantum engineering have led to the design of several molecules with properties that are suitable for making quantum bits (qubits). While these molecules promise improved performance in quantum computation due to their large coherence times, they are also harder to polarize and read out, making it challenging to use them as a platform for quantum computation. One approach to tackling this problem involves the use of nitrogen-vacancy (NV) defects in diamond. NV defects are a well-studied, easily polarizable, and optically addressable quantum system with recently proposed applications as sensitive probes of spins and magnetic fields, and as a medium to polarize other atoms and molecules. This project aims to characterize the polarization transfer from NV centers to molecular qubits as well as the quantum sensing capabilities of this system using a confocal fluorescence microscopy setup. We discuss the design of the confocal setup used as well as the implementation of the different polarization transfer protocols used to polarize the molecular qubits using the NV centers.

Developing an Automated Particle Tracking Method to Measure Sediment Settling Velocity
Ayush Bhattacharya
Mentors: Michael Lamb and Justin Nghiem

Relative sea level rise can flood and erode coastal land. Building land with sediment deposited from rivers is a major mitigation strategy to counteract this. However, predicting sediment deposition rate is highly uncertain because flocculation, the process of sediment grains combining into larger particles called flocs, can dramatically increase the settling rate of mud, which is abundant in coastal areas. Direct camera measurements of mud floc size and settling velocity are required to constrain the environmental conditions leading to and the effects of flocculation. Particle tracking is needed to track flocs across multiple frames and estimate the floc settling velocity. However, past measurements faced difficulties in automating the floc tracking process. To address this knowledge gap, we are currently training a convolutional neural network model to automatically track particle movement based on the floc images. With these images, we furthermore compared the grain size and particle size distribution to determine whether the sediment in the experiments was flocculated. Next, we will work on increasing the number of particles that the model can handle and improving the model accuracy.

Investigating the Migration of p97 Into the Nucleus in K562 Cells Due to Treatment With H_2O_2
Berglind Bjarnadóttir
Mentors: Tsui-Fen Chou and Vivian Lai

VCP/p97 protein is an ATPase protein that is involved in various cellular processes, including protein degradation and DNA damage repair. Many mutations in p97 have been linked to several diseases, including cancer. We observed that p97 is more abundant in the nucleus of K562 leukemia cells treated with H_2O_2 than in untreated leukemia cells. However, it is unknown why it is more abundant or how it migrates into the nucleus. Therefore, we have tried to gain a better understanding of this by doing an immunoprecipitation for p97 with treated and untreated K562 cells and sent the result from that for further analysis using mass spectrometry. We are analyzing the data from the mass spectrometry looking for proteins that are upregulated in H_2O_2 treated cells and could be involved in transporting p97 into the nucleus. We are also currently checking one another cell line to see if the same increase of p97 happens in the nucleus under H_2O_2 treatment.

Genetic and Pharmacological Modulation of Mitochondrial DNA Heteroplasmy
Michael Bohl
Mentor: Bruce Hay

This research project explored the impact of different compounds on the selective removal of deletion-bearing mtDNA ($mtDNA^{\Delta}$) in *Drosophila melanogaster* and C2C12 mouse myoblast cells. This was done by determining the ratio of $mtDNA^{\Delta}$ to $mtDNA^{total}$ copies with qPCR. Results suggest that spermidine and urolithin A promote the selective removal of $mtDNA^{\Delta}$, while resveratrol reduces the abundance of $mtDNA^{\Delta}$ by predominantly reducing the overall mtDNA. Preliminary results obtained from experiments on C2C12 mouse myoblast cells further confirmed the efficacy of urolithin A and additionally revealed the modulatory effects of the Bax inhibitor peptide V5 and the integrated stress response inhibitor ISRIB on $mtDNA^{\Delta}$ levels. The role of PINK1, Parkin, and BNIP3 in the removal of mtDNAΔ was also investigated. RNAi knockdown of these genes increases $mtDNA^{\Delta}$/mtDNAtotal ratios while overexpressing PINK1 reduces $mtDNA^{\Delta}$ copy numbers. By crossing flies with tissue-specific GAL4 expression to UAS-mitoAflIII flies, this research revealed that mtDNA heteroplasmy in tissues expressing the lozenge gene results in visible non-lethal phenotypes.

Although the data provides valuable insights into the modulation of selective $mtDNA^{\Delta}$ removal, the variability observed among replicates limits the precision of the results. Further research is necessary to validate and expand upon these findings.

Developmental Milestones in Children With Agenesis of the Corpus Callosum
Ella Bohlman
Mentors: *Ralph Adolphs, Lynn Paul, and Jasmin Turner*

Congenital malformations of the corpus callosum include agenesis (complete or partial callosal absence, ACC), dysgenesis (malformed callosum), and hypoplasia (thin callosum). Evidence to date suggests delays in language, adaptive functioning, and social communication, among other aspects. This study explores development as a whole within infants and children with ACC. Through a variety of parent-report surveys, analyses were conducted to summarize these delays and developmental milestones, as well as the outcomes per callosal diagnosis (isolated ACC, dysgenesis/hypoplasia, or ACC plus (agenesis combined with other developmental brain malformations)). A preliminary review of summary statistics indicates that there are delays within the language and motor areas of development. Further analysis will likely confirm and expand on these findings.

Solubility of Water in Sodium Aluminosilicate and Calcium Aluminosilicate Melts
Ambre Brabant
Mentors: Ed Stolper and Mike Baker

Water dissolves in silicate melt as OH and H_2O and has an enormous impact on the melt's physical and chemical properties. At low pressure, OH is the dominant species. However, the compositional dependence of OH solubility is not well-constrained, making it difficult to accurately model low-pressure magmatic degassing. We measured the 1-atm solubility of water at 1300°C in melt compositions in the Na_2O-Al_2O_3-SiO_2 (NAS) and CaO-Al_2O_3-SiO_2 (CAS) systems. Melts were equilibrated with CO_2-H_2O gas mixtures in a 1-atm furnace (pH_2O=0.298-0.314atm) and quenched after 24-64h. Glass compositions were determined using a scanning electron microscope equipped with an energy dispersive spectrometer. Water contents were measured using Fourier Transform Infrared Spectroscopy. The NAS glasses contained 800-1400ppm water, with water contents correlated with Na loss from the different experiments. The CAS system has been less well-studied; time-series experiments show that water contents reach an approximately constant value after 24h. Subsequent experiments will involve three modified CAS compositions.

These data combined with 1-atm solubility data from the glass literature will be used to investigate simple models of water solubility as a function of melt composition in conditions where OH is the dominant water species.

Structural Analysis of MurG Interactions With Substrates, Inhibitors, and MraY
Helen Brackney
Mentor: William Clemons Jr.

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

Characterization and Design of a Mach-Zehnder Setup for Quantum Frequency Conversion of Ion-Trap Photons to Telecom Wavelengths
Michael Bregar
Mentors: Maria Spiropulu, Prathwiraj Umesh, and Raju Valivarthi

The development of light-matter quantum networks for applications such as entanglement distribution is a thriving area of research that could enable quantum technologies to transmit information over long distances, probe fundamental physics, and simulate physical phenomena. In a quantum network envisioned by the Spiropulu Group, two ion trap nodes (Ca+), one at LBNL and the other at UCB, emit photons at 854 nm that must travel 10 km between nodes. To achieve low loss transmission, the frequencies of these two photons need to be converted to the optimal value of 1550 nm while also converting both h and v polarizations. The goal of this project was to characterize, design, and test various components in a Mach-Zehnder quantum frequency conversion (QFC) setup to find the most efficient configuration that can be used for quantum communication. A Python feedback system was designed on a separate homodyne detection setup using an NI-DAQ device and two balanced homodyne detectors to stabilize the output quadratures, which was later used to stabilize the Mach-Zehnder QFC setup. Subsequent work involves performing sum frequency generation using a 1902 nm pump laser and a 1550 nm tunable telecom laser to characterize PPLN waveguides to be used for QFC.

Robotic Optical Ammonia Detection—Materials Acceleration Platform (ROAD-MAP)
Bryan Burnell
Mentors: John Gregoire and Ryan Jones

Automating the characterization of possible ammonia-generating electrochemical processes will greatly accelerate the search for a renewable method of ammonia production. The High Throughput Experimentation Group is currently working with several other labs to develop electrochemical reactors that will autonomously facilitate electrochemical processes to potentially produce ammonia from N2. Designing a Robot Solution Handling System to automatically prepare and spectrometrically analyze the samples produced by such a reactor will allow the rapid characterization of electrochemical processes' ability to produce ammonia. A flow cell was designed to have samples injected into a 0.04" ID electrolyte flow path, with a broad-band LED shining through a 3" long optical absorption path to be measured by a spectrometer on the other end. A Python program will then automatically analyze the collected spectra to determine the ammonia content of each sample.

Unsupervised Re-Identification of Primates Through Self-Supervised Learning
Kevin Cai
Mentors: Pietro Perona and Markus Marks

Primate re-identification is a critical task in primate behavior research, which involves tracking and identifying individual primates from video footage. Primatologists, anthropologists, zoologists, ecologists, and wildlife biologists gather terabytes of video footage per camera each field season; thus, the current gold standard, manual annotation of this footage, is not scalable. Machine learning techniques have been applied to automate primate re-identification. However, the existing state-of-the-art methods are supervised, which require manually labeled training data, making them impractical in real-world scenarios where the data gathered is too large to actively label. Moreover, domain experts often do not know and therefore cannot label all the individuals. We propose an unsupervised primate re-identification framework that automatically identifies individual primates from video footage without requiring full training on a manually labeled dataset. Our framework will consist of a self-supervised student-teacher network that will train an identification model through which we will embed the video frames and cluster the individuals, so they can be tracked across multiple views. To evaluate the proposed framework, we will conduct experiments on various primate datasets to compare our model to existing benchmarks, and we will test our framework on a curated dataset with different environmental and lighting conditions to show that our framework can generalize across different environmental conditions, field sites, seasons, time of day, and primate groups.

Error Cancellation in Analog Quantum Simulations
Yiyi Cai
Mentors: John Preskill and Yu Tong

While fully fault-tolerant quantum computers are still work in progress, analog quantum simulators are projected to be able to solve relevant problems in many-body physics in the near term. However, the presence of noise introduces challenges in determining the extent of analog quantum simulator's advantages with respect to classical computers. In our work, we consider an error model in which the actual Hamiltonian differs from the target Hamiltonian to simulate by small local perturbations, which are assumed to be random and unbiased. We analyze the error accumulated in observables in such a setting and show that due to stochastic error cancellation, the error scales with the square root of the number of qubits instead of linear. We explore the concentration of such error as well as its implication for local observables in the thermodynamic limit.

Randomized Algorithms for Efficient Tensor Network Contraction
Chris Camaño
Mentors: Joel Tropp and Ethan Epperly

The contraction of tensor networks is a crucial computational issue in various fields of quantum physics, including quantum information theory and condensed matter physics. As network complexity increases, many iterative algorithms become inefficient and prohibitively expensive. In response to this challenge, we introduce a novel randomized algorithm for contracting high-rank MPO and MPS tensor networks. Our algorithm uses a randomized sketch, represented as a random tensor embedding, to reduce computational overhead in complex networks while maintaining accuracy consistent with traditional non-randomized methods. By leveraging random sampling and decomposition, our approach avoids exhaustive computations and provides efficient tensor contraction approximations. We demonstrate the utility of our algorithm through numerical experiments, specifically focusing on power iteration for ground state identification and Hamiltonian time evolution.

Joint Reconstruction-Segmentation Using the Bhattacharyya Coefficient
John Z. Cao
Mentors: Franca Hoffmann and Jeremy Budd

The practical application of image segmentation is often accompanied by the problem of noisy, distorted images. Traditional sequential methods suffer from the loss of segmentation-relevant information after reconstruction is performed, while contemporary learning-based methods are often hard to explain and do not give an explicit reconstruction of the image. Joint reconstruction-segmentation is a recent approach to overcome these difficulties, performing both tasks at the same time, using one to guide the other. In this project, we implement joint reconstruction-segmentation using the gradient flow stemming from the Bhattacharyya coefficient. Specifically, we model the segmentation as the variational problem of maximizing the distance between two probability distributions, one associated with the object to be segmented and the other with the image background. We model the reconstruction as the inverse problem of recovering the image from an indirect observation, under the constraint of respecting the previous segmentation. We test the efficiency of our algorithm on medical images provided by the Memorial Sloan Kettering Cancer Center.

Performance Testing for IceCube-Gen2 Upgrade's Long Optical Module for Astrophysical Neutrino Detection and Resolution
Chi Cap
Mentors: Chris Wendt and Ryan Patterson

The IceCube Neutrino Observatory (IceCube), located at the South Pole, utilizes glacial ice as a Cherenkov medium to detect secondary particles produced by astrophysical neutrino collision with the ice using optical sensors. The newly developed Long Optical Modules (LOMs) is part of the IceCube-Gen2 Upgrade, which aims to increase the sensitivity and detection rate of IceCube. The LOMs is designed to have the same effective area as previous modules (DOMs) and at the same time are four times more sensitive. The LOMs are comprised of 14 or 16 subassemblies of photomultiplier tube (PMT) and its data acquisition base (wuBase). The goal of this project is to design a streamlined PMT-and-wuBase sub-assembly testing procedure, define pass-fail operational criteria to determine whether the sub-assembly can be placed in the LOM, and setting up the testing environment. The procedure will identify the operational parameters for a subassembly detecting single photoelectron (SPE), its SPE time- and waveform- resolution, the dark noise characteristics, and its multiple photoelectrons (MPE) resolution and dynamic range. It is anticipated that about 200 sub-assemblies will be tested for the upcoming IceCube-Upgrade launch. With the procedure, we are expected to find the ideal operational parameters for individual subassembly and assess other pass-fail criteria. This allows us to identify nonfunctional subassemblies with anomaly that will affect their data-taking ability and learn about the operational and dynamic range of the subassemblies.

Mechanical Modes in Tethered and Freely Accelerated Lightsails
Luis Carretero López
Mentors: Harry A. Atwater, Lior Michaeli, and Ramon Gao

Laser-driven lightsails represent a cornerstone of interstellar exploration as envisioned by the Breakthrough Starshot initiative. Understanding the emergence and evolution of mechanical modes excited by the driving laser in such freely accelerated membranes is crucial to assess structural and beam-riding stability. Vibrational modes offer insights into complex mechanical systems, and can be analyzed in stationary membranes and compared those in accelerated lightsails. Two types of numerical mass-spring models were implemented in MATLAB to simulate and visualize the dynamics and mechanics of ring-supported lightsail membranes. In the linear model, simulated modes match analytical predictions, but challenges arise due to the lightsail's extreme aspect ratio (subwavelength thick, yet meter-sized) and large optical forces, particularly in the limit of zero tension. In comparison, the geometrically nonlinear model takes into account pretension, arbitrary orientation and large shape deformations, resulting in more realistic mechanical and dynamical representation of lightsails. Bridging the linear and nonlinear regime with my modelling approach establishes the framework for comparative modal analysis to deduce what one could infer from experiments on tethered lightsails in the laboratory about the structural dynamics of freely accelerated lightsails in space.

Radiative-Convective Equilibrium in the CliMA Model for Climate Sensitivity Analysis
Etienne Casanova
Mentors: Tapio Schneider, Zhaoyi Shen, and Dennis Yatunin

Radiative-convective equilibrium, the balance between incoming radiation absorbed by Earth and the outgoing radiation emitted to space with a convective heat adjustment, can be very insightful when it comes to analyzing the climate's sensitivity to greenhouse gases. CliMA has been working on implementing cloud processes inside the atmospheric model, which would allow the convective adjustment of radiative-convective equilibrium to be possible. My project is to implement radiative-convective equilibrium inside the CliMA atmosphere model codebase in single column models and analyze how changes in greenhouse gas concentrations affect the atmosphere. I did this by prognostically calculating surface temperature at every time step, updating the state of the surface model, and feeding that surface temperature back into other components of the model to allow for coupling between surface temperature and atmospheric processes. I then altered the general atmospheric model to support prognostic surface temperature feedback in any given simulation. Finally, I conducted simulations with varying greenhouse gas concentrations and analyzed their effect on surface and air temperature.

Identifying Fast X-Ray Transients Over 11 Years of NuSTAR Data
Joahan Castaneda Jaimes
Mentors: Fiona Harrison and Murray Brightman

Fast X-ray transients (FXRTs) are astrophysical sources such as gamma ray bursts, stellar flares, and X-ray binaries which emit an outburst of X-ray emission and have characteristic timescales of a few thousand kiloseconds or less. The luminosity-duration phase space for X-ray transients (XRTs) is not as well explored for FXRTs as for XRTs of longer characteristic timescales. We perform a search on the past 11 years of data collected by the Nuclear Spectroscopic Telescope Array to identify FXRTs of characteristic timescales ranging from a few hundred seconds to five kiloseconds. We provide an upper bound on the number of potential FXRT candidates within the 11 years of NuSTAR data provided and present a final catalog of FXRT candidates with preliminary light curves, spectra, and image files.

Transforming Metal-Organic Materials Into Wide Band Gap Semiconductors and Metals by Using Direct Write Electron Beam Lithography
David. A. Castillo Lozada
Mentors: Axel Scherer and Scott Lewis

The ability to write structures at the nanoscale using lithography underpins all modern society. The electronic devices we take for granted contain integrated circuits, and the key component of those circuits are field-effect transistors (FETs). They have reduced in size by a factor of two every two years for over fifty years, following "Moore's Law". The roadmap for the electronics industry now assumes that this constant reduction of size will continue – at least until the mid-2020s[1]. However, there is a significant challenge immediately ahead because to produce the latest microprocessor requires approximately 60 photomasks to fabricate each layer in the device. Unfortunately, to produce this, multiple materials and multiple processing steps are required and these are subject to failure. To alleviate this issue, we describe how metal-organic materials can be transformed from a highly insulating materials to produce a semiconductors and metals using an electron beam. This is of particular interest because it demonstrates that active semiconductor devices such as field effect transistors can be simple to produce with no photomasks or etching steps or impurity doping being required, which inherently drives the manufacturing cost's down while increasing the throughput.

Development of a Propulsive Vertical Landing Vehicle
Enzo Celis
Mentors: Morteza Gharib and Jack Caldwell

In recent years, private space launch vehicle companies have developed propulsive vertical landing technology, allowing rockets to return in more reusable conditions, leading to reduced costs and increased launch frequency. However, there is much to explore regarding the control schemes behind vertical landers and their limitations in adverse wind conditions. For the Graduate Aerospace Laboratories (GALCIT) to conduct experimental research on these topics, this project is dedicated to developing a proof-of-concept cold gas vertical landing vehicle, implementing its preliminary control scheme, and verifying its functionality. Our work has shown that cold gas, despite its low specific impulse, produces sufficient thrust for powering a descent-controlling main nozzle and attitude-controlling RCS nozzles. Our pneumatic circuitry design also circumvents flow limitations imposed by commercial off-the-shelf components and delivers throttling capability to our main nozzle to more closely replicate true vertical landing vehicles. Future work includes implementation of a PID loop that controls RCS actuation and benchtop testing to verify its functionality. Final demonstrations in an aerodrome will provide full-system reliability confidence and testing against a wind maker that emulates shear wind patterns at flight-realistic Reynolds numbers will provide insight on the limitations of these systems.

First Principles Calculation of Spin Spectra of Magnetic Systems
Shashwat Chakraborty
Mentors: Marco Bernardi and Khoa B. Le

First-principles calculations of material properties have always been crucial to scientific research. Computationally solving the Schrödinger equation to explain the behavior of electrons and various quasiparticle interactions in materials provides novel insights at the micro- and even nano-scales. Magnetic systems are in the limelight in the current condensed matter physics scenario. Consequently, the field of magnonics has gained significant attention from the quantum materials community. Therefore, developing a solid framework for analyzing the spin spectra of magnetic systems is of crucial importance. One of the most widely used tools for magnon dispersion computation is the SpinW library, based on the Linear Spin Wave Theory (LSWT) for quantum Heisenberg Hamiltonians. In this work, we calculate the magnon dispersion of a Manganese Phosphorus Sulfide, a 2D antiferromagnetic material using spin-polarized Density Functional calculations and the Bethe Salpeter equation. We also match the dispersions obtained using first-principles calculations, LSWT calculations, and Neutron scattering fit.

Retrieval-Augmented Theorem Proving in Lean
Rahul Chalamala
Mentors: Anima Anandkumar and Kaiyu Yang

Formal theorem proving is essential for mathematicians to write complex proofs without error. Automated theorem provers (ATPs) allow us to augment formal theorem proving with a learning-based approach. To the best of our knowledge, all state-of-the-art large language model (LLM) ATPs are closed-source or require unreasonable compute power. Our prior work released an open-source theorem proving dataset and ATP (trained with 120 GPU hours) to allow mathematicians and other community members access to a strong prover. After a successful release, we strengthened the ATP using LLMs trained on code datasets. Preliminary results indicate a potential for significant improvement when switching to specialized LLMs.

Creating Superconducting Resonators to Probe Thin-Film Quality
Matthew Chalk
Mentors: Joseph Falson and Matthew Libersky

Falson Lab focuses on using molecular beam epitaxy (MBE) to grow high quality thin-films. Some of these films, such as those made of Niobium, can be fabricated into superconducting circuits for quantum information and sensing applications. Thin-film attributes undesirable for these fields, such as dielectric loss and two-level systems, can be measured by etching the films into microwave resonators. Varying geometric features of these resonators provides a method of probing the location and causes of these unwanted effects.

In this work, we use thin-films of Niobium on sapphire grown using MBE to create coplanar waveguide resonators. A recipe for photolithography was developed to realize the desired resonator geometry. Subsequently, we probed these resonators at DC and microwave frequencies. Automated measurements were performed in a Physical Property Measurement System (PPMS) down to single-digit Kelvin temperatures using lock-in amplifiers for low-frequency measurement and a vector network analyzer for microwave frequencies. The quality factor of the resonator as well as the residual-resistance ratio of the film will be used as guidance for subsequent resonator creation and future thin-film growths.

Building an Autonomous Testbed for Motion Planning Algorithms on a Modified RC Car

Aditi Chandrashekar
Mentors: Soon-Jo Chung, John Lathrop, and Ben Rivière

The INDY Autonomous Project is a global competition aimed at advancing autonomous vehicle technology through the design of high speed self-driving race cars. There is significant financial risk in testing planning and control algorithms on real race cars. There is a need for a fully functional autonomous testbed on an RC car. To this end, a Traxxas X-Maxx RC car was modified to carry an NVIDIA Jetson Orin for onboard computing as well as a ZED 2 AI camera for perception, object detection, and odometry. This hardware stack was tested with path planning and control algorithms including the A* algorithm. This testbed will enable the development of more sophisticated motion planning algorithms in the future.

Optimizing WIRC+Pol Pipeline and Characterizing Brown Dwarf Circumstellar Disks in the Taurus Molecular Cloud via Near-Infrared Spectropolarimetry

William Chang
Mentors: Dimitri Mawet, Maxwell Millar-Blanchaer, and Ricky Nilsson

Compact circumstellar disks cannot be spatially resolved with current 8-m class telescopes but can create a measurable linear polarization at near-infrared wavelengths. WIRC+Pol, a low-resolution, near-infrared spectropolarimetry mode of the Wide-field InfraRed Camera (WIRC) aboard the 200-in Hale Telescope at Palomar Observatory, took advantage of this property. We tailored the WIRC+Pol data reduction pipeline to process the J and H band polarimetric data, enabling us to study the structure of the disks, the magnetic field of the brown dwarf, the oblateness of the atmosphere, and the presence of horizontal cloud bands. In particular, we extracted and analyzed the time and wavelength variability of the Stokes I, Q, U, and V to investigate the disk of CHFT-BD-Tau-4 (CT4), a brown dwarf on which two of the strongest superflares ever observed took place. By comparing the CT4 signal to that of IRAS F04366+2555, a nearby T Tauri star, we conclude that CT4 exhibits no time variability and has a consistent linear polarization of $0.63 \pm 0.03\%$ in the J-band and $0.54 \pm 0.01\%$ in the H-band. Such findings allow us to look for dust scattering via spectral slopes and characterize the interstellar polarization of the Taurus Molecular Cloud via Serkowski's polarization law.

Investigating Climate Impacts Through the Offset of Paired Kerogen-Pyrite Sulfur Isotopes in Marine Sediment

Andrea Chen
Mentors: Alex Sessions and Selva Marroquin

Analyzing marine sediments can provide insights into the ocean's redox state through time, helping to develop a framework for understanding Earth's history. Sulfur isotopes ($\delta^{34}S$), commonly buried in its reduced form as pyrite (FeS_2), can be measured to reconstruct past global marine redox and estimate past atmospheric oxygen content. Here, we investigate the utility of adding coeval $\delta^{34}S$ measurements from sulfur bound into kerogen, to track environmental conditions recorded in $\delta^{34}S$.

To explore the relationship between water column redox and sulfur isotopes, we measured the kerogen and pyrite $\delta^{34}S$, and total organic carbon (TOC) of International Ocean Discovery Program (IODP) ocean cores from the Agulhas Current. We did a sequential sulfur extraction on a single sediment aliquot to separate the different sulfur phases, which are then measured using an Elemental Analyzer and Isotope Ratio Mass Spectrometer. We predict sulfurization of organic matter in an anoxic water column leads to the formation of δ34S-depleted kerogen and a smaller kerogen-pyrite offset. Understanding the δ34S offset for pyrite and kerogen in the modern era will give us insights on using sulfur records to reconstruct the biogeochemical response of the ocean due to past climatic events and varying oxygen levels of the water column.

Characterizing the Energy Release Rate of Bi-material Interfaces Present in Nanoarchitected Composites

Belle Chen
Mentors: Julia Greer and Kevin Nakahara

The Greer Group has previously utilized holographic lithography to prepare nanoarchitected materials at the macroscale. These materials possess extraordinary properties and are commonly bolstered with epoxy, creating a composite material. To better understand and model this composite system, a study of the adhesive strength between the two components is necessary. Oxygen plasma treatment is known to affect the adhesive strength of the system through surface functionalization and roughening. ASTM-compliant mode 1 fracture samples were plasma treated and assembled. These samples were then fractured with a dynamic mechanical analyzer and filmed. The load/displacement data and video recording were used to calculate an energy release rate, which describes the adhesion, for stick and slip regimes. An analytic estimate of the energy release rate was also calculated with a J-integral. These energy release rates will play an integral role in capturing the true performance of a computationally modeled the nanoarchitected composite matrix.

Neutralization, Binding Affinity, and Kinetics of Monoclonal Antibodies Elicited From Sarbecovirus Mosaic RBD Nanoparticles

Jason Chen
Mentors: Stephen Mayo and Adrian Bahn

Neutralizing antibodies are key to providing protection from infectious diseases. However, not all antibodies that bind to antigens have neutralizing potential, and the biophysical and biochemical properties that predict neutralization have been incompletely described. Previous reports on the effects of kinetics, binding affinity, and epitope have suggested varying levels of importance of each to neutralization. To clarify those effects on neutralization, we have used surface plasmon resonance to determine precise binding kinetics and affinities of two class 4 and class 1/4 neutralizing and non-neutralizing murine monoclonal antibodies against four different sarbecovirus RBDs. Our results show that M8a-3 and M8a-6 had similar association rate constants, ranging from 1.10×10^4 - 3.16×10^5 $M^{-1}s^{-1}$ for M8a-3 and 1.50×10^4 - 4.83×10^4 $M^{-1}s^{-1}$ for M8a-6. In contrast, M8a-3's dissociation rate constants ranged from 4.24×10^{-5} - 9.15×10^{-3} $M^{-1}s^{-1}$, which was significantly slower than M8a-6's range from 3.13×10^{-2} - 7.42×10^{-2} $M^{-1}s^{-1}$. This finding supports previous reports on the mutational escape of SARS-CoV-2 epitopes from neutralizing antibodies, suggesting that slower dissociation kinetics enhance neutralizing ability. These results can inform future design considerations for the prediction and generation of neutralizing antibodies.

Design and Characterization of Citrus Peel Bioinspired Composites for Enhanced Energy Absorption

Kyle Chen
Mentors: Chiara Daraio, Chelsea Fox, and Tommaso Magrini

Our project centers on designing novel synthetic composite materials inspired by citrus fruit peels. Composite materials are made up of different components that combine to yield distinct characteristics from the original constituents. These materials offer many applications due to their unique attributes of high strength-to-weight ratios, cost-effectiveness, and the ability to be shaped. Nevertheless, their applications are hindered by limited energy absorption and poor fracture toughness. To overcome these limitations, we turn to bioinspiration from nature. Through evolution, citrus fruit peels protect the fruit even after falling from great heights off a tree, showing incredible energy absorption. In this project, we create tile features that mimic the peel material structures and utilize them to build new designs using our virtual growth program. Upon 3D printing the designs as polymer composites, we conduct quasistatic compression and tensile tests on the samples to measure the material's strength. We then perform dynamic testing by dropping masses onto the samples to assess their energy absorption. During these tests, we gather images of the deformation process for digital image correlation analysis. Citrus peel bioinspired composites could have the potential to represent a significant advancement in the development of enhanced composite material energy absorption.

Dark Current Estimation in SPHEREx Intensity Mapping

Shuang-Shuang Chen
Mentors: James J. Bock and Ari Cukierman

We calibrate the dark current (DC) of SPHEREx, an upcoming all-sky near-infrared survey, through observations. Since the dark current remains fixed to the detectors, by averaging multiple exposures from different pointings, we can reduce the sky signal and estimate the contribution of the dark current. In this project, we simulate observations for various sky components: Extragalactic Background Light (EBL), Diffuse Galactic Light (DGL), DC, zodiacal light, and photon noise. Stacking the exposures of each component and combining them yields DC estimations for each detector array. To enhance the averaging of DGL signal, we impose a criterion of Galactic latitude exceeding 60 degrees to exclude the exposures pointing towards the Galactic plane, and separate the exposures by 3 degrees to ensure non-overlapping. Additionally, we filter out the horizontal stripe patterns in the DGL stacks due to their wavelength dependence. With around 4,000 effective exposures, our DC estimation achieves a robust 98% correlation coefficient with the original DC template. Furthermore, we will subtract the DC estimation from each exposure, and propagate the data to generate mosaics and power spectra for evaluating the effectiveness of the DC estimation.

Grothendieck Classes of Melonic Graphs and Log Concavity

Stephanie Chen
Mentors: Paolo Aluffi and Matilde Marcolli

Given a graph G, one defines its Grothendieck class to be the class of its affine graph hypersurface complement in the Grothendieck ring of varieties. When applied to Feynman graphs, this mapping defines an algebro-geometric Feynman rule. In their work on motives of melonic graphs, Aluffi, Marcolli, and Qaisar determined a recursive relation for computing the Grothendieck class of a melonic graph and proved that the Grothendieck class of any melonic graph may be written as a polynomial in the class of the moduli space $M_{0,4}$ with positive coefficients. They further conjectured that the polynomials are log-concave. In recent years, log-concavity in several long-standing conjectures has been found to be related to the Kähler package, the analog of key properties of the cohomology of Kähler manifolds for mathematical objects of interest. The Rota-Heron-Welsh conjecture, for instance, was proved by Adiprasito, Huh, and Katz using the combinatorial analog of Hodge-Riemann relations for matroids. In our project, we investigate and prove parts of log-concavity conjecture for melonic graphs. We show that the three key polynomials involved in the recursive deletion-contraction formula are all log-concave and prove the conjecture for the classes of banana graphs and 'clasped necklaces'. We explore constructions that may give rise to a Kähler package for melonic graphs that could then be used to prove the full conjecture.

Conformal Prediction for Protein Design
Chu Xin Cheng
Mentors: Yisong Yue and Raul Astudillo

In the field of protein engineering, the discovery of sequences with high fitness is crucial. These sequences exhibit increased potency, affinity, or specificity for a particular antigen, offering significant scientific value. As such, understanding both the fitness value and the associated model uncertainty is essential for purposes such as bias correction or risk mitigation. This project focuses on the utilization of Graph Neural Networks (GNNs) for predicting protein fitness values, while also integrating Conformal Prediction (CP) methods to provide robust confidence sets for these predictions. We propose an approach to apply conformal prediction to the learned feature embeddings of protein sequences, with the aim of creating more precise confidence sets. In future work, we plan to incorporate conformal prediction into multi-fidelity optimization and experiment design problems. Our ultimate goal is to design a comprehensive, end-to-end differentiable pipeline for the efficient and reliable optimization of protein fitness.

Classifiers for Measurement Error Correction in Causal Inference
Sayuj Choudhari
Mentors: Zach Wood-Doughty and Chris Umans

Current methods for measurement error correction for classification of unobserved confounding variables in causal inference involve a manual calculation of error rates for different examples of data for a training set that includes the true unobserved confounding. This method becomes vulnerable to miscalculated error rates for cases with increased dimensionality of the observed data that influences the classification of unobserved confounding. A larger variation in examples of data over a set training size would result in less data per example and risk of miscalculation. We propose an alternative method of training a classifier to predict the error rate of a given example of data from which the predicted error rate on each example can be used to correct the distribution of the unobserved confounding variable. This classification method should perform better in higher dimensional cases where the model can learn the impact of each dimensional variable on the error rate and better learn the true error rate of examples with little training data. Our results show that in higher dimensional cases of classification on simple synthetic text generation, that the classification model performs significantly better than the original method.

Optimizing Sample Preparation Protocols for Ca Isotope Analysis of Urine Samples
Rithika Chunduri
Mentors: Francois Tissot and Rosa Grigoryan

Calcium is a vital element for many physiological processes in the body. Decreases in bone mass density - for instance, during osteoporosis - are associated with a net loss of calcium from the body via urine and incur an increased fracture risk. To gauge bone health in populations at risk of osteoporosis (e.g., post-menopausal women), bone density is measured via dual-energy X-ray absorption. This technique requires exposure to radiation and a hospital visit, which makes the test less accessible to at-risk individuals. In contrast, measuring calcium isotopes in urine via multi-collector inductively coupled plasma-mass spectrometry (MC-ICP-MS) has shown potential as a novel tool for diagnosing changes in bone mineral balance in conditions such as osteoporosis. However, current methods for calcium isotope analysis of urine are time-consuming and present a major bottleneck in clinical-scale studies. We systematically tested two different sample preparation protocols to optimize calcium isotope analysis of urine samples. Oven baking in glass test tubes was tested alongside the current sample digestion method, acid attack in PFA beakers. The residues were then purified via ion exchange chromatography to obtain pure calcium. The calcium concentrations and their isotopic ratios were measured using an iCAP ICP-MS and an MC-ICP-MS, respectively. This data will be analyzed, and subsequently, the most efficient sample preparation method will be identified for large scale Ca isotope analysis of urine samples.

Thermal Characterization of Silicon Nitride Lightsails
Nina Cielica
Mentors: Harry Atwater and Ramon Gao

The Breakthrough Starshot Initiative envisions accelerating ultrathin lightsails to relativistic speeds with laser radiation pressure. Silicon nitride is a promising candidate material for lightsails, which must exhibit low absorption at the propulsion wavelength and efficient infrared emission for thermal management. We report first steps towards comprehensive characterization of the thermal properties of suspended subwavelength thick silicon nitride. To measure the temperature distribution of a laser-heated sample, an uncooled infrared thermal camera was set up. Radiometric calibration was needed to convert recorded values to temperature units using a black soot sample with an emissivity of one, heated to temperatures between 25°C and 100°C. To determine the emissivity of silicon nitride, infrared ellipsometry measurements were taken at 25°C, 50°C and 100°C. In this range, silicon nitride's emissivity appears to be independent of temperature. To model laser-induced heating and design photonic structures for enhanced thermal cooling, finite-element simulations were carried out in COMSOL. The proposed structures will be fabricated and experimentally characterized in the home-built setup to compare both unpatterned and patterned laser-heated silicon nitride membranes in terms of their thermal performance and thus suitability for laser-driven lightsails.

A High-Resolution Study of AGN Variability With TESS
Sophie Clark
Mentors: Matthew Graham and Szymon Nakoneczny

It is our understanding that every galaxy possesses a black hole at its center, which can form an accretion disk of infalling matter that becomes thermally excited and emits a massive amount of light across the electromagnetic spectrum. When the accretion disk is luminous enough to outshine the stars in its galaxy, the region is considered an active galactic nucleus (AGN). AGN exhibit irregular and stochastic variability that is not well understood, and studying this variability requires collecting data from telescopes with a wide range of observational cadences. The Transiting Exoplanet Survey Satellite (TESS) is a space-based telescope designed to detect planets orbiting stars outside of our solar system. Because TESS was designed to make high-precision, high-cadence observations, it is a naturally beneficial addition to the sky surveys being applied to studies of AGN variability. Caltech's Zwicky Transient Facility (ZTF) provides AGN light curves on month to year timescales, and can thus be used as a quality check for the light curves from TESS. We present our findings from modifying the existing Quaver data pipeline to accelerate and automate the process of producing accurate short-timescale AGN light curves and applying it to data from TESS and ZTF in tandem.

Measurements of a Quantum Spin Glass
Tommy Clark
Mentors: Tom Rosenbaum and Dan Silevitch

We investigate the Ising spin glass $LiHo_{0.167}Y_{0.833}F_4$ in the presence of a transverse magnetic field. By cooling to millikelvin temperatures in a helium dilution refrigerator, we can observe quantum effects related to the spin glass phase and its quantum phase transition. By manipulating temperature and longitudinal and transverse magnetic fields we observe complex phenomena related to the behavior of a spin glass. Of particular interest are memory effects whereby the spin glass, after a short-time perturbation, appears to remember its prior state. Furthermore, we measure the distribution of states to study tunneling effects in the system and the predicted square-root relaxation of the magnetization for short times. The goal is to uncover "hole-digging" effects where quantum tunneling can be seen to cut holes in the probability distribution at an associated resonance. Through measurements of the spin glass, we gain a deeper understanding of its free energy landscape and the comparison of classical and quantum transits through the free energy surface.

Exploring Calcium Isotopes Ratios in Urine as a Tracer of Bone Health
Dylan Cleveland
Mentors: Francois Tissot, Rosa Grigoryan, and Michael Kipp

Bone formation favours the incorporation of lighter calcium isotopes over heavier ones, leading to isotopic fractionation. If bone resorption exceeds growth, the isotope composition in bodily fluids shifts to be lighter, which is reflected in the isotopic ratio of urine. This project aims to analyse the calcium isotope ratio ($^{44}Ca/^{42}Ca$) in human urine to explore its potential for bone disease diagnosis. Low pressure chromatography is used to isolate the calcium, and the isotope ratio measurements carried out via MC-ICP-MS. The data generated over summer will allow a preliminary quantitative analysis of population-scale calcium isotope variability across various parameters of interest, including age, sex, diet, and lifestyle. This will give a significant indication of the efficacy of isotope ratios as a diagnostic tool, and guide future project work.

Stability of Shock-Induced Separated Flow (SWBLI)
Kyla Cook
Mentors: Chih-Yung Wen, Jiaao Hao, and Tim Colonius

To optimize aeronautical performance, we must investigate the effects of shock wave and boundary layer interactions, which are observed frequently in practical situations and often become a limiting factor of aeronautical design. Obtaining a base flow allows for us to perform a stability analysis on the flow profile and helps us understand the transition between laminar and turbulent flow in shock induced separated flow. We first performed flow simulations using ANSYS Fluent and extracted a base flow at predetermined flow conditions. Then, we performed a stability analysis of the flow profiles to understand how the stability properties were altered by flow separation. The Navier-Stokes equations were linearized around the obtained base flow, which could then be reduced to an eigenvalue problem by substituting periodic perturbations in the streamwise and spanwise directions, thus creating a problem that could be solved using linear algebra tools.

Enhancing Millimeter-Wave Kinetic Inductance Detector Camera Observations Through Statistical Processing
Sage S. Crystian
Mentor: Jack Sayers

This research focuses on the application of advanced statistical processes to improve the observation capabilities of a long-range telescope located at the Jet Propulsion Laboratory (JPL). The crux of the study involves the utilization of techniques like outlier rejection, data normalization, Gaussian fits, KS tests, and density clustering methodologies such as DBSCAN to precisely distinguish between noise and signal in the observation data.
This project explores how this strategy is likely to enhance the filtering process by ensuring valuable signal data is not discarded as noise. One proposed method was an iterative approach, cycling through the observed map to efficiently identify and distinguish the signal from the noise. We also delve into the potential role of time-ordered data in this context and how an analysis of its effects can improve observations.

Initial results demonstrate our ability to successfully separate signal from noise, suggesting promising implications for the overall observation accuracy of the telescope. These findings have substantial significance in the realm of long-range imaging, particularly pertinent to millimeter-wave kinetic inductance detector cameras designed for imaging through optical obscurants.

This work aims to contribute valuable knowledge to our scientific community, enabling better understanding and utilization of long-range telescopes for more accurate and efficient long-range, terrestrial observations in the future.

LDMX HCal Sensitivity Optimization for Light Dark Matter Search
Patill Daghlian
Mentors: David Hitlin and James Oyang

The upcoming Light Dark Matter eXperiment (LDMX) will probe the largely unexplored MeV to GeV range for stable dark matter (DM). The expected dark bremsstrahlung events will result in either direct DM production or mediator particles decaying into DM. Highly sensitive event rejection using a hadron calorimeter (HCal) constructed of scintillator bars is critical to isolating these otherwise undetectable dark-sector particles. While Titanium Dioxide (TiO_2)-Polystyrene co-extruded bars have been standard with past experiments like Mu2e, we aim to maximize photoelectron readout and sensitivity by exploring the novel use of Barium Sulfate ($BaSO_4$) and Boron Nitride (BN) nanoplatelets, which have shown promise in other fields and applications. We conducted both Monte Carlo and experimental studies to confirm the optimization of the scintillator coating and the use of optical resin around the fiber embedded in the scintillator bars. Since the current literature suggests that nanoplatelet morphology in the paint solvent matrix affects reflectivity, we plan to probe and improve different procedures for making polystyrene and acrylic-based paints, which will translate to nanoplatelet/polystyrene co-extrusion for future LDMX bars.

Tunable RFI Bandstop Filter for the DSA-2000 Analog Front-end
Saren Daghlian
Mentors: Gregg Hallinan, Sander Weinreb, and Kiran Shila

With recent advances in radio frequency imaging and hardware, the possibility of radio telescope arrays consisting of hundreds or even thousands of individual telescope elements has become very real. To this end, designs have begun for the DSA-2000, a 2000-element radio telescope array operating from 0.7GHz-2GHz for several scientific purposes, including full-sky surveys (to be made available in a multi-purpose, open-source format), gravitational wave observations, and deep-field observations; the array's novelty lies in its rapid survey speeds and highly detailed angular resolution. The sheer quantity of telescopes (due to the notable absence of cryogenically-cooled analog hardware) provides a relatively complete, robust view of the sky that ensures minimized back-end computation, primarily limited to Fourier-analysis techniques. Due to local communications in DSA-2000's operational band, radio-frequency interference (RFI) poses a significant threat to the scientific data being collected through the array's vast analog pipeline. Therefore, a bandstop filter will be used to omit these frequencies, thereby maintaining the integrity of collected data while protecting sensitive hardware. Because different sites require unique bandstop frequencies with varying attenuation, generalized bandstop filters have been designed that incorporate voltage-controlled frequency and attenuation control with a sharp notch to minimize effects on signals outside this notch.

mRNA Targets of miRNA-190b in Ovarian Cancer
Sophie Dalfonzo
Mentors: Stefán Sigurðsson and Karen Kristjánsdóttir

MicroRNAs (miRNAs) are short RNA sequences which downregulate or silence genes whose mRNA transcripts are partially complementary to the miRNA. MiRNAs bind to the RNA-induced silencing complex (RISC) and guide it to the target mRNA, where RISC blocks the translation of the mRNA into protein. The Sigurðsson lab previously found that expression of microRNA-190b (miR-190b) correlates to a higher survival rate in Luminal A estrogen receptor-positive breast cancer patients. Through immunoprecipitation experiments, they have shown that miR-190b interacts with, among others, the mRNA for the RFWD3 protein; lower levels of RFWD3 also correlated to a higher survival rate in patients. Interestingly, the group found that higher levels of miR-190b correlate to lower survival in ovarian cancer patients. This suggests that miR-190b may function differently in ovarian cancer cells than in breast cancer cells. To investigate this, we transfected two ovarian cancer cell lines with a biotin-labeled oligonucleotide mimicking miR-190b and performed immunoprecipitation to extract the mRNA associated with the miR-190b mimic. In the future, this miRNA can be aligned to the human transcriptome, and targets found through this method can be confirmed with Western blot analysis and luciferase assays.

Linking Structure and Function at Synapses in the Visual Cortex
Anwesha Das
Mentors: Michael Hausser, Arnd Roth, Jan Funke, and Shinsuke Shimojo

Connectomics is an approach for establishing the "wiring diagram" of synaptic connections in the brain. It offers crucial insights into how neural circuits are structured and how they work. Conventional methods in connectomics aim to unravel how these connections are structured. However, circuit structure by itself is not sufficient to understand their function – we also need to know the strength and activity of synapses. The host lab has been working on a novel method that combines functional synaptic labeling in vivo, focused ion beam scanning electron microscopy (FIBSEM), and machine learning-based segmentation to quantify the strength and activity of synapses.

During my SURF, I worked on adapting and developing machine learning tools using convolutional neural networks (CNNs) to segment photoconverted vesicles in 3-dimensional images acquired using FIBSEM. Once the pipeline was robust enough, I worked on choosing appropriate subvolumes for training and validation, generated ground-truth datasets by manually labeling aforementioned volumes, trained models using this data, and ran predictions. I iterated this process for three separate (large) datasets.

This project has the potential to further our understanding of how neural circuits operate in vivo and to introduce useful new tools for functional connectomics.

Bacterial Trait Prediction From Gappy Data
Progyan Das
Mentors: Ashish Mahabal and Nitin K. Singh

Next-generation sequencing technologies have resulted in a rapid expansion of biological data, requir- ing new computational tools for analysis and reporting. At JPL, a variety of biological data is collected from spacecraft-associated environments and organisms, including NSA-culture-based, MALDI (mass spec), and multi-omics analysis. This data is used to understand spacecraft cleanliness and quantify biological contamination (bioburden) for Planetary Protection purposes. However, there is currently no technology or tool that harmonizes the diverse data types for bioburden estimation, a critical need in the field.

Machine Learning (ML) programs can be used to predict bacterial traits using data scraped from resources like BacDive. BacDive is a bacterial metadatabase that provides strain-linked information about bacterial and archaeal biodiversity. The database contains different types of metadata in- cluding taxonomy, morphology, physiology, environment, and molecular-biology, with data manually annotated and curated. As of December 2022, BacDive offered information for 93,254 strains, includ- ing 19,313 type strains. The data in BacDive are divided into categories like "Name and taxonomic classification", "Morphology", "Culture and growth conditions", "Physiology and metabolism", "Iso- lation, sampling and environmental information", among others. The database can be accessed either via a GUI or via the RESTful web service. Software clients in Python and R are available to support the use of the API.

However, in a vacuum, these ML algorithms result in faulty predictions due to the nature of the data – general data imbalance that does not reflect the availability of bacteria in nature, the often confusing nature of the data gathered from BacDive, etc, result in unusable results from simply passing the data through a classifier. Therefore, a systematic study of the data has been done to ensure that domain knowledge is integrated into our pipeline.

All of this has been packaged into an easy-to-use CLI called predictContamination that allows users to scrape BacDive, pass contamination information, and generate contamination scores based on pre-baked heuristics or custom values. This is followed by a thorough study of various statistical models on the data, where we achieve an accuracy of over 94% in some cases, with strong gener- alizability scores. We believe this is the first statistical bacterial classification work done at this scale.

VorGLEAM: Enabling Large-Scale Robust Accelerated MRI Reconstruction With Greedy Consistency Learning
Soham Dasgupta
Mentors: Shreyas Vasanawala and Elena Mantovan

Magnetic Resonance Imaging (MRI) \cite{carmo2023automated} is a vital tool in medical diagnostics, yet accelerated image reconstruction remains a challenge. Recent advances in deep learning \cite{DBLP:journals/corr/HammernikKKRSPK17} \cite{DBLP:journals/corr/SchlemperCHPR17} have shown promise in addressing this challenge, but there is a need for methods that are robust, efficient, and can generalize across various perturbations. In this work, we introduce VorGLEAM, a novel approach that synergistically combines the strengths of Vortex \cite{desai2022vortex} and GLEAM\cite{ozturkler2022gleam} methodologies for optimized MRI reconstructions. By leveraging the consistency training from Vortex and the greedy optimization of unrolled networks in GLEAM, VorGLEAM delivers reconstructions that surpass the performance of its parent models. Experimental results confirm the superiority of VorGLEAM in terms of key metrics such as SSIM, nRMSE, and PSNR. Furthermore, our approach demonstrates robustness against common MRI perturbations and offers a new paradigm in MRI image reconstruction that has the potential to advance clinical diagnostics.

Lung-on-a-Chip Device to Access the Effects of Inhaled Nitric Oxide on Hospital Acquired Pneumonia
Maya de Luis
Mentors: Lorenzo Berra, Ellen Rothenberg, and Hatus Wanderley Vianna

A lung-on-a-chip is a novel microfluidic device that offers an *in vitro* approach to studying and experimenting in the environment of a lung. It simulates the alveolar-capillary interface found in human lungs. This interface is the principal site of respiration and serves as a barrier between air and blood. In the chip, there are two chambers with a thin, porous poly(dimethylsiloxane) (PDMS) layer separating them. The first chamber mimics the environment inside the alveolar with a layer of epithelial cells and air flowing through it. The second chamber mimics the environment inside the capillary with a layer of endothelial cells and blood flowing through it. The chip simulates the mechanical movement of the lung during inhalation by stretching. The primary goal of this project is to build a working lung-on-a-chip device using PDMS and human epithelial and endothelial cells. Inhaled Nitric Oxide (iNO) has been shown to decrease bacterial count in the lungs of patients with hospital acquired pneumonia (HAP) and other lung infections. However, the effects of high dose iNO on HAP has yet to be studied in a clinical environment due to the unknown hazards of the high concentrations of iNO. The lung-on-a-chip device provides a way to experiment with high dose iNO to access its effects and any hazards.

A Globally-calibrated Hillslope Routing Model Based on Recurrent Neural Networks for Use in Land Surface Models
Mauricio De Moura Lima
Mentor: Tapio Schneider

Recurrent neural networks (RNNs) are powerful tools for transforming observed precipitation into streamflow. Calibration of such a model in the continental United States, using a Long-Short-Term-Memory (LSTM) RNN, demonstrated that a single set of parameters can be used across basins for predicting streamflow, and that LSTMs can outperform physical models when those physical models are not tuned for specific basins. In this work, we extend this LSTM model in two ways: by using instantaneous runoff calculated from physical models as mass input on the network (instead of precipitation), and by extending the training data, training, and testing of the model to basins across the world. The resulting hillslope-routing model can then be integrated into Land Surface Models (LSMs), which often require runoff to be separated from precipitation in order to track the soil moisture content. By using a vectorized map with timeseries driven by reanalysis, we can perform world-wide calibrations and global simulations, outperforming existing global physically based models in commonly used scores in hydrology.

Analysis of Bacterial Genome Content Diversity Through Structural Studies of ClC Chloride Channel Homologs
Lily K. DeBell
Mentor: William M. Clemons, Jr.

The unreliability of membrane protein expression in recombinant systems is a persistent issue for structural studies of membrane proteins. Although membrane proteins are advantageous therapeutic targets, there are fewer solved structures of this group than of soluble proteins due, in part, to poor expression. Previous studies established that the amino acid sequence of first transmembrane helices varies widely across bacteria in a manner corresponding to genomic GC content, which may hinder recombinant expression. We expanded on this observation to demonstrate that the amino acid composition of the total proteome changes with genomic GC content. Using ClC chloride channels as our model protein group, we found that the canonical residues of the chloride binding site lack broad conservation in homologs sourced from genomes spanning the range of known GC content. Further, we explored the prevalence of helix packing motifs in ClC homologs, concluding that helix packing motifs are more prevalent in proteins from higher GC genomes. We continue to apply structural and biochemical methods to ClCs to assess the consequences of differential patterns of amino acid usage on membrane protein structure and function.

Analyzing Sensitivity of an Atmospheric Circulation Model to Stability Functions in Monin-Obukhov Similarity Theory
Gerard Decker
Mentors: Tapio Schneider, Akshay Sridhar, and Lenka Novak

The Monin-Obukhov Similarity Theory permits computation of atmospheric turbulent surface fluxes by modifying flux-gradient equations using universal stability functions to account for different atmospheric static conditions. These non-dimensionalized height functions allow the recovery of mean temperature and wind profiles, as well as surface fluxes near the atmospheric surface boundary layer. These recovered surface fluxes are then utilized as boundary conditions for atmospheric, land, and ocean models. Different formulations of these stability functions have been proposed in early literature, each suitable for particular terrain, but have yet to be rigorously tested in a computational model. In this project, we investigate the performance of six different stability function formulations in CliMA's Earth System Model through metrics such as mean temperature structure, jet strength and latitude, eddy covariances, and precipitation. Sensitivity analyses with data from observational campaigns and reanalysis data reveal minor differences in the relative performance of the stability functions.

Machine Learning Acceleration for Astronomical Events Using Field Programmable Gate Arrays (FPGAs)
Catherine Deng
Mentor: Matthew J. Graham

Modern astronomy is facing an increasingly large amount of data, and the computational challenge of quickly processing this data presents a significant challenge for astronomers. Machine learning algorithms can now efficiently analyze these massive datasets and detect rare events with high accuracy, however the latency is still too high. We aim to accelerate our ML models by deploying them to FPGAs; to do so, we will take existing deep learning algorithms that classify transient alerts developed for the Zwicky Transient Facility (ZTF) and port them to run on a FPGA using the hls4ml Python compiler. In particular, we will run **braai**, real/bogus CNN classifier, on a PYNQ-Z2 FPGA. We present the results of an optimized and compressed version of **braai** that has 4.4k trainable parameters, compared to the original 312k. On the PYNQ-Z2, our adapted model averages 520 inferences per second, which is over ten times faster than a standard CPU and 1.5 times faster than a USB Edge TPU accelerator. These results demonstrate the potential of FPGAs in enabling comprehensive and efficient astronomical data processing.

Joint Sensitivity Map Estimation and Image Reconstruction for MRI Using Neural Fields
Zijun Deng
Mentors: Katie Bouman and Zihui Wu

Magnetic Resonance Imaging (MRI) is a crucial diagnostic tool in modern medicine, providing detailed internal images of the body's structures. However, the physics of the data acquisition process poses challenges to MRI image reconstruction. Parallel Imaging is an advanced medical technology that uses multiple receiver coils to concurrently acquire data from different parts of the imaging region, which significantly reduces the acquisition time while introducing coil sensitivity to the MRI reconstruction problem. In our project, we aim to train a specialized, end-to-end coordinate-based model for each MRI image to predict the pixel value and coil sensitivity simultaneously. By applying a Poisson mask on MRI measurements, we aim to simulate Compressed Sensing applied in the MRI data acquisition process. We also integrate the model with the idea of Neural Fields to learn from frequency information, thereby improving the quality of the reconstruction image. We hope to facilitate MRI image reconstruction and improve medical diagnostics with our approach.

SQUID Noise Spectroscopy: Designing Superconducting Qubits for Environmental Flux Noise Measurement
Alexander Deters
Mentors: Oskar Painter, Andreas Butler, and Gihwan Kim

Superconducting quantum interferometry devices (SQUIDs) have long been used for designing superconducting qubits with flux dependence. While primarily employed for in situ parameter tuning, these components have also been shown to make superconducting circuits effective tools for flux noise spectroscopy. This project aims to design an experimental setup wherein several tunable qubits, each with distinct SQUID geometries, are used to achieve accurate measurements of the environmental flux noise—distinct from local noise sources such as fabrication defects and atomic spins. To this end, we produce a fabricatable design for an eight-qubit quantum computer optimized for this measurement. Additionally, we introduce PySon, a Python library capable of automating design processes in the electromagnetic simulation software Sonnet. PySon's automation of design, simulation, and post-processing tasks enables the creation of a physically informed procedural generator for metamaterial Purcell filters. This generator is then applied to mitigate extraneous noise in our design.

Identifying the Role of Arp6 and H2Av in piRNA Cluster Biogenesis
Curtis DeVerinne
Mentors: Katalin Fejes Toth and Norbert Andrasi

The short, non-coding RNA class, PIWI-interacting RNAs (piRNAs) primarily act to protect from dysregulation of transposable elements (TEs) with support from the Piwi clade of Argonaute proteins in silencing and biogenesis. These RNAs are generated from dual-strand genomic clusters in the germline of *Drosophila*, characterised by Rhino-Deadlock-Cutoff (RDC) complexes bound to H3K9me3 chromatin marks. Although Rhino, an HP1 homologue, binding facilitates complex recruitment and read-through for piRNA precursor transcription, the ubiquitous presence of H3K9me3 marks and HP1 proteins leaves the unspecific mechanism of piRNA biogenesis incomplete. Therefore, we are using a series of biochemical and imaging techniques on mutant *Drosophila* ovaries to investigate our hypothesis that candidate proteins Arp6 and/or H2Av act as a 'bridge' between Piwi and Rhino to direct piRNA cluster biogenesis. Arp6 is a component of the DOM-B chromatin remodelling complex which replaces histone H2A with a repressive, H2Av, variant in *Drosophila*. Preliminary studies promisingly demonstrate interactions between Arp6 and Piwi, while disrupted Rhino localisation has been observed in H2Av mutant ovarian germ cells. Establishing a canonical interaction can be furthered by investigating additional interactions of Arp6/H2Av with the piRNA system and can inform research on mechanisms of generating specificity from diverse readers of epigenetically interacting systems.

Score-Based Diffusion Models for Photoacoustic Tomography Image Reconstruction
Sreemanti Dey
Mentors: Katherine Bouman and Berthy Feng

Photoacoustic Tomography (PAT) is a low-cost, diversely applicable and relatively radiation free medical imaging technique [6]. One part of the PAT process is the reconstruction of the image itself from the signals that the process acquires, and there are three major ways to do the reconstruction. The most feasible method is model-based, which uses a model matrix to invert the measurements into the image [3]. In this work, we will use score-based diffusion models to solve the inverse problem of reconstructing the image from PAT measurements, creating a comprehensive and fast end-to-end pipeline for the process that is robust under varying

Implementing Nonlinear Control in a Classical Experiment to Reduce Measurement Noise
Andrei C. Diaconu
Mentor: Rana X. Adhikari

A central problem in control theory is that most of the field focuses on linear controllers, even though most of the systems we are aiming to control are nonlinear in nature. To circumvent this issue, control theory aims to approximate the behavior of the nonlinear system around the desired mode of operation by a linear function. This unfortunately creates a theoretical limit on the performance specification of the linear as it tries to control a nonlinear system with a linear control law. We aim to show that this limitation can be overcome with a nonlinear controller based on Reinforcement Learning (RL) methods. As a proof of our concept, we aim to implement the RL-based controller in a purely classical experiment: temperature stabilization of a test mass. Moreover, we explore the possible implications of such a nonlinear controller in the field of quantum mechanics and non-classical experiments, where nonlinearities can be encountered even in the vicinity of the desired setpoint/mode of action of the system, exacerbating the need for a controller that can manage such nonlinearities.

Modeling the Aging Eye: A Matlab Based Analysis of the Geometric Properties of the Zebrafish Eye
Marama Diaz-Asper
Mentors: Paul Donaldson and Justin Bois

As the aging population grows across the world, so do optic-based issues such as Presbyopia. In an effort to slow and treat the effects of optical ailments, research into how the geometry of various components of the eye, with the species zebrafish as a model, has been conducted. This project presents a matlab software which cleans, corrects, and analyzes components of the eye from an optical coherence tomography imaged zebrafish. This includes lens curvature, retinal thickness, and more, all as influenced by different refractive indices per component of the eye. From this, research can be conducted into the movement of the lens nucleus over time, as well as geometric changes in the eye as one ages. This will provide a necessary basis and tool for further research into the mechanisms of the aging eye.

Joint Optimization of Data Sampling and Reconstruction for Dynamic MRI Data
Andy Dimnaku
Mentors: Shreyas Vasanawala, Cagan Alkan, and Mikhail Shapiro

Magnetic resonance imaging (MRI) is a powerful diagnostic imaging technique, however it is limited by the long acquisition times. To shorten the acquisition times, MRI data is undersampled by reducing the number of spatial frequency (k-space) measurements. This requires using advanced reconstruction techniques, such as deep neural networks, that produce high fidelity images without artifacts. However, the sampling patterns used for undersampling MRI data are typically chosen heuristically. Recently developed techniques proposed joint optimization of data sampling and reconstruction for static MRI acquisitions, taking into account only the spatial redundancies. In this proposal, we extend the joint data sampling and optimization framework to dynamic MR imaging where the data is acquired in k-t space that includes an additional temporal dimension. Our aim is to find sampling patterns that explore spatiotemporal redundancies across a wide range of acceleration factors. The proposed process involves representing the data sampling with a non-uniform FFT and then using an unrolled neural network consisting of spatial and temporal convolutions to reconstruct the final dynamic MR images. On a dataset consisting of 2D+time abdominal scans, our optimized sampling patterns show improved image quality compared to the traditionally used variable density sampling patterns. Our findings highlight the importance of joint learning of data sampling and reconstruction for dynamic MRI and provide insights about designing k-t sampling patterns.

Discovering Planetary Nebulae With the Census of the Local Universe Hα Emission Line Survey
Rong Du
Mentor: Shrinivas R. Kulkarni

Planetary nebulae serve as crucial windows into the late-stage evolution of low- to intermediate-mass stars and the ionization and refill of the interstellar medium. Modern discoveries of these nebulae primarily stem from extensive Hα surveys. In this study, we harness data from the Census of the Local Universe Hα emission-line survey to uncover new planetary nebulae, assessing the viability of this approach. We validate our method by cross-referencing with an INT Photometric Hα Survey catalog of known planetary nebulae in the northern Galactic plane, based on rediscovering these sources through careful, rigorous, visual scrutiny of photometric images in our survey. Results show that out of the 317 true, 49 possible, and 76 likely planetary nebulae identified in previous studies, our investigation rediscovers 329 obvious, and 97 perceptible sources while encountering 4 undetectable sources and 12 sources with imaging issues. This pilot project successfully demonstrates the potential of conducting planetary nebula searches across the entire sky, particularly extending beyond the confines of the Galactic plane.

Estimating Stability Function Formulation With Ensemble Kalman Inversion
Wilson Duan
Mentors: Tapio Schneider, Akshay Sridhar, and Lenka Novak

The goal of the CliMA research group is to develop a Julia-language Earth System Model (ESM) capable of modeling intricate and detailed processes in a wide variety of conditions across the globe. In order to model the Earth's atmosphere accurately, it is necessary to quantify turbulent surface fluxes induced by flows that cannot be simulated directly. These fluxes represent the exchange of quantities such as momentum, heat, and moisture between the surface and the atmosphere. Surface fluxes, which are parametrized through the Monin-Obukhov Similarity Theory (MOST), are highly dependent on profiles such as wind, heat and moisture in the atmospheric boundary layer. MOST expresses wind and heat profiles in terms of stability correction functions, MOST stability functions are derived empirically from observational data from sources such as SHEBA. Because the stability functions' parameters may vary from dataset to dataset, it is necessary to estimate these parameters in a general way given observational data. In this paper, we perform parameter estimation with the Ensemble Kalman Inversion (EKI) process with Julia, employing the CliMA-developed packages EnsembleKalmanProcesses.jl and SurfaceFluxes.jl. In doing so, we evaluate the efficacy of the EKI algorithm in the context of MOST.

Studying the Explosions of Intracluster Stars
Ujjawal Dugar
Mentors: Shrinivas Kulkarni and Yu-Jing Qin

Intracluster Light (ICL) is a luminous component of galaxy clusters, composed of stars gravitationally bound to the cluster potential but not associated with individual member galaxies. ICL is useful for understanding the evolution of galaxy clusters but directly studying it is challenging due to its low surface brightness, making accurate measurements elusive. To overcome this, we propose an approach using supernovae (SNe), which are highly luminous, as tracers to probe ICL properties and mass fraction. The Zwicky Transient Facility Bright Transient Survey (ZTF BTS) provides a suitable database of SNe for the analysis, which overcomes problems encountered in the past, including limited sample sizes and selection biases.

Our objectives include identifying and characterizing ICL SNe, comparing them with cluster-member-hosted and field SNe, and estimating the ICL stellar mass fraction. Through subtype distributions, peak luminosities, and light curve shapes of different SN samples, we aim to gain insights into the stellar population properties of ICL and its role in shaping the evolution of galaxy clusters over cosmic time. Additionally, we are developing a method that could be used for identifying host galaxies for any SN dataset.

Exploring an Attention Based Alternative to Skip Connections in Deep Neural Networks
Zack Dugue
Mentor: Georgia Gkioxari

Skip Connections have been ubiquitous in deep neural networks since their inception in the ResNet architecture (He 2015). However, their relatively simple structure means that they have limited expressivity when compared to the standard feed forward approach that preceded it. we propose an architecture which uses Query Integrated Memory Interfacing Attention (QIMIA) as a middle ground between fully connected networks, and standard skip connections. QIMIA is an attention-based approach which uses learned queries to attend to the outputs of prior layers in order to construct the inputs to each layer. We evaluate QIMIA architectures against skip connection based architectures on both vision and language tasks, and find inferior performance when compared to standard skip connection Architectures.

Channel Selection for Feature-Extracted Data From Microelectrode Array Brain-Machine Interfaces
Lynn Feng
Mentors: Azita Emami and Benyamin Haghi

Implantable microelectrode arrays are a type of brain-machine interface consisting of hundreds of electrodes, each transmitting a channel of neural data to be decoded into instructions. The quality of data varies between channels, and changes over time. Currently, we are feeding all channels to our decoder, but this approach is inefficient. Channel selection could enable the elimination of all but the top channels, improving the efficiency of decoding without sacrificing accuracy. In this project, we explored different architectures for channel selection algorithms. We developed binary good/bad classifiers for post-feature-extraction neural data, based on set-length segments of feature-extracted data from individual channels, which are labeled "good" or "bad" depending on the performance of a linear decoder trained on just those channels. We compared the effectiveness of several high-performing algorithm designs, including: gradient boosting, support vector machines with linear and RBF kernels, and fully connected networks. Currently, we have achieved an accuracy of 81% overall and 60% for good channels only. We will continue to evaluate more algorithms, and explore methods of improving performance, with the goal of designing a robust, accurate channel selector which proves effective on future days and with new patients.

Analysis of the Higgs Boson Pair Decay Channel in Final States With Two Bottom Quarks and Two Photons in Proton-Proton Collisions in CMS at the Large Hadron Collider
Elizabeth Field
Mentors: Harvey Newman and Irene Dutta

The Higgs Boson is a major element of the Standard Model Theory of particle physics, as it is responsible for the mass of every fundamental particle and explains the breaking of electroweak gauge symmetry. In order to understand it, we must study its production mechanisms and decay modes. In particular, we aim to do this through constraining the trilinear self-coupling constant, as the potential of the Higgs Field is theorized to be dependent on only that and the mass of the Higgs Boson itself. In order to do this, we perform γ reconstruction through a combination of machine learning techniques trained on simulated proton-proton collision events that include two Higgs Bosons decaying to two bottom quarks and two photons ($HH \rightarrow b\bar{b}\gamma\gamma$), under the CMS detector and LHC conditions experienced by the experiment in 2017. We then use this data, in combination with data from the quantum chromodynamics (QCD) background, to identify and reconstruct these di-Higgs to bb-bar gamma gamma events, improve current methods of reconstruction, selection, and background suppression, and improve upon and determine final efficiencies for signal and background through machine learning based classifiers using different weightings and combinations of the kinematic variables describing these particle collisions.

Characterizing the Influence of Ascarosides on *Ins-6* Expression in ASJ
Nerissa Finnen
Mentors: Paul Sternberg and Mark Zhang

Understanding how organisms make decisions in response to multitudes of sensory cues is fundamental for expanding the knowledge of organism behavior. In *Caenorhabditis elegans* interest for uncovering the mystery behind the behavioral stress induced alternative developmental stage (dauer) is abundant. Recent findings show that the ins-6 gene is essential in exiting dauer. However, the process can be impeded by stress; the principal factor being pheromone and its chemical molecules (ascarosides). The aim of the project is to illuminate the effect of individual ascarosides on dauer exit. To do so, *C. elegans* are exposed to the individual ascarosides upon exit. Through fluorescence tagging of the *ins-6* genes in the ASJ neuron it is then possible to quantitatively measure gene expression to determine exit efficiency. At increased concentration of ascarosides, the *ins-6* expression after exit was greatly diminished compared to unexposed nematodes. This followed behaviorally, as exposed *C. elegans* exhibited typical dauer traits, like reduced movement and coiled resting positions. The results characterize the effect of the ascarosides on the *ins-6* gene and the behavior of the nematodes that fall in line with existing knowledge. A possible next step would be to ablate genes in *C. elegans* to verify what was observed.

Custom Fluxmeters for CO_2 Degassing Analysis
Kayleigh Fischer
Mentors: Joann Stock and Alexander Berne

Studying CO_2 degassing, the process where CO_2 is released from the earth's mantle or crust, allows scientists to discern locations and properties of subsurface fault systems, as more gas is often present in tectonically active areas. By measuring these aboveground CO_2 levels with specialized devices, scientists can accurately pinpoint these areas. However, while commercial equipment created to measure these gas levels in the field does exist, these devices, called fluxmeters, are expensive (approx. $20,000 per unit) and therefore not readily accessible for widespread use. The purpose of this project is to create relatively inexpensive, yet efficient versions of these fluxmeters to make the equipment more accessible to scientists in the field. These customized fluxmeters use cheap, off-the-shelf materials. They are also simple to use, and easy to manufacture. Because of the ease of production and simple usability, these fluxmeters are perfect for smaller labs or student projects with less funding who can't afford the commercial devices. In addition, being cheaper to manufacture means more units can be produced, increasing the number of devices in the field. With more devices, more measurements can be taken, increasing speed and accuracy.

Beyond Standard Model Theories and Analyses of Leptoquark Couplings to τ Leptons and Bottom Quarks in Proton-Proton Collisions at the CMS Experiment
Ania Freymond
Mentor: Harvey Newman

The strong CP problem, the pattern of particle masses, neutrino oscillations and the matter-antimatter asymmetry in the universe are only but a few of the fundamental questions that remain unanswered by the Standard Model (SM) of particle physics, in spite of its past successes. This has led to the elaborations of many Beyond Standard Model (BSM) theories. Hints of differences from SM predictions have notably emerged in measurements of semileptonic B hadron decays that could reveal Lepton Flavour Universality Violation (LFUV). Models that propose the existence of a new class of particles called leptoquarks (LQ), hypothetical colour-triplet bosons, are strongly motivated as a possible explanation as they could provide insight on the three-generation hierarchical mass pattern, the underlying connection between quarks and leptons and explain the observed flavour symmetries. The latest LHC Run 2 search by the CMS Collaboration has shown an interesting excess of 2.8σ in certain channels involving τ leptons but not the b-quark + τ signatures as expected in the models, which has further motivated new physics searches, including this project. After reproducing the Run 2 analysis, this project will focus on improving the analysis of this excess for LQs using a joint Run 2 and 3 dataset with new Machine Learning techniques, and will generalize the analysis to search for other possible new physics signatures, with an emphasis on new particles that couple preferentially to third generation τ leptons. This will further be accompanied by a side focus on ameliorating the identification efficiency of hadronic tau (τ_h) decays, while further suppressing the jet backgrounds. This will be accomplished by shifting the measurements from an event-by-event basis to a jet-by-jet one. An additional strong motivation arises from the longer-term goal of better understanding the implications of the existence of leptoquarks in BSM theories such as the Pati-Salam or Georgi-Glashow Grand Unified Theories (GUTs).

Physics-Informed Neural Networks for Modeling Slow Slip Events in a 2D Fault
Rikuto Fukushima
Mentor: Jean-Philippe Avouac

The episodic transient fault slips called slow slip events (SSEs) have been observed in many subduction zones. These slips often occur in regions adjacent to the seismogenic zone during the interseismic period, making monitoring SSEs significant for understanding large earthquakes. Various fault slip behaviors, including SSEs and earthquakes, can be explained by the spatial heterogeneity of frictional properties on the fault. Therefore, estimating frictional properties from geodetic observations and physics-based models is crucial for fault slip monitoring. We propose a Physics-Informed Neural Network (PINN)-based new approach to simulate fault slip evolution and estimate frictional parameters from observation data. PINNs, which integrate physical laws and observation data, represent the solution of physics-based differential equations. In the previous study, a PINN-based approach was applied to a simple single-degree-of-freedom spring-slider system to model SSEs. In this study, we applied this method to a 2D fault model and validate its effectiveness in a forward problem. We successfully reproduced the spatio-temporal evolution of SSEs and this result indicates the significant potential of PINNs for simulating slow slip events in a 2D fault model.

Mousify: Fast Structure Calculation for Thermostability Validation
Jessie Gan
Mentors: Steven Mayo and Lucas Schaus

Antibodies are valuable therapeutics that require humanization for drug viability. Computational humanization models often generate large libraries of antibody sequences, which can be further improved with thermostability validation. To obtain more accurate thermostability calculations, researchers often make use of the protein structure as an input to their scoring functions. While recent advances in *in silico* methods of structure prediction have increased accuracy to investigate protein properties, the most accurate structure prediction model, AlphaFold2, is not computationally viable to structurally validate protein sequence libraries on the order of millions. To accelerate the calculation of reliable antibody structures for these libraries, we combine Alphafold2 with homology modeling software, Promod3, for unknown, but closely related, structures. Our hypothesis is that homology modeling based on an AlphaFold2 template of a highly related structure is reasonably similar to an AlphaFold2 structure of the query sequence, orders of magnitudes faster, and near-indiscernible in thermostability calculations. Currently, the AlphaFold2 generated cluster representatives have been successfully calculated, and we find generally well modeled domains and distinct structural differences. We continue to train a classifier for identifying query sequence cluster membership, and are currently experimenting with various embeddings and models to improve performance.

Decoding Transcriptional Regulation: Measuring RNA Interactions in the Nucleus
Tanvi Ganapathy
Mentors: Mitch Guttman and Andrew Perez

The 3-D structure of the nucleus as well as the interactions between nuclear nucleic acids and proteins is key to understanding how differential transcription leads to different cell types and states. Traditional methods, such as Chromatin Immunoprecipitation (ChIP), are limited to testing a single protein per experiment. Previous work includes designing experimental protocols, such as RNA/DNA SPRITE and ChIP-DIP, to multiplex the measurement of protein and nucleic acid interactions in the cell. These methods rely on building a barcode by attaching multiple tags to crosslinked molecules through the split-and-pool method which is then sequenced to match associated proteins and nucleic acids. Currently, these tags are attached to the end of DNA molecules, but unfortunately, is it more difficult and less accurate to use the same method for RNA. An alternate method is to use DNA probes to detect RNA and perform tag extension on the DNA probes using the established protocol. As such, here we present a proof-of-concept experiment using DNA probes designed with the OligoMiner method to show whether DNA probes can be used to detect the transcription level of mRNA and nascent RNA in K562 cells.

Analyzing Metal Carbonate Sorbents for Point Source Carbon Capture
Genevieve Gandara
Mentors: Melany Hunt and Leopold Dobelle

In the United States, greenhouse gas point source emitters, such as power plants, refineries, and coal and gas facilities, emit over 3 gigatons of carbon dioxide, or approximately 50% of the country's CO_2 emissions. Flue gas emitted by these sources contains high concentrations of CO_2 (~ 5-15%), which can be captured directly at a high efficiency through point source capture. The current state-of-the-art method for carbon capture at the industrial scale uses amine-based solvents, but these are toxic and corrosive. In this project, we study metal carbonate sorbents, which are less expensive and non-toxic alternatives. Sorbents were prepared using the methods of extrusion and spheronization. Experiments were conducted in a fixed bed reactor with a nearly saturated gas stream. Our most promising sorbent is potassium carbonate, which absorbs over 99% of CO_2 in a C10 gas stream (90% Ar and 10% CO_2). Regeneration was also explored, but a K_2CO_3 sorbent which can be regenerated to its full capacity is yet to be found. The other constituents of the sorbent include binders and other absorbent materials such as $Ca(OH)_2$, $CaCO_3$, and starch. Different combinations of these constituents were tested to find a sorbent that is regenerable, does not burn at high temperatures, has a high surface area, and has good mechanical structure.

Analyzing Large-Scale Circulation in the CliMA Aquaplanet Simulation and Its Sensitivity to SST and Resolution
Kahaan Gandhi
Mentors: Tapio Schneider and Zhaoyi Shen

We use aquaplanet simulations to examine atmospheric circulation in an idealized climate. These numerical models represent an Earth-like planet covered entirely by water, simplifying topography and radiation to study the hydrosphere and atmosphere in isolation. Though conditions are simplified, these simulations maintain the physical complexity of their global climate model counterparts. We evaluate how the atmospheric circulation responds to changes in sea surface temperatures (SST) and model resolution. We force the model with zonally symmetric and zonally asymmetric sea surface temperatures and vary the horizontal and vertical resolution of the model. Since the aquaplanet is purely theoretical, simulated outputs cannot be compared against real-life observations. To establish a comparative framework, we cross-analyze results across a diverse suite of aquaplanet simulations, each uniquely forced. This experimental approach can be used to examine the sensitivity of convective parametrization that models the dynamics of turbulence, convection, and clouds. Our numerical investigation targets linear and nonlinear responses to these perturbations, and our analysis focuses on zonal mean changes in atmospheric circulation. This project advances CliMA's mission to reduce climate prediction uncertainties with a robust, scalable, open-source model.

Numerically Consistent Data-Driven Subgrid-Scale Model for Large-Eddy Simulation
Michael Lawrence Garcia
Mentor: H. Jane Bae

In this work, we train a data-driven subgrid-scale (SGS) model for large-eddy simulation (LES) which incorporates numerical error arising from the LES equations. LES solves the low-pass filtered Navier-Stokes equations while using a model for unclosed SGS terms. The typical approach for generating data-driven closure models in LES computes required SGS terms using a filtering operator on direct numerical simulation (DNS) data. Recent research highlights that the numerical error between the derivative and filter operators is comparable to the modeling error of traditional SGS models. We develop an artificial neural network (ANN) trained on both filtered DNS data and computed commutation error to act as a numerically consistent closure model in LES. We develop an artificial neural network (ANN) trained on both filtered DNS data and computed commutation error to act as a numerically consistent closure model in LES for forced isotropic turbulence. Our goal is to create a high fidelity SGS model for LES which can adapt to different numerical methods in computational fluid dynamics solvers. We discuss the details of the LES model and the training process.

Variational Methods For Gradient Flows in Riemannian Manifolds Using Partitions of Unity
Ricardo Garcia
Mentors: Yakov Berchenko-Kogan and Melany Hunt

Discrete differential geometry is a growing field of research with applications in fields such as physics, computer graphics, and robotics. We develop a variational method to compute curve shortening and curve straightening flows on arbitrary Riemannian manifolds. Curve shortening flow and curve straightening flows are examples of geometric flows, where every point in a curve moves with a velocity to minimize a quantity associated with the curve, thus making the curve as a whole change over time. Previous work focuses on methods for Riemannian metrics that are conformally flat, and we aim to extend this to arbitrary Riemannian metrics. Moreover, we used partitions of unity to develop algorithms to evolve curves in Riemannian manifolds constructed from multiple charts, something not previously seen in the literature. This allows us to simulate flows of curves that span multiple charts, such as noncontractible loops in tori.

Investigating Subsidence Associated With Anthropogenic Activity Over Riyadh Using InSAR
Jabri Garcia-Jimenez
Mentors: Charles Elachi and Yuan Kai Liu

This project aims to search for subsidence associated with anthropogenic activity over Riyadh, Saudi Arabia. This is achieved using Interferometric Synthetic Aperture Radar (InSAR), a method used to measure land deformation over time and large areas with accuracy by using radar signals from Earth-orbiting satellites.
Advanced Rapid Imaging and Analysis Sentinel-1 Geocoded Unwrapped Interferograms (ARIA S1 GUNW) are interferometric products generated by the JPL ARIA project. ARIA-tools, an open-source package in Python, is used to download the products and extract data and meta-data necessary for time-series analysis. MintPy, another open-source package in Python, performs time-series analyses and reads the stack of interferograms and produces three dimensional (2D in space and 1D in time) ground surface displacement in line-of-sight direction. By looking at annual and secular decomposition of the time series subsidence can be searched for by superimposing the deformation maps (and decorrelation maps) on optical imagery within Google Earth.

Developing a Python Package for Fitting Late Time Light Curves to Disk Dominated TDEs
M Gardner
Mentors: Fiona Harrison and Edward Nathan

A Tidal Disruption Event (TDE) occurs when a star closely approaches a supermassive black hole and is ripped apart by a large difference in gravitational force on its near and far sides. The debris of the star then forms an “accretion disk” which orbits the black hole and releases radiation as it falls inward. A python package, FiTeD, models the evolution of the radial temperature and density profiles of these disks over time to calculate their expected lightcurves in a many wavebands. The package implements statistical methods like MCMC to fit these models to late-time multi-band observations of TDEs. With the public release of FiTeD, many TDEs may be studied to understand the statistics of the underlying physical parameters and therefore to understand both the physics behind TDEs and black hole accretion disks in general. It will enable the use of TDEs to sample the underlying mass population of supermassive black holes. We present how we improved the data handling and overall structure of the code, and initial results using the package to analyze TDEs with SWIFT X-Ray and UV data to find their physical parameters and compare the models.

Robust Warming in the Deep Indian Ocean
Miles Gee
Mentor: Jörn Callies

The accumulation of anthropogenic greenhouse gasses in the atmosphere is expected to not only warm the surface climate but also the deep ocean. Recent observations that make use of seismically generated sound waves propagating across the Indian Ocean show decadal warming trends, but it is unclear whether this is a forced signal or natural variability. This distinction can be made in large ensembles of climate model simulations such as the Max Planck Institute for Meteorology Grand Ensemble (MPI-GE), which capture different realizations of the random natural variability. We sample these simulations along the same two paths along which the seismically generated waves traveled. We find that the observed trends are compatible with the simulation ensemble, falling within the upper range of trends seen in the simulations. The simulations further indicate that the observed warming trends are forced—virtually all simulations display a positive trend. What depths contribute to these trends is incompletely captured by the observations but largely compatible with the model.

Latent Diffusion Models for Controllable Generation of Piano Music
Adishree Ghatare
Mentors: Yisong Yue and Yujia Huang

While existing machine learning models can generate convincing music, these models do not allow fine-grained artist control on generation, limiting their utility in helping artists iterate quickly on their ideas. This work introduces an interpretable controllable piano music generation model using latent diffusion models, which have proved successful at generation in the image domain are extended here into symbolic music domain. Particularly, this work examines how several domain-specific tricks such as denoising objectives can improve performance, robustness, and expressiveness of a musical latent space for MIDI files. Ongoing efforts focus on using domain-specific rule-based guidance in diffusion and manipulating factor graph representations to enable long-range coherent generation, a problem still unsolved across domains.

Developing a Simulator to Study Rydberg Gate Fidelity
Mark Gherghetta
Mentors: Mark Saffman, Trent Graham, and Nick Hutzler

Neutral atom quantum computing with Rydberg atoms is proving to be a promising approach in achieving full-scale quantum computers. Two-qubit quantum gate operations on this platform take advantage of strong atomic interactions in the highly excited Rydberg states. However, in experiment these Rydberg gates are prone to a variety of sources of error that must be mitigated in order to achieve high-fidelity computations. In this project, a simulator was developed to study gate operations via laser pulses. Pulses were optimized to be time-optimal (TO) and amplitude-robust (AR). Fidelity measurements were calculated and compared with experimental performance and past literature. Further work was done in reducing AC Stark effects on atomic ground state energy levels during a 2-photon excitation to the Rydberg state, and in reducing photon scattering of the intermediate state. With these error sources accounted for, experimentally viable robust Rydberg gate pulses can be realized. This will enable quantum circuits to run large multi-gate algorithms accurately. Future work will incorporate additional sources of error and consist of a similar analysis for multi-qubit gates.

Design and Testing of Nanophotonic Cavities for T-center Integration
Antonia Ghita
Mentors: Andrei Faraon and Adrian Beckert

Quantum networks require optically-addressable qubits with long coherence times. Spin qubits in solid state luminescent centers are promising candidates for such light-matter interfaces. The T-center, a recently rediscovered silicon color center, is a suitable photon-spin interface for quantum networks thanks to its high radiative efficiency in the telecommunications O-band and long-lived nuclear spins. Measurements of the linewidths of waveguides containing ensembles of T-centers have shown near-transform limited optical transitions which makes the T-center very promising for high fidelity entanglement. Purcell enhancement via integration into a nanophotonic resonator will further increase its emission rate and pave the way to transform limited and indistinguishable photons. To couple the on-chip cavity electromagnetic field to the control and readout optics, high efficiency grating couplers and low loss waveguides are needed. I optimized the efficiency of grating couplers using subwavelength structures, simulated waveguide losses and designed a high Q-factor cavity with high transmission at the T-center optical transition wavelength. I tested the simulated devices experimentally and worked towards achieving fabrication tolerant designs. In the future, these designs will be fabricated on SOI wafers containing T-centers for characterization and control of silicon-based spin-photon interfaces.

Vertebrate Sleep Regulation With Zebrafish Models
Madelyn Gilbert
Mentors: David Prober and Jasmine Emtage

Although sleep is a highly conserved behavior, not much is known about the genetic and neuronal mechanisms that are responsible for sleep regulation. Zebrafish (*Danio rerio*) have recently been introduced as a behavioral sleep model because they are diurnal vertebrates that exhibit similar sleep behaviors to mammalian sleep. An advantage to using zebrafish models is that there are many mammalian genes with zebrafish orthologs. The human gene *stk32a* was identified via a genome-wide association study (GWAS) and found to have a zebrafish ortholog that when mutated, causes a disordered sleep phenotype. The function of the *stk32a* gene in zebrafish is unknown, but it is endogenously expressed in the neuromasts along the lateral line system. Ablation of hair cells in the neuromasts can be used to observe potential sleep phenotypes and determine if *stk32a* in the lateral line impacts sleep. Perturbation of the hair cells in the lateral line system was attempted via drug-induced ablation and capsaicin-mediated conditional ablation. Should ablation of the hair cells work in *stk32a*$^{-/-}$ zebrafish mutants, it is expected that behavioral experiments will show no additive effect on the sleep phenotype and indicate that *stk32a* acts in the hair cells to regulate sleep.

Disentangling a New Compton-Thick AGN From a Serendipitous Quasar Using Broadband X-Ray Spectral Modelling
Annie Giman
Mentors: Fiona Harrison and Peter Boorman

Active Galactic Nuclei (AGN) are the extremely luminous centers of large galaxies containing an accreting supermassive black hole. The majority of AGN are thought to grow beneath thick parsec-scale layers of gas and dust which obscure their innermost regions at lower energies. The most extreme obscured AGN are optically thick to Compton scattering, with line-of-sight column densities $N_H > 1.5 \times 10^{24}$ cm^{-2} (aka Compton-thick). Understanding the geometry and properties of Compton-thick AGN is key to understanding obscuration in AGN more broadly, but not many examples are known. In this work, we explore a candidate AGN that has been missed by previous large-scale AGN surveys, 2MASX J21391374–2646315, in addition to a serendipitously observed contaminant galaxy, using *NuSTAR* and *XMM-Newton* X-ray observations. We conduct follow-up optical spectroscopy of the contaminant and classify it as a previously unidentified quasar at redshift $z \sim 1.8$. Through broadband X-ray spectral modeling and Bayesian sampling algorithms, we disentangle the contaminating flux from the background quasar to unambiguously confirm the AGN to be Compton-thick. Our study highlights the power of combining hard (> 10 keV) X-ray observations with high angular resolution X-ray images in uncovering hidden sites of supermassive black hole accretion in the local Universe.

GPU Optimization for Parameter Estimation in the Attentional Drift Diffusion Model
Jacob Goldman
Mentors: Antonio Rangel and Zeynep Enkavi

The Attentional Drift Diffusion Model (aDDM) is a computational model that describes the impact of visual attention on decision-making. It expands the widely used algorithm of evidence accumulation models to account for how visual fluctuations influence information intake and bias choice. Estimating free parameters that best describe empirical data poses a computational challenge because the model does not have an analytical solution for the likelihood function of choice dependent response times. One way to compute the likelihood of any observed choice and response time given a set of parameters and fixation patterns is through a sequential updating of the probability of crossing decision boundaries. Likelihoods for each observed data point can be computed independently but together identify the parameters with the maximum likelihood. In this project, we utilized Graphics Processing Units (GPUs) to optimize model fitting performance. GPUs offer increased parallelism and higher memory bandwidth, making them suitable for this task. We developed a CUDA-based software toolbox to perform aDDM model fitting and data simulation, providing significant speedup from previous implementations. This research presents a significant step forward in increasing the broader adoption of models designed to increase understanding of the role of attention in decision-making.

A Photosensor for the Fast Component of Barium Fluoride Scintillation Light
Victor Gomez
Mentors: David Hitlin, James Oyang, and Jason Trevor

Through collaboration with the Bruno Kessler Foundation (FBK) and the Jet Propulsion Laboratory (JPL), a new generation of Silicon Photomultipliers is being developed with the ability to filter out light above 240nm. BaF2 has two emission bands, a fast and a slow component. The slow component has a decay time of 650ns and emits light with wavelengths above 240nm. The fast component has a decay time of 600-800 ps and emits light with wavelengths below 240nm. Such photosensors will be capable of detecting only the fast component of BaF2 scintillation light, improving the time resolution at which data can be captured. Properties of these new devices, such as gain, noise, and photon detection efficiency (PDE), were characterized in the lab in order to see them

immediately applied in the Mu2e experiment. Monte Carlo computer simulations were also performed to test the properties of the scintillation crystal–photosensor system.

A Comparative Study of Gene Regulatory Network Changes in Healthy and Cancerous Tissues With Single-Cell Atlases
Yingying Gong
Mentor: Matthew Thomson

Gene regulatory networks control the organization of biological activities and dictate cellular information processing from physiological conditions. The advent of multiplexed single-cell sequencing technology has yielded diverse atlases of transcriptional profiles across different tissue and disease conditions. However, a mechanistic view of how the regulatory networks change in diseased conditions is yet to be established. In this study, we highlight the differences in regulatory networks between healthy and cancerous tissues by dissecting the regulatory networks from an integrated atlas of 2.1 million single cells, including Tabula Sapiens Atlas and datasets across 24 tumor types. We applied D-SPIN, a statistical framework, to identify a set of gene programs that represent core cellular activities, establish a regulatory network model among these programs, and discern how the network is sparsely modified in each cancerous sample. We found the changes in regulatory networks are grouped by the tissue type of cancer samples. Our results suggest that cancers of different tissues have distinct features of regulatory network shifts and thus regulatory networks can serve as powerful tools for both understanding and diagnosis of cancer.

On the Computation of the Functor $TC^+(-;\mathbb{F}_p)$ for Local Integer Rings
Samuel P. Goodman
Mentor: Matthias Flach

In this project, we fully determine $\text{TC}^+(\mathcal{O}_F; \mathbb{F}_p)$ when F is a finite extension of $\mathbb{Q}_p$ and thus $\text{TC}^+(\mathcal{O}_K; \mathbb{F}_p)$ for any number field K. The functor TC^+ has proven to be the more natural description, compared to the more well-known TC, for the arithmetic invariants appearing in the formulae for special values of Dedekind ζ-functions, the zeta functions corresponding to number fields. In addition to directly pertaining to special values of ζ-functions, these groups (and more generally groups coming from topological Hochschild homology) are taking center stage in modern number theory and arithmetic geometry, meaning that understanding them better is of great importance. Prior research has already elucidated connections between $\text{TC}^+_{2n-1}(\mathcal{O}_F; \mathbb{F}_p)$ and $\text{TC}^+_{2n}(\mathcal{O}_F; \mathbb{F}_p)$ but doesn't give much information about the structure of $\text{TC}^+_n(\mathcal{O}_F; \mathbb{F}_p)$ for a particular value of n. Recent techniques, however, have determined the structure of $\text{TC}(\mathcal{O}_F; \mathbb{F}_p)$, which was the launching point for understanding this related functor. By determining this structure, we complete the next step in understanding how these groups behave. We hope that these techniques can soon be extended to understanding $\text{TC}^+(\mathcal{O}_F)$ more generally, for example $\mod p^k$ for $k \geq 1$.

Galaxy Quenching in FIRE-3 by AGN Cosmic Ray Feedback
Charvi Goyal
Mentors: Phil Hopkins and Sam Ponnada

Super-massive black holes at the centers of galaxies, known as active galactic nuclei (AGN), provide energetic feedback necessary to "turn off" star formation in high-mass galaxies ($M_{halo} \geq 10^{12.5}$ M_{Sun}) as observed. However, the physics that drives this "quenching" remains uncertain. Cosmic rays (CRs) have been proposed as a promising channel of AGN feedback, but the nature of CR-feedback from AGN requires further theoretical and observational constraints. Thus, we analyze a set of high-resolution simulations of massive galaxies from the Feedback in Realistic Environments (FIRE) project including AGN feedback with different CR physics parameters and compare them to observed galaxy scaling relations. We find that all runs agree with observed galaxy scaling relations, demonstrating that all CR physics parameters explored produce galaxies with reasonable bulk properties. More detailed investigations of these simulations characterizing gas properties in the halos and modeling detailed emission properties for closer observational comparisons may help in understanding the physical mechanisms leading to similar bulk properties and plausibility of certain CR models, further constraining the parameter space.

A Novel 2*H*-1-Benzopyran Mechanophore Derived From Carbazole
Wendy Granados Razo
Mentors: Maxwell J. Robb and Yan Sun

Polymer mechanochemistry is an emerging field of research where mechanical force is used to promote chemical transformations of force-sensitive molecules termed as mechanophores incorporated into polymers. Mechanophores that undergo a visible color change upon being subjected to mechanical force enable the straightforward visualization of stress in polymeric materials. Benzopyrans are a well-known class of photoswitches that generate a colored merocyanine species under ultraviolet light; however, the mechanochemical reactivity of benzopyran remains unexplored. Herein, we designed and investigated the mechanochromic behavior of a novel 2*H*-1-

benzopyran derived from carbazole. The mechanochemical ring-opening reaction of the targeted benzopyran compound was successfully predicted by computational simulations. Encouraged by these computational predictions, we synthesized polymers containing the benzopyran motif and investigated its mechanochemical reactivity in solution using ultrasonication techniques. Notably, in addition to undergoing a mechanochemical ring-opening reaction, we discovered a bathochromic shift in the absorption of the merocyanine product in the presence of acid resulting in pH-dependent chromogenic behavior. We are exploring applications of this benzopyran mechanophore that leverage its unique multimodal reactivity for force sensing as well information storage through logic gating.

Upgrading the Gridding Machine: A Database and Software for Earth System Modeling on Various Scales
Emily Gu
Mentors: Christian Frankenberg and Yujie Wang

The advancements of Earth system modeling rely on calibrations using the increasingly comprehensive data from satellite-based observations. Navigating the sheer volume and variety of data requires more efficient and user-friendly tools. The GriddingMachine package was designed to address the above needs, both acting as a database of standardized global-scale datasets and an open-source software for downloading and preparing data for researchers. This project focuses on expanding the functionalities of GriddingMachine through the development of two new modules: Processer and Partitioner. The Processer module includes semi-automated processes for standardizing raster datasets from the research community to add to the database, and the Partitioner offers streamlined methods for partitioning and gridding vector datasets from satellite platforms for future queries. Wrapper functions of the above processes are designed to effectively replace the need for manual scripting to preprocess and/or filter data. Alongside these modules, an automated pipeline was established to routinely fetch new data from satellites, including TROPOMI, OCO-2 and MODIS, and visualizations are generated for researchers to explore data trends. With the most recent satellite data readily available, researchers could make investigations at different complexities and scales with ease.

Modeling the Reflection Spectra of the Black Hole X-ray Binary GX 339-4 From Its 2021 Outburst
Sanya Gupta
Mentors: Fiona Harrison and Oluwashina (Shina) Adegoke

We report on the overarching properties of the black hole binary GX 339-4 to, for the first time, model the broadband X-ray reflection spectrum based on its 2021 outburst observed by the \textit{NuSTAR} telescope. During this outburst, the source successfully went through all state transitions over the course of thirteen different observations. The source exhibited strong relativistic reflection features including the broad iron K_{α} line at 6.4 keV and the Compton hump that peaks around 20 keV. Using basic phenominological/physical models, we probe the evolution of important accretion flow parameters over the entire outburst. These include the powerlaw photon index, the disk blackbody temperature, and its normalization. We further computed the inner disk radius corresponding to each of the observations. This is important to study the evolution of the inner accretion disk as the source transitions from one state to another. We also quantified the strength of the reflection spectrum (importantly, the broad iron K_{α} line) for any correlations with the illuminating X-ray flux.

Joint Reconstruction-Segmentation Using Graph-Based Methods
Ashug Gurijala
Mentors: Franca Hoffmann and Jeremy Budd

This research is focused on tackling the task of segmenting imperfect images. Prior implementations that sequentially reconstruct and segment images are limited because the reconstruction task is unaware that segmentation will follow. Another approach involves the use of neural networks, which although powerful, lack explainability. This research explores the novel approach of simultaneously reconstructing and segmenting the image. We allow for the reconstruction task to aid segmentation process, thereby overcoming the limitations of previous methods.

We use a graph-based approach, representing the image as a graph with pixels as vertices and weighted edges according to pixel similarity. The approach is integrable in a variational framework where the goal is to minimize functionals across functions defined on a graph utilizing gradient flows. We formulate the reconstruction-segmentation process as the minimization of Tikhonov reconstruction and Ginzburg-Landau segmentation energies.

To facilitate wider adoption and practical usage of the proposed approach, particularly in fields like medical imaging, we introduce a Python pipeline. Developing the Python pipeline required implementing various optimization strategies to align the principles of the proposed approach with the practical constraints of coding.

Evidence for a Single Astrophysical Origin of Fast Radio Bursts
Michael Gutierrez
Mentors: Charles Steinhardt and Rob Phillips

Fast radio bursts (FRBs) are bright, millisecond-duration radio transients of extragalactic origin. Due to the difficulty of detecting them, the physical nature of their sources remains unclear. Here we present the development of a machine learning algorithm, using UMAP for dimensionality reduction and HDBSCAN for clustering, to analyze the morphology of 700 bursts – including about 200 from known repeating sources – from the Canadian Hydrogen Intensity Mapping Experiment (CHIME) FRB Catalog. Consistent with other studies on the catalog, we find evidence for distinct archetypes of bursts which share similar pulse widths, bandwidths, or scattering times. However, we also find that individual repeating sources can produce FRBs spanning all of these archetypes. We argue that these data are consistent with a single astrophysical origin of FRBs exhibiting a continuum of properties, and that any apparent clusters of properties can be explained by different internal emission mechanisms or selection effects. We evaluate the theories and predictions of previous publications regarding repeating vs. non-repeating categories of FRBs and assess the implications of this unified FRB model.

Assessing Environmental Factors on Preimplantation Development Using a Stem Cell Embryo Model
Christoph Markus Haefelfinger
Mentors: Magdalena Żernicka-Goetz and Sergi Junyent Espinosa

Human fertility is declining at a concerning pace. With maternal age at conception considered a driver of this trend, novel approaches for preserving maternal fertility are urgently required. Meanwhile, many environmental factors have been shown to impact female fertility, as well as development of the preimplantation embryo, leading to subfecundity. However, the morphological changes and mechanisms impacting early development remain to be uncovered. As access to human embryos is extremely limited, we chose the most extensively studied model organism for mammal development, the mouse embryo. Therefore, we engineered a model of mouse preimplantation embryos from stem cells and exposed them to various xenobiotics determined as relevant from a literature research. Then, embryos were fixed and analyzed using brightfield and immunofluorescence imaging. Treatment with toxins resulted in disruption of several features of normal embryo development. The addition of nutritious compounds however, lead to accelerated development and favorable morphological features. Our study provides a proof-of-concept and framework for future high-throughput studies using human stem cell derived embryo models. Subsequent research could yield unprecedented insights and guidelines for the preservation of human fertility and drug testing.

Design of Hydrogels Incorporating Acoustic Cavitation-Induced Mechanochemistry
Tiba Hamza
Mentors: Mikhail Shapiro, Yuxing Yao, and Stella Luo

Mechanochemistry is the study of chemical reactions that are induced by mechanical force. This field provides opportunities for noninvasive drug delivery systems that can be activated using biocompatible ultrasound. The common way to activate a mechanophore is to incorporate it into a polymeric material that transduces mechanical forces required for the chemical reactions. However, the polymers can be diffused in the body before activation such that a carrier to precisely deliver the polymers i*n vivo* is needed. The carrier must incorporate and retain the mechanophore's activation properties to be an effective drug release system that promises high spatial and temporal resolution via focused ultrasound activation. Hydrogel can act as a vehicle to retain the mechanophore for longer periods of time and allow for a controlled release upon ultrasound. In this work, the activation of the mechanophore incorporated in a gel matrix is investigated in an *in vitro* setting. This system has the potential to be controlled via ultrasound parameters with its extents under investigation in this study. The mechanisms of the activation of the mechanophore in solid state are being explored utilizing a new testing protocol that involves fUS activation of the gel within an acoustically transparent material as well as previously established methods. The novel application of focused ultrasound-activated mechanochemistry will enable new possibilities in the design of implantable drug-release vehicles.

Exploring Lightweight Debiasing and Enhancing Robustness Through Data Augmentation in Pretrained Language Models
Pengrui Han
Mentors: Anima Anandkumar and Rafal Kocielnik

Large-scale pretrained language models, while revolutionary, can inadvertently incorporate biases from their training data, leading to potential unintended outcomes. Traditional debiasing methods, although effective, are resource-intensive and may adversely affect a model's linguistic capabilities. In contrast, lightweight debiasing offers a more efficient approach, but its effectiveness is often constrained and challenges in generalization arise. In response to these challenges, our research adopted a dual-pronged approach. We first investigated the Mass Memory Editing Technique, a novel lightweight method that modifies the original model by adjusting weights over specific critical layers. This was contrasted with the prevalent adapter tuning, an approach that retains and freezes the original model, introducing subsequent adapter layers for fine-tuning. Despite the Memory Editing Technique's prowess in targeted debiasing, its generalizability was limited. This realization transitioned our focus to the second phase: fortifying the robustness of lightweight debiasing through data augmentation tailored for adapter tuning. This involved the exploration of term-based, sentence-based, synonym-based, and task-based augmentations. Preliminary findings highlight that these augmentations not only enhance debiasing efficacy but also preserve the model's inherent linguistic strengths.

The Ebb and "Floe" of Energy in the Upper Ocean: Exploring the Energy Budget of Ice-Covered Oceans
Rohaiz Haris
Mentors: Andrew Thompson, Mukund Gupta, and Skylar Gering

Sea ice plays an important role in constraining the oceanic energy budget by mediating energy transfer between the atmosphere and the ocean. Climate models typically represent sea ice as a continuum which do not capture small-scale ice floe dynamics. SubZero, a discrete-element model, represents floes as polygons with time-evolving shapes to simulate floe-scale dynamics. Here, we use SubZero to investigate how floe-scale dynamics and properties can influence energetics in the upper ocean.

We conduct deformation experiments on ice packs with varying floe sizes and configurations to determine how these properties influence the effective rheology of the pack. We find that smaller-sized floes are more likely to fracture, and that the response of an anisotropic pack is highly sensitive to the directionality of deformation. We also investigate how floe dynamics influence the meridional transfer of zonal momentum across an ice pack experiencing ocean shear flow. Preliminary results indicate a sensitivity in momentum transfer to floe size and pack concentration, highlighting the need to further investigate the mechanisms that drive this behavior. Accounting for floe-scale dynamics may be critical for representing coupled ocean-ice processes for boundary currents in seasonally ice-covered regions, such as the Antarctic Slope Current, which influence the global climate.

Making Sense of Zwicky Transient Facility Anomalies
Muhammad Yusuf Hassan
Mentors: Ashish Mahabal and Brian Healy

The current systems in the Zwicky Transient Facility (ZTF) detect and classify a large number of transients. These classifications can hold some anomalies, which may indicate gaps in our knowledge or that we might be looking in the wrong parameter spaces. As such, anomalies can be the tips of icebergs, hiding families of similar objects from our knowledge. In this project, we aim to apply data-driven techniques and astronomical domain knowledge to find interesting objects and future areas for astronomical research. We work on the existing ZTF anomaly detection pipeline, making use of Isolation Forest and HDBSCAN techniques to find outliers in addition to analyzing lightcurves, object cutouts, and other data to finetune our results. We use visualizations based on object features and TSNE plots to find patterns in the data. Another way that we use to find interesting objects is to exploit the hierarchical tree structure of SCoPe classifications to find conflicting classes of interest. A major part of the work is on automating the entire pipeline to reject junk anomalies early on to prioritize genuine anomalies for further investigation. An automatic pipeline that performs anomaly detection is essential because it acts as a preliminary filter, flagging potentially interesting cases in massive data regimes.

Finding Hard Tests for Autonomous Systems
Kimia Hassibi
Mentors: Richard Murray and Apurva Badithela

With the growing development of autonomous systems, including ongoing advancements in technologies like self-driving cars and AI language models, the need to verify that these autonomous systems operate safely and strictly as intended is becoming more important. We consider that an autonomous system works as intended when it behaves in accordance with its formal specification, which is often encoded as a General Reactivity [1] (GR[1]) winning condition. The GR[1] winning condition is a linear temporal logic formula that states that if the environment behaves according to some specifications, then the autonomous system should behave according to its own specifications. However, testing an autonomous system in all possible environmental conditions is not always feasible. Therefore, we present algorithms that attempt to identify hard tests for any GR[1] winning condition. A hard test is a choice of environment behavior that has a large likelihood of the autonomous system failing to satisfy its winning condition. Our algorithms find hard tests by identifying the least robust system states and choosing environment strategies that lead the system to those states. With these hard tests, the capabilities and limits of autonomous systems can be better understood in fewer tests.

Treatment of Bladder Cancer With Bubble-Powered Microrobots
Claire Hays
Mentors: Wei Gao and Hong Han

Microrobots have the potential to greatly improve cancer treatment methodologies by allowing anticancer drugs to be targeted directly to tumor sites, allowing for higher efficacy treatment with fewer side effects. But, designing a microrobot for this purpose requires it to be able to travel rapidly, be easily directable, have a sufficiently long lifetime to allow it to reach its destination, and degrade naturally after attaching to the tumor. By designing a bubble-based microrobot, the microstreaming effects resulting from application of ultrasound waves can be optimized for high-speed motion. By incorporating iron oxide nanoparticles into the microrobot, the direction of its motion can be directed by magnetic fields. These crucial aspects of the microrobots' function are tested in vitro and in vivo using mouse subjects, showing them to be effective in treating bladder cancer tumors, but continued work will need to be done improving and testing their function before use in treating cancer patients.

Investigating the Stability of Metal Oxide Protection Layers for Solar Water Splitting Photocathodes
Noah Hicks
Mentors: Nathan S. Lewis and Alexandre Ye

The development of renewable energy storage devices like photoelectrochemical cells (PECs) are crucial as we move towards a greener future. PECs utilize light-absorbing semiconductors with the appropriate bandgaps to excite charge carriers and split water into oxygen and clean, renewable hydrogen. However, these devices are yet to make way in industry as they are most efficient in highly corrosive environments. Therefore, our goal is to find protection layers that can both stabilize the substrate (here the photocathode) and permit charge carrier flow. Here, we report the behavior of atomic layer deposited (ALD) metal oxide protection layers such as Ta_2O_5, TiO_2, and HfO_2 on p-InP in aqueous and nonaqueous redox couples such as Vanadium^{3+}-Vanadium^{2+}, Ferrocenium-Ferrocene, and Cobaltocenium-Cobaltocene. Ellipsometry and X-ray photoelectron spectroscopy (XPS) were used to physically characterize the protection layers, while cyclic voltammetry (CV) and Mott Schottky analysis were used to electronically characterize the protection layers. Future research will include characterization of other metal oxides and eventually the optimization of a protective layer for the photocathode in H_2O, increasing the stability and practical usability of solar fuel cells as a renewable energy storage option.

Electrolessly Plated and Low-Temperature Annealed Ohmic Contacts to n-type GaAs for Low-Cost GaAs Solar Cells
Hana Hisamune
Mentors: Harry Atwater and Phillip Jahelka

The Space Solar Power Project (SSPP) seeks to deploy large arrays of low-cost solar cells in space and wireless transmit usable energy back to Earth. III-V materials such as GaAs and InP are promising solar cell materials for SSPP, but they are hindered by requiring expensive metallization processes. Because ohmic contacts to III-V compounds are traditionally fabricated using vacuum evaporation and precious metals such as gold, an alternative cheaper, low-temperature method must be pursued in order to meet the cost and thermal-budget requirements of SSPP. In this project, we present an electrolessly plated Pd/Sn-based contact structure that becomes ohmic when annealed at temperatures less than 200ºC. The contact is fabricated using simple chemical baths to deposit Pd and Sn onto n-GaAs and relies on the solid phase regrowth of a Sn-doped GaAs lattice for the actual contact formation—replicating the low contact resistivities obtained in Pd/Ge/Au-based systems at ~180ºC but using much lower cost processing. Through phase identification using x-ray diffraction, we demonstrate the rapid formation of a $PdSn_4$ intermetallic and the onset of ohmic behavior with contact resistivity of approximately $1\Omega cm^2$ at low temperatures. We investigate the phase formation and performance of the Pd/Sn n-GaAs contact at various annealing temperatures less than 200ºC and explore the feasibility of low-cost scalable ohmic contacts for SSPP applications.

Querying Protein Interactions Software Package Using Eukaryotic Linear Motif Database
Chi Hoang
Mentors: Lior Pachter and Laura Luebbert

Proteins in a cell fulfill their function by interacting with other proteins. One example are transcription factors, which are proteins that regulate gene expression levels. Transcription factors regulate gene expression by binding to DNA regulatory proteins. Similar to a key and lock mechanism, proteins have specific interaction domains for different tasks, which can be recognized from their amino acid sequence. Many human diseases, including most cancers, are caused by mutations of protein interaction domains. Understanding how changes in amino acid sequences disrupt protein interactions is crucial for mapping the potential pathological effects and predicting the consequences of a mutation. Here, I introduce a new Python and command line program, called *gget elm*, which allows researchers to identify protein interaction domains directly from an amino acid sequence or UniProt ID by pulling information from the Eukaryotic Linear Motifs (ELM) database.

Utilizing Plasmid Machinery to Improve Syn61
Ella Holland
Mentors: Kaihang Wang, Jianyi Huang, and Jolena Zhou

Syn61 is a synthetic E. coli, created in Dr. Wang's previous research, which has a recoded genome with only 61 codons. This organism presents exciting potential for creativity in biological designs that take advantage of such a reprogramming. A current challenge of working with Syn61 in this manner is its relatively slow growth rate in comparison to its wild-type counterpart, MDS42. In order to create a variant with an improved growth rate, a conjugation plasmid is utilized to systematically replace segments of the Syn61 genome with MDS42 DNA from a donor library over multiple rounds of conjugation. This DNA is then integrated into Syn61 by recombineering, and the growth over time of the resulting clones is analyzed. Clones thus far have demonstrated potentially improved growth rate, and the project is moving forward with the goal of conjugating over shorter fragments of MDS42 DNA across multiple rounds to pinpoint a few recoded codons that could have caused the growth defect in Syn61. Additionally, to improve conjugation efficiency, the conjugation plasmid has been sequence optimized and cloned, and tested for conjugation efficiency.

Understanding Pupil Response Patterns in Autism
Qianhui Hong
Mentors: Ralph Adolphs, Qianying Wu, and Na Yeon Kim

Autism Spectrum Disorder (ASD) features atypical social and emotional processing, which can be reflected in the pupil dilation response (PDR) to external audio-visual stimuli. This project aimed to quantify how different features in naturalistic movies affect pupil dilation using an eyetracking dataset collected in 20 healthy controls and 13 high-functioning ASD participants. In particular, we extracted changes of the pupil diameter at a high sampling rate (600 Hz) while participants were watching 18 sounded, short YouTube movies. After data preprocessing and normalization, we found that the pupil diameter is affected by various factors in the movie, including lighting, changing of scenes, sound volume, emotion arousal, etc. Compared to the control group, the ASD group in general has greater dilation when the emotion arousal is high and when a new human subject appears. These preliminary findings can thus form the basis of fine-grained future analysis that will comprehensively characterize the importance of different features in inducing atypical pupil dilation patterns in ASD.

Accessible and Extensible System for Real-time Animal Tracking and Behavior Quantification
Brian Hu
Mentors: Athanassios Siapas and Jonathan Kenny

The ability to provide feedback to animals in real time is an invaluable tool for neuroscience and animal research in general to establish causal relationships between stimuli and the corresponding behaviors. Recent advancements in deep learning have allowed researchers to estimate animal poses in a non-invasive manner. However, experiments often require specialized hardware that can't be easily integrated with state-of-the-art machine learning algorithms. My project aims to bridge this accessibility gap and create RataGUI: an intuitive and extensible system that connects video streams from an arbitrary number of different cameras to a customizable processing pipeline with the ability to trigger external hardware. This integrated system enables real-time experiments with low-latency, closed-loop feedback to directly relate behavior with neural activity. RataGUI's modular structure streamlines user customization while also resulting in improved reproducibility as experimental parameters are automatically saved and restored. Written from the ground up entirely in Python, RataGUI's open-source codebase is designed to be extensible to user-submitted code and future innovations in computer vision.

Tidal Interactions of Helium Stars in Compact Binary Systems
Emily Hu
Mentors: Jim Fuller, Linhao Ma, and Daichi Tsuna

The development of gravitational-wave astronomy brings an influx of novel compact object merger event detections, sparking great interest in the origins of such events. A promising signature of the progenitor system of these merger events is the spins of the compact objects, which can be inferred from the gravitational-wave signal. One possible progenitor binary system of these merger events is a helium star and a compact companion, such as a neutron star or a black hole. By simulating the tidal interactions of this progenitor system, we predict the final spin of its merged compact object at the end of its orbital evolution. This simulation largely consists of three stages: (1) evolving a single helium star model through its core-helium burning lifetime, (2) computing the internal oscillation modes of the helium star, and (3) performing discrete time step-wise calculations of the tidal spin-up of the helium star due to factors such as mass loss from stellar winds, gravitational radiation, and tidal dissipation. Our careful implementation of tidally excited oscillations in evolving these binary systems will improve our understanding of their final spins.

Mice in Manhattan: Navigation, Rapid Learning, and Memory in a Reconfigurable Maze
Jennifer Hu
Mentors: Markus Meister and Jieyu Zheng

Cognitive flexibility allows mice to quickly adapt to and memorize new paths through mazes. To observe this flexibility, we used the Manhattan maze, a novel 3D maze structure that can be easily modified using masks which selectively limit the traversability of the maze. Masks tested include O, a one-decision training mask to acclimatize the mouse to the maze; and A, B, and C, distinct mostly-linear 9-decision masks with similar local turn patterns and distances. Mice were either given a 1 day control test wherein scent tracks in the maze were shuffled halfway through the day; or a 2 day memory and learning test consisting of one training day with masks O and A, and one testing day with masks A, B, and C. A total of 20 mice were tested: 5 were given the control, and 15 began the 2

day test. Of 11 mice that successfully completed at least 10 round trips through mask A on day 1, all showed similar improvement in performance over time, and demonstrated quick mastery over all 9-decision masks in just a few hours.

Benchmarking and Advancing SOTA Segmentation on Primates in the Wild
Mark Hu
Mentors: Pietro Perona and Markus Marks

The fields of primatology, anthropology, and psychology currently rely heavily on visual imagery of primates in the wild, which is hard to capture accurately and requires time to process. Analyzing such data requires manual inspection, which is time-consuming and biased, and therefore can lead to errors that affect subsequent findings. Supervised Machine learning helps to automate the analysis process by training to predict humanly annotated labels for domains where large-scale annotated datasets are available. In this project, we evaluate the performance of a combination of the Grounding DINO object detection model and the Segment Anything Model (SAM) on a dataset consisting of camera-trap primate images and hand-held recordings of chimpanzees collected by the Wild Minds Lab across field sites in Africa. By selecting input prompts to the models through manual inspection and random selection, we optimize the detection capabilities on the data. Our goal is to reach an accuracy rate of primate detection comparable to manual scanning, which allows primatologists to improve the efficiency and accuracy of work with video imagery of primate behavior.

Integration of Human Stem-Derived Retinal Ganglion Cells Into Zebrafish
Simon Hu
Mentors: Jeff Mumm, Anneliese Ceisel, Gianna Graziano, and David Prober

Retinal ganglion cells (RGCs) are neurons that bridge the retinal input to the processing neurons in the central nervous system. The loss and/or faultiness of these cells characterize progressive blinding diseases like glaucoma, the leading cause of blindness worldwide. Cell replacement therapies may be the key to curing these diseases. However, the feasibility of incorporating human stem cell-derived RGCs as a therapeutic approach has yet to be deeply explored. Since zebrafish have naturally regenerative properties, we used zebrafish as a model organism to study the potential of human RGC (hRGC) regeneration. In this study, we injected hRGCs transgenically labeled with a red fluorescent protein into zebrafish and visualized the presence of such cells using confocal imaging. Zebrafish were injected at various time points in development to determine which stage best promotes hRGC survival, integration, and function. By using transgenic zebrafish lines expressing bacterial nitroreductase (NTR) in RGCs, we also selectively ablated zebrafish RGCs by adding the prodrug prodrug Metronidazole (Mtz), which is converted into a cytotoxin in the presence of NTR. These assays provide insight as to how injections act in an environment similar to that of a neurodegenerative disorder.

Scalable Gaussian Processes for Non-ergodic Earthquake Models
Stephen Huan
Mentors: Houman Owhadi and Grigorios Lavrentiadis

Non-ergodic ground-motion models attempt to estimate the probability an earthquake will exceed a certain intensity and are used to assess the seismic hazard at nuclear power plant locations, among other applications in civil engineering. However, current codes scale cubically with the number of data points, severely limiting the size of processable datasets. This work applies recent state of the art results in sparse approximate Cholesky factors to significantly accelerate the computations necessary in statistical inference. Our method enjoys a number of advantageous properties, including near-linear time and space efficiency, optimality in Kullback–Leibler divergence, and embarrassingly parallel computation. We develop two code repositories: SparseKolesky.jl, a user-friendly, well-documented library for sparse factorization of generic covariance matrices and EarthquakeGPs.jl, specializing our methodology to earthquake models. We write our codes in Julia, the high-performance scientific programming language with the intention of targeting supercomputing clusters. The project website and additional resources may be found at https://kolesky.cgdct.moe/.

LunaX Moon Base Simulator: Exploring Lunar Development and Sustainability
Bo-Ruei Huang
Mentors: Yuk Yung and Jonathan Jiang

The LunaX Moon Base Simulator project exemplifies a dynamic undertaking inspired by NASA's Artemis program, which seeks to reintroduce humans to lunar landscapes and establish a self-sustaining lunar base by 2024. In response to this ambitious endeavor, we present an immersive video game experience that enables participants to delve into the intricacies of lunar development.

Leveraging the versatile Unity platform, the game offers a comprehensive simulation of lunar base operations. Core features encompass sophisticated resource management, intricate life support systems, and strategic infrastructure creation. Players have the opportunity to construct their lunar base and formulate strategic approaches for sustainable development.

The potential of this game transcends mere entertainment; it serves as an educational instrument, affording players insights into the multifaceted intricacies of lunar exploration and the challenges of establishing a habitable environment. By bridging the realms of gaming and tangible lunar endeavors, the LunaX Moon Base Simulator possesses the ability to ignite curiosity and cultivate enthusiasm for space exploration within a diverse array of audiences.

Creating a Second LEONARDO (LEgs ONboARD drOne) With Updated Components and Revamped Hardware
Fangyao Huang
Mentor: Soon-Jo Chung

LEONARDO is an innovative robotics system that combines a bipedal robot with a propeller-based stabilization system, this combination allows it to navigate terrain inaccessible to traditional bipedal robots while achieving higher energy efficiency compared to conventional drones in the same weight class. The existing LEONARDO robot has stayed relatively unchanged since its completion in order to preserve its functionality, this project seeks to create an updated version of the LEONARDO robot using existing designs but with updated hardware and software which would facilitate further testing of the bipedal-drone system. One such test involves the installation of wheels onto LEONARDO which would allow it to traverse flat terrain at a significantly higher energy efficiency; ongoing efforts have been made to enable cooperation between multiple robots made possible by the construction of a second LEONARDO.

Preventing False Scientific Predictions in Quantum Experiments
Jerry Huang
Mentors: John Preskill and Hsin-Yuan Huang

Learning properties of quantum systems is an important task for developing quantum technologies. Since obtaining new quantum data is usually expensive, scientists will often reuse the data to predict many properties. However, quantum experimentation is inherently an adaptive process where the scientist will typically decide what to test after seeing previous results on the data, and improperly reusing this data can lead to false predictions. In this work, we show that for certain properties, it is in general impossible to design an algorithm that can prevent this failure when predicting many adaptively-chosen properties. Specifically, when predicting adaptive local and Pauli observables, we proved a polynomial lower bound in the number of queries for the required number of samples of the quantum state. However, predicting many adaptive properties becomes possible for bounded Frobenius-norm observables, where we designed an algorithm that requires only a logarithmic number of samples with no dependence on the dimension of the state.

Exploration of the Learning From Hints Paradigm
Paul Huang
Mentor: Yaser S. Abu-Mostafa

In machine learning, the goal is often to approximate some unknown target function by utilizing learning algorithms to exploit the information contained in the training data distribution. While raw training data serves as a foundational input, there is potential in utilizing transformed versions of this data. Such transformations convey human knowledge about the target function, acting as "hints" for the learning algorithms. Although the concept of using hints in learning algorithms has been widely studied in machine learning literature, most works focused on data augmentation, also known as duplicate examples. This narrowed focus has ignored the potential of another effective hinting technique - the deployment of virtual examples. Virtual examples offer the advantage of guiding the model to learn hints in a broader input domain, as opposed to the limited scope of duplicate examples confined to the training data distribution. Our research focuses on the utilization of virtual examples as a hint-providing mechanism, testing their efficacy against using duplicate examples as hint-providers. We evaluate these techniques based on the resulting model's performance and robustness on both data highly correlated to the training set and out-of-distribution data that models have not seen in the training stage.

A Type Checker for Mathematical Proofs Written in LaTeX
Zachary Huang
Mentor: Adam Blank

The primary goal of this project is to answer the question: how can we best apply modern programming language technologies in order to help students learn proof-based discrete mathematics? A tool which could analyze student proofs written in LaTeX and identify common mistakes such as type mismatches and circular logic would be invaluable to the learning process and help students improve the rigor of their mathematical proofs. The objective is to implement such a tool and test its effectiveness in CS 13, a new course on discrete mathematics intended for CS majors. LaTeX, however, is quite difficult to analyze statically, but if we ignore the advanced features of LaTeX, we can parse out the overall textual and mathematical content of proofs using a context-free grammar. We can then fit a Hindley-Milner-like type system onto the extracted mathematical content to perform type inference/checking in a similar manner to functional programming languages. We cover the main “data types” of discrete math, including numbers (naturals, integers, rationals, and reals), sets, and sequences. In addition, the system can process arithmetic operations, inequalities, set operations, and more. Then, pattern-matching can be used to perform ad-hoc proof recognition and analysis.

Gaussian Process Regression With a Random Kernel Produced by a Mondrian Process
Evelyn Huerta
Mentors: Houman Owhadi, Ricardo S. Baptista, and Eliza W. O’Reilly

There are numerous techniques used for predictive modeling, such as random forests, neural networks, Gaussian process regression, etc. They each possess different strengths and weaknesses, thus they perform better on specific types of data sets. In particular Gaussian process regression with a common kernel such as a RBF (radial basis function) or linear kernel perform well on continuous data but poorly on discontinuous data. Thus a common approach to fit discontinuous data accurately is to use discontinuity detection algorithms before applying predictive modeling technique. However, our approach is to attempt to use a Gaussian process with a random Mondrian kernel to directly generate a discontinuous function that fits the discontinuous data and avoid the discontinuity detection step altogether. The success of this project will improve the accuracy of fitting discontinuous functions while minimizing computational cost.

Topological Transport Induced by Coherent Phonons
William Hunt
Mentors: Gil Refael and Iliya Esin

Periodic drives can induce a wide range of exotic phases beyond those accessible at equilibrium, including generating non-trivial topological transport properties ‘on demand.’ Here, we demonstrate that periodically driving a conducting wire with coherent phonons induces a steady state with a quantized current response. The quantized current arises from a drive-induced topological Floquet spectrum, and non-equilibrium steady state occupation stabilized by coupling to a low-temperature heat bath. We present a simple analytical model of the steady-state and quantized current by modeling weak phonon driving and coupling to a heat bath in a Lindblad master equation. We support these analytical results with a numerical analysis of a coherent-phonon-driven lattice model. Our results suggest, that quantized current is a characteristic feature of coherent phonons and therefore can be used in the detection of coherent phonons.

Characterization of Swarming and Collective Behavior in Brine Shrimp *(Artemia salina)* Populations
Joonha Hwang
Mentors: John Dabiri and Nina Mohebbi

Studying collective animal behavior requires a multidisciplinary approach with context provided by organismal biology, statistical mechanics, lab and field studies, and computational modeling. Previous studies have investigated the diel migration of brine shrimp (Artemia salina) and the hydrodynamics of induced vertical swarm motion. We propose a set of metrics to characterize this collective behavior, including velocity distributions, nearest neighbor distances, and the polarity coefficient Φ. We examine the effects of agent density and light source properties on these metrics to evaluate their effectiveness and discuss causes for trends present. Further studies, such as one on collective wake propagation of brine shrimp, may leverage these metrics to analyze gathered swarm data and validate theoretical models.

Improving Cardinality Estimation of Sum of Sets With Convexity
Jun Ikeda
Mentors: Nets H. Katz and Shukun Wu

For two sets of numbers, the sumset consists of numbers that can be represented as a sum of an element from each set. The convexity problem is on the size of the sumset of convex sets. Historically, it is conjectured that the lower bound of the size of sums of convex sets is arbitrarily close to that of geometric progressions, which implies that convexity almost destroys additive structures. In recent years, there have been multiple improvements of the lower bound, but the conjecture is yet to be proved. With additional assumptions on the discrete analog of higher derivatives, better bounds were found in 2020. In this research, I obtained a slight improvement of this bound.

Non-Invasive Neural Decoding
Ahamed Raffey Iqbal
Mentors: Yisong Yue and Sabera Talukder

Millions of people suffer from debilitating neuromuscular diseases and injuries that severely limit motor function and communication, such as ALS, Parkinson’s, and Dystonia. Brain-machine interfaces (BMIs) work by extracting and subsequently decoding signals from the brain and muscles to enable people with such diseases to regain functionality and independence. Unfortunately, these systems typically require electrodes implanted via highly invasive neurosurgeries, which greatly reduces their accessibility.

Non-invasive electroencephalogram (EEG) recordings collected from a person's scalp result in noisier signals, but enable wider adoption. Therefore we explored the feasibility of a high-accuracy, generalizable, non-invasive neural signal decoding pipeline to facilitate widespread BMI adoption. To this extent, we developed a multimodal data collection and processing pipeline and are developing and evaluating deep-learning neural decoders. Our deep learning models utilize an autoencoder backbone to generate low dimensional latent spaces and contrastive loss for performant latent space separation. Together these techniques extract useful neural-task-dependent information from the noisier EEG data. We aim to extend our data-collection platform and models to non-invasively control a robotic arm via shared autonomy.

Investigating the Role of Non-NF2 Genes in Meningioma-Genesis Using Zebrafish
Anushka Irodi
Mentors: Marianne Bronner and Ayyappa Raja

Paediatric meningiomas have been shown to exhibit unique clinical features such as a higher mitotic index and more frequent invasion when compared to their adult counterparts. Most paediatric cases, like adult meningiomas, show abundant alterations in the NF2 gene, but the overall mutational genetic landscape for these tumours remains poorly characterised. Using CRISPR/Cas9- mediated mutagenesis in the zebrafish embryo, we have generated, in combination with NF2 knockouts, knock-outs of ten candidate genes occasionally altered in paediatric meningiomas: CDKN2A/B, TERT, SMO, SMARCE1, FUBP1, BRAF, KDM5C, SETD2, NOTCH2, ATM. We will validate the guide RNAs for these genes and ascertain knock-out success by quantitating the efficiency of mutagenesis. Using a meninges-specific transgenic line, we expect to quantify *in vivo* cellular proliferation across the knockouts to decipher the cumulative effect of mutations in meningioma-genesis.

Deciphering the Components of *Pseudomonas aeruginosa*'s Response to Nitric Oxide
Emma Isella
Mentors: Dianne Newman and Zach Lonergan

Bacterial infections are of great concern to public health. Some pathogenic bacteria have developed ways of evading the hostile environment of the host's immune system, enabling them to establish chronic infections. One such bacterial species is *Pseudomonas aeruginosa*, which has evolved mechanisms to survive in the presence of nitric oxide (NO), a highly reactive and toxic molecule produced by host immune cells to dispel pathogens. This project aims to discover and characterize novel genes that may be responsible for the bacteria's ability to persist in NO-rich conditions. To do this, we screened a subset of a non-redundant transposon mutant library to find strains that have reduced growth in the presence of NO. Based on their growth characteristics, we compiled a list of genes whose disruption sensitized the bacteria to NO. Bioinformatic methods and secondary screens were employed to characterize the functions of these genes, including their role in other behaviors such as biofilm formation or response to other stressors, such as iron-limitation or antibiotic exposure. We also created and tested clean deletions of several genes either known or suspected to be involved in the bacterium's NO survival mechanisms using the same methodology. This analysis develops a more comprehensive molecular understanding of components involved in *P. aeruginosa*'s evasion of one of the most important antimicrobial metabolites produced by the host immune system, laying the groundwork for future studies on the specific functions of our flagged genes. Ultimately, this work may inform the development of therapeutics to help combat bacterial chronic infections.

The Young Stellar Object Corral (YSOC) Backend: Retooling to Improve Content and Efficiency
Sujit Iyer
Mentor: Lynne Hillenbrand

The Young Stellar Object Corral (YSOC) serves as a central science archive for young stars. When the YSOC database infrastructure was first created, backend scripts were coded with an emphasis on adding new content: stellar clusters, individual stars, and mass amounts of information on them. Now an established catalog, focus has shifted towards updating YSOC through the assimilation of data from cutting-edge surveys and other literature. This project aims to enhance YSOC's backend infrastructure to make the incorporation of new information efficient, accurate, and complete. We identified inefficiencies and outdated code in the backend through empirical analysis of sandbox data. The core issues lay in error-handling and documentation. We automated several manual processes (table splitting, paper referencing, etc.) and added beneficial error statements in instances where user handling was necessary. These changes to the codebase will allow efficiency and improved ease of backend usage for data ingestion, allowing YSOC to provide the latest updates in astronomical data.

Weathering of Ultramafic Rocks and Formation of Magnesite: Major Element Mass-Balance From Source to Sink
Mehul Jangir
Mentors: Theodore Present and Surjyendu Bhattacharjee

We report CIA (Chemical Index of Alteration) and WIS (Weathering Intensity Scale) values for rocks from Queensland, Australia. These rocks are part of a source-to-sink weathering environment where ultramafic rocks are weathered to form magnesite downstream. Using an INAM Eagle XRF unit, we collect elemental composition data for homogenized soil and clay powders, and plot ternary plots for the data. We then attempt to construct a box model to explain this source-to-sink sedimentary environment to explain magnesium ion transport.

Safety Aware Human Robot Collaboration: A System to Fuse Human Intention Estimation and Multiple Robust Backup Controllers
Neil Janwani
Mentor: Joel Burdick

Human Robot Collaboration is an important paradigm in the field of robotics, and has been the subject of intense research. Here, robots may be required to follow trajectories that satisfy complex safety constraints and reach goals that align with their human partner's intention. However, state-of-the-art systems currently achieve only one of these objectives–resulting in robots that either provide *safer* guarantees (rather than *always safe* guarantees) or robots that do not utilize human intention to adjust safety behavior. For instance, choosing backup, safe behaviors for robot motion, like stopping or changing orientation, may depend on high level goals such as mission objectives. Thus, we present a pre-trainable, online robust safety system with minimal violations and conservatism for enhanced human robot collaboration and safety. A neural network will be used to translate multi-modal robot and human input into a choice of backup controller–represented as a control barrier function. The robustness of the backup safe sets will be addressed by utilizing a Gaussian Process-based online residual dynamics estimator and its forward propagation. We demonstrate the efficacy of our method on a tracked robot in various environments with backup control requirements. With our intention-aware backup safe control method, the robot remains safe.

Leveraging Seismic Interferometry to Image Hidden Fault Lines
Armeet Jatyani
Mentors: Rob Clayton and Etorre Biondi

The objective of this study is to leverage *seismic interferometry*—a method in which ambient seismic noise is processed to generate geophysical images—to image fault lines in the Long Beach area. The *virtual source method* is an application of time-reversed acoustics in which the original signal is cross correlated with the inverted signal at varied time lags. The resulting Green's function usually describes how seismic waves propagate between two points. However, interferences (fault lines) in an array of seismic sensors show up as characteristic peaks in the cross-correlated signals. By repeating this procedure for every node pair in a large array of seismic sensors, features like the depth and appearance of a fault can be extracted and imaged with high resolution and confidence. This method has shown promise and was previously used to image fault lines in the nearby Seal Beach area. 5 weeks of data from 7,800 seismic sensors, taken from the LB3D and ELB surveys, were analyzed in this study. Both previously established fault lines and new fault lines were imaged. The locations of these faults were compared with previous USGS surveys and the accuracy of this method was quantified.

On a Conjecture on the Values of Psi Correlators
Toyesh Jayaswal
Mentor: Tim-Henrik Buelles

Moduli spaces are parameter spaces for certain geometric objects which allow for the study of enumerative problems, that is counting how many objects satisfy certain constraints, through cohomological methods. One important class of spaces is the moduli space of stable curves, and psi correlators are numbers naturally arising from their cohomology. They give insight to the geometry of the spaces, but while recursive formulas exist, an explicit formula is deemed intractable. This project explores a conjecture by Liu and Xu stating that these numbers should be maximized when certain parameters are evenly distributed by analyzing different methods that can be used for computation. We prove the conjecture for the case of two-correlators by analyzing an explicit formula recently derived by Zograf. Understanding the relationships between these numerical values could provide insight into geometric problems which can be solved using psi correlators.

Developing End-user AI Inspection Tools for Large Language and Vision-Text Models
Roy Jiang
Mentors: Anima Anandkumar and Rafal Kocielnik

Modern language and vision models learn implicit social biases such as gendered and racial prejudices due to the media and texts they are trained on, which may propagate discriminatory effects where AI is employed. As such, methods for bias detection and quantification understandable to non-technical social experts is imperative. Existing methods for auditing models prove inadequate, relying on the use of fixed datasets and being severely unusable for non-technical experts. This project aimed to address these issues through the design, development, and iteration of end-user tools for the inspection of stereotypical bias in state-of-the-art large language (LLM) and text-vision AI models. These tools were developed through a process of UI/UX prototyping, technical feasibility evaluations, as well as stress testing with novice users and both technical and non-technical experts. Currently, we have a working

version of the LLM testing tool and an initial prototype of the text-vision tool on the HuggingFace platform. We conclude that such a task is accompanied by challenges in balancing, efficiency, clarity and faithfulness, and that these tools are a necessary step in the development of fairer AI. Lastly, we recommend more principled evaluation of the tools with the target audience of social scientists and ethics experts.

Kilonova Light Curves of HD 222925's Progenitor
Ian Johnson
Mentors: Erika Holmbeck and Ryan Patterson

Despite their familiarity on Earth, the origin of elements heavier than iron remains mysterious. Currently, the leading theory for heavy element nucleosynthesis is that a majority of observed isotopes are formed in neutron star mergers, visible though the "kilonovae" that proceed them. Owing to their rarity, studying kilonovae presents an observational problem and a limited sample size. In this work, we reproduce the light curves associated with past mergers. Specifically, we derive a kilonova light curve from the elemental abundances of the "gold standard" star HD 222925, which is metal-poor and thought to be enriched by a single neutron star merger. We find a variety of simulated neutron star merger models were able to reproduce HD 222925's observed abundances; therefore, we construct their corresponding light curves in hopes of distinguishing between valid merger models. We find that the merger models produce light curves that are observationally too alike to distinguish between. Moving forward, performing this analysis on more stars like HD 222925 should yield a robust population of kilonova light curves to better inform future models and live observations.

Creating an Intuitive XR Space for Efficient 3D Data Inspection and Direct Manipulation Supported by 2D and 3D Interfaces
Sam Johnson-Lacoss
Mentors: Santiago Lombeyda and S. George Djorgovski

There are certain phenomena that in order to be fully understood, one must first grasp their three-dimensional spatial relations. For these situations, two dimensional screens and a passive point-of-view fail to allow a viewer to fully utilize the extent of our cognitive faculties to understand three dimensional structures and retain those intricacies. As such, extended reality environments often prioritize the third dimension in representations of data, in the attempt to provide clearer insight into these phenomena. However, this priority often neglects data that is more effectively conveyed by both two-dimensional and complex connected three-dimensional representations, rendering such data difficult to navigate in an efficient or meaningful way. This project defines an intuitive and efficient extended reality space for object-focused visualization that combines two- and three-dimensional interaction techniques as well as representations, to create a tool for more efficient and meaningful data analysis.

Developing an Inner Cell Mass Model Using Extended Pluripotent Stem Cells and Embryonic Stem Cells
Jolie Jones
Mentors: Magdalena Zernick-Goetz and Sergi Junyent

As cells continue to split after initial fertilization, they eventually begin to differentiate into three cell types: Epiblast cells that give rise to all the cells in the body, Primitive endoderm cells (PrE) that give rise to the yolk sack surrounding the organism, and Trophectoderm cells that become the placenta. The Inner Cell Mass (ICM) refers to the collection of Epiblast and PrE cells inside the trophectoderm layer. There is often difficulty in studying the development of the ICM because of this trophectoderm layer, creating the need for a model that mimics ICM development. Extended Pluripotent Stem Cells (EPSCs) were used to create this model by collecting small aggregates of them in cells numbers that resemble the ICM, as EPSCs have been shown to be capable of giving rise to both cell fates within the inner cell mass. Markers specific to PrE and Epiblast cells were used to visualize and justify the components of these models. The optimization of this model is ongoing as data and results are still being collected to verify this model.

Distinguishing Feeding Habits in Fossil Organisms Using Amino Acid Compound Specific Isotope Analysis
Linet Kahuria
Mentor: Julia Tejada

This abstract focuses on the need for an alternative method to distinguish feeding habits among fossil organisms, particularly omnivores, as traditional methods based on cranial morphology may not be sufficient. This research project proposes the use of amino acid compound specific isotopic analyses (AACSIA) to assess feeding ecology by measuring and evaluating the d15N values of specific amino acids. AACSIA offers advantages over bulk tissue nitrogen stable isotope analysis as it provides trophic information and provides records the d15N values of both the baseline primary producer community and the organism being studied. This abstract highlights the limitations of using bulk tissue d15N values alone and emphasizes the isotopic linkage between an organism's body tissues and its sustenance. The project aims to test the predictive power of AACSIA in modern species and understand the physiological and metabolic processes behind the observed variation among different taxa. By developing an accurate database on modern omnivory, we hope to apply the data to predict and differentiate types of omnivory and carnivory in fossil species.

Sharpened Bounds for Polynomial Roth Type Theorem in Finite Fields
Necef Alp Kavrut
Mentor: Shukun Wu

We improve the previous best decay estimate for the bilinear average $p^{-1}\sum_{y} \quad f_1(x+y)f_2(x+y^2)$ in a finite field of size p, where p is a prime sufficiently large. Our method involves interpolation and careful evaluation of numerous linear and quadratic gauss sums obtained through applications of the Cauchy-Schwarz inequality and change of variables. As a consequence, we guarantee the existence of triplets of the form $x, x+y, x+y^2$ for nonzero y inside any subset of the finite field of proportional size.

Self-Supervised Keypoint Discovery for Behavioral Videos (Multiple Agent Adaptation)
Daniel Khalil
Mentors: Pietro Perona and Markus Marks

Quantifying the motion of groups entities is important for studying the behavior of humans and other animals in a setting with multiple agents at once, but manual pose annotations are expensive and time-consuming to obtain. Self-supervised keypoint discovery is a promising strategy for estimating poses without annotations as it addresses this issue. However, current unsupervised keypoint discovery approaches commonly process videos with only singular agents of a certain appearance. We propose a new method to perform self-supervised keypoint discovery on videos with multiple agents by coupling keypoint discovery with image segmentation, without any keypoint or bounding box supervision. Our method, BKinD-multi, uses an encoder-decoder architecture in conjunction with Segment-Anything and Grounding-Dino, trained to reconstruct spatiotemporal differences between grames. In this way, we discover keypoints without requiring manual supervision in videos of humans and rats, demonstrating the potential of keypoint discovery for studying multiple agent behavior.

MineDojo 2: A Minecraft Environment With a Unified Observation and Action Space to Build More Powerful Embodied Agents
Bilal Khan
Mentors: Anima Anandkumar and Guanzhi Wang

Fan et al. 2022 introduced MineDojo: an environment built in Minecraft for training reinforcement learning agents on open-ended tasks. Recently, Wang et al. 2022 introduced Voyager, an LLM-powered agent that interacts with Minecraft through text observations and high-level actions using a text-only environment to solve complex tasks. To combine the strengths of MineDojo and Voyager and solve the most difficult open-ended tasks in Minecraft, we develop MineDojo 2: a Minecraft environment with a unified observation and action space that provides access to both visual and text-based observation APIs and both high-level and low-level action APIs to build more powerful embodied agents.

Optical Parametric Amplifiers on Lithium Niobate for Single Photon Detection
Eleanor Kim
Mentors: Alireza Marandi, Elina Sendonaris, and James Williams

Photonic quantum systems often require the detection of a single photon. Superconducting nanowire single-photon detectors (SNSPDs) are the current state-of-the-art device being used for this process. However, SNSPDs lack bandwidth and require time for the current in the nanowire to reset. Recent developments in on-chip optical parametric amplification (OPA) have made OPA devices a promising possibility for single photon detection. By amplifying single photons with sufficient gain, the resulting photocurrent can be read out on a fast photodetector to infer the presence of a single photon. Here, we present a parametric amplifier capable of distinguishing single photons from a vacuum state.

Facial Expressions in Mice
Joseph H. Kim
Mentors: David J. Anderson and Amit Vinograd

Investigation of emotional states in mice have been hindered by the inaccessibility of their internal states. We demonstrate a novel method of extracting facial expressions from head-fixed mice, interpreting them, and comparing them across trials, mice, and setups. Facial expression analysis on optogenetically stimulated mice identifies unique, scalable, and persistent facial expressions associated with aggression and mating behaviors. Mouse facial expressions induced by different stimuli—physical and optogenetic—are unique and distinguishable at millisecond time scales. The scalability, generalizability, and persistence of emotion states are reflected in their respective facial expressions, suggesting that the facial expressions can be used as an objective readout of emotional states in mice. Furthermore, the direction of certain features correlates with and may encode the valence of the emotional state. Our method, hence, provides an objective tool for measuring and comparing emotional states in mice.

Effectiveness of Reward Systems in Preventing Toxic Disinhibition
Julia Kim
Mentors: Dean Mobbs and Swati Pandita

Online disinhibition is a common phenomenon in internet spaces, characterized by less restraint in a person's words and actions when they are online compared to in-person. Toxic disinhibition is a type of online disinhibition in which a person displays more harmful behavior towards others (i.e. making discriminatory comments, using rude language) when they are online. Social media is the birthplace of a lot of toxic disinhibition. Users are being exposed to increasingly more toxic disinhibition, which is correlated to becoming perpetrators themselves. This project aims to mitigate toxic disinhibition online by developing an "honoring" system that uses positive reinforcement within a chat room app. The system introduces "honors", which are awarded by a user to another user that they feel made a positive influence on the chat. As a user earns more honors, they increase their honor level and their ranking on a public leaderboard that orders all registered users. We also implement avatar border customization, where users unlock more customization options as their honor level increases. We expect that we see less signs of toxic disinhibition in the chats when the honoring system is implemented compared to without the system.

Developing a Secondary LEONARDO (LEgsONbARDdrOne) System
Matteo Kimura
Mentor: Soon-Jo Chung

This project focused on developing an updated LEONARDO system, a bipedal robot enhanced with quadcopter motors, to utilize new hardware and an updated control system. I worked on determining new, updated hardware to integrate onto a second version of the LEONARDO robot in addition to rewriting parts of the software to reflect these changes in the hardware. Developing this system has been relatively successful, however, there were several challenges that had to be overcome with troubleshooting much of the new hardware and integrating it with the rest of the system. Overall, this secondary LEONARDO provides an exciting updated and adequate test platform to continue testing multimodal forms of robotic locomotion.

Exploring Highly Energetic bbγγ Signatures From the NMSSM at the LHC
Stavros Klaoudatos
Mentors: Maria Spiropulu and Si Xie

The Next-to-Minimal Supersymmetric Standard Model (NMSSM), motivated by the μ-problem present in the N=1 extension of the Standard Model, the Minimal Supersymmetric Standard Model, in its soft supersymmetry breaking term gives rise to a trilinear coupling between 3 fields, which yields a cross section for the cascade decay of the form X -> HY. Exploring this cascade decay can give us insights into the self-coupling constants of the Higgs, whose understanding can help us better comprehend the nature of the Higgs Boson and it's potential. This study presents the terms describing said decay and presents the findings from simulations based on CMS 2017 conditions, on said cascade decay quantities. Additionally, machine learning methods for particle reconstruction in the CMS are explored, making use of signal and background data generated from the simulation.

Studying Neuronal Circuitry of Human Brain Organoids via Transparent Microfluidic Electrodes
Esme Knabe
Mentor: Maria Spiropulu

Currently, the lack of understanding of the algorithms which the human brain uses to respond to external stimulation is a limitation in numerous cutting-edge fields of research, from medicine to quantum machine learning. Since human brain organoids are grown from stem-cells in isolation from external stimuli, the provide a promising platform for understanding how neurons pattern themselves in response to specific stimulation inputs. This project aims to design and fabricate an microelectronic electrode array that is able to both stimulate and record electrical response from brain organoids grown in lab. The array will also include microfluidic pathways and optical fiber tracks, and will be completely optically transparent in order to allow for neuron identification via light microscopy.

Improving Methods of Amphibole, Pyroxene, and Zeolite Mineral Quantification With Shortwave Infrared Spectroscopy Through Analysis of Earth's Ocean Crust
Rory Knight
Mentors: Rebecca Greenberger and Bethany Ehlmann

Hydrothermal processes, while critical to the formation and alteration of the ocean crust on Earth and other planets, are not well understood due to difficulties in sampling ocean crust. Samples of the Samail Ophiolite from the Oman Drilling Project provide key insight into the hydrothermal alteration of the ocean crust. Previous studies of Samail Ophiolite samples have developed mineral occurrence maps from micro-imaging infrared spectroscopy (Greenberger et al. 2021). From scanning electron microscope measurements, we derive mineral mappings of seven oceanic crust samples acquired from Hole GT1A, including ten mineral groups: amphibole, calcite, chlorite, clinopyroxene, epidote, plagioclase, prehnite, serpentine, and zeolite. We present correlations between the micro-imaging infrared spectroscopy mineral maps and the scanning electron microscope mineral maps for amphibole, clinopyroxene, and zeolite in the Oman Drilling Project ophiolite samples.

Evolving Biocatalysts for Stereodivergent Cyclopropanation
Catherine Ko
Mentors: Frances Arnold, Jennifer Kennemur, and Yueming Long

Abstract withheld from publication at mentor's request.

Observational Signature of a Massive Neutral Gas Reservoir in the Intracluster Medium of a Galaxy Cluster at z=5.4
Umran S. Koca
Mentors: Kasper Elm Heintz and Melany Hunt

In the current concordance cosmological model, galaxies and clusters are thought to be formed through hierarchical structure formation in matter overdensities. The formation and evolution of galaxies and in particular their efficiency at producing stars and initiating the large-scale reionization of the universe is expected to predominantly occur in these regions. Identifying these overdensities of cold, neutral gas needed to fuel this process, is significantly limited due to the inaccessibility of the hyperfine 21-cm transition from neutral atomic hydrogen (HI) at these redshifts. However, HI can be probed in an alternative way through the Lyman-alpha features, imposed in absorption on bright background sources such as quasars or gamma-ray bursts, or in rare cases on galaxy spectra as well. With the James Webb Space Telescope (JWST), we have identified several galaxies in close projected distance but in the background of a proto-cluster at z=5.4 showing prominent Lyman-alpha absorption features. There is preliminary evidence that the strong Lyman-alpha damping feature observed in these galaxies are evidence of HI in the foreground cluster opposed to gas in the galaxies themselves. To solve this, I use Bayesian inference in conjunction with least squares and Nelder Mead fitting methods to constrain the redshift of the absorption feature, modeling it as a Voigt profile. Further, using the photometric template fitting code, EAZY, I extend these models to include reconstructed spectra with an added Lyman-alpha damping wing. Based on these results I identify 3 galaxies that show damped Lyman-alpha absorption features (N_HI > 10^20 cm^-2) consistent with the proto-cluster redshift, excluding a local origin at > 3 sigma. From this, I estimate the size and mass of the HI in this cluster overdensity. This is the first such detection, and provides valuable insight into the early processes of galaxy and structure formation when the universe was less than 1 Gyr old.

Devising an Algorithm to Predict Viscoelastic Properties of the Brain From Magnetic Resonance Elastography
Rohan Kolhe
Mentors: Mikhail Shapiro and (Amir) Hossein Salahshoor

The brain is a highly heterogeneous media with patient-specific material properties. Accelerated and accurate prediction of the spatially-varying material properties in a personalized manner is useful for many therapeutic applications. This project focuses on creating a computational model to find viscoelastic properties of the brain using displacement field data that is obtained from procedures like magnetic resonance elastography. We were able to complete a computational framework to derive the heterogeneous properties from the strain field data. Our physics-based approach utilizes advanced clustering techniques in data science. We showcase our approach in simple models, like a block of heterogeneous soft gel. Future steps will apply this algorithm to strain fields of the brain under ultrasound pressure to understand how ultrasound affects the elasticity of the brain.

Mechanical Characterization of Chainmail-inspired Mechanical Metamaterials
Aashutosh Kulakarni Prachet
Mentors: Chiara Daraio and Wenjie Zhou

Chainmail-inspired metamaterials are novel architected structures composed of interlocked unit cells. Their mechanical characteristics can be tuned to fulfil specific energy absorption demands by varying cell geometry, topology, and crystallography. Of particular interest is the shear response of these structures, as they demonstrate a region of zero stress that is fluid-like and a non-zero region analogous to solids, demarcated by a phase transition point. The phase transition point was found to be tunable by varying the angular arrangement of the chains. Rheological testing again revealed fluid-like decreasing trends in the storage and loss moduli until a similar critical strain was reached, after which the moduli increased sharply. This solid-like behavior observed in the shear and rheology tests was further investigated via quasi-static tensile experiments. Certain geometric and topological configurations of the chainmail had the ability to withstand 10% strain, while the material elongation at break is around 6%. Finally, tensile experiments were conducted on chains composed of interconnected trefoil knots, revealing drastic changes in stiffness with varying rotational angles. Collectively, the tunability of chainmail structures provide opportunities to service diverse areas such as robotics and structural protection, among others.

Early Detection of Alzheimer's Disease in Non-Symptomatic Older Adults: Identifying Potential Biomarkers Using Subliminal Processing Paradigms
Shrujana Kunnam
Mentors: Shinsuke Shimojo and Lara Krisst

Alzheimer's disease (AD) is an irreversible neurodegenerative disease characterized by the progressive loss of memory, cognitive ability, and executive function. Although there is no existing treatment, early intervention can delay disease progression. The most frequently used diagnostic biomarker for AD involves measuring Aβ and tau protein levels in an individual's cerebrospinal fluid. However, this technique is expensive and invasive. The current project aimed to identify a robust, non-invasive diagnostic for preclinical AD to enable early detection and response. We examined participants' performance during subliminal processing tasks rather than more explicit working memory or executive function tasks which typically only capture abnormalities during later stage AD. In one study, we recorded EEG data during a subliminal saccade/antisaccade task from cognitively healthy older adults with differing levels of amyloid/tau pathology at the Huntington Medical Research Institutes. Previous research has shown that eye movements are preceded by a shift in covert attention, as indexed by the N2pc ERP component, particularly under conditions which require increased attentional filtering. Therefore, we compared the N2pc component in participants with differing risk for AD during congruent/incongruent subliminal priming conditions to examine the hypothesis that high-risk participants have decreased attentional resources compared to low-risk participants.

BenthIQ: A Benthic Classification Tool for Coral Restoration
Rupa Kurinchi-Vendhan
Mentors: Drew Gray, Elijah Cole, Ritwik Gupta, and Pietro Perona

Coral reefs are essential ecosystems that support marine biodiversity, coastal protection, and the livelihoods of communities around the globe. Climate change-induced threats like mass bleaching, pollution, and unsustainable harvesting serve as stressors to reefs, leaving them vulnerable to disease and invasive species. High-resolution underwater benthic composition maps are critical tools for reef conservation, as they identify regions where restoration efforts should be concentrated to ensure the successful growth of planted corals. We introduce BenthIQ, a multi-label classification network which achieves pixel-wise labeling of underwater substrates such as live coral, rubble, sand, and algae. Commonly deployed CNN-based semantic segmentation models are limited by their inability to learn global and long-range semantic information well due to the locality of the convolution operation. Recently, Vision Transformers have achieved state-of-the-art performance in vision tasks such as object detection and image classification. We integrate the hierarchical Swin Transformer as the backbone of a U-shaped encoder-decoder architecture for local-global semantic feature learning. Preliminary results demonstrate that BenthIQ outperforms traditional CNN-based approaches on multi-label classification accuracy metrics. Our model can be integrated into reef analysis tools to create benthic classification visualizations and provide statistics on the relative abundance of underwater substrates for areas of interest in shallow reefs.

Recyclable Porous Carbon Solids for Oxygen Recovery in Long-Term Space Exploration
Alice Kutsyy
Mentors: Katherine Faber and Laura Quinn

The Sabatier reactor has traditionally been utilized for CO_2 to O_2 recycling within spacecraft cabins. However, only around 50% of oxygen is recovered, so recent work has been done to add a methane pyrolysis reactor, which breaks down methane and increases oxygen recovery to nearly 100%. This groundbreaking technology only has carbon as its byproduct, which is then deposited onto high-surface area carbon capture substrates. However, the consumable substrates required for long-term exploration are heavy - about ⅔ of the system weight for a 1000-day mission. Therefore, this study aims to design a porous carbon solid that can be used, broken down into a powder, then remade into a fresh substrate. Crucially, this solid must be entirely composed of carbon to keep the chemical composition constant despite carbon deposition across lifecycles. Sample substrates were provided by Honeywell Aerospace, which were then characterized via scanning electron microscopy, Raman spectroscopy, X-ray diffraction analysis, and mercury porosimetry to determine the ideal properties of the final porous solids. These substrates were broken down into a powder using various crushing processes, including a sledgehammer and a ball mill. The ball milling process was optimized by exploring various parameters such as solvents, milling media, and rinse conditions. Subsequently, the resulting powder was freeze-cast, yielding various porous carbon solids by adjusting freezing conditions, sintering temperature, and solvent selection. These newly formed specimens were characterized and compared against the original substrates before being broken back down into a powder. This study can help evaluate how the carbon capturing substrates in the methane pyrolysis may be broken down, as well as explore freeze-casting as a new fabrication method for such substrates.

Progress Toward a Divergent Total Synthesis of the Mitomycins
Lulu Kwan

Mentors: Brian Stoltz and Kevin Gonzalez

Mitomycins are a family of natural products which have been of interest to the scientific community due to their potent anticancer properties. Since their isolation in 1965, only two total syntheses of any A or B series mitomycin have been achieved. Although successful, these syntheses were racemic and lacked divergence due to the complex framework of the mitomycins. A novel route to synthesise mitomycin B will allow for the preparation of non-natural analogues and will open up routes to create mitomycins of other series. Our route centres around accessing a key vinyl-quinone to use as an electrophilic coupling partner. Successful amination of this quinone will forge a crucial C-N bond and will enable completion of our total synthesis via an asymmetric, convergent total synthesis of mitomycin B.

Bacterial Biosensors for Ultrasound Imaging of Intestinal Diseases
Jamie Ha-Young Kwon
Mentors: Mikhail Shapiro and Marjorie Buss

The rapid advancements in the field of synthetic biology have facilitated the genetic manipulation of bacteria to incorporate sensors capable of detecting biomarkers associated with intestinal inflammation. These genetically engineered bacteria, commonly referred to as "diagnostic gut bacteria," exhibit immense potential due to their enhanced efficacy, cost-effectiveness, and reduced invasiveness. Acoustic reporter genes code for gas vesicles (GVs), which are nanostructures with hollow interiors, can be genetically encoded within bacterial strains. With the incorporation of acoustic reporter gene that induces gas vesicle formation, we aim to spatially image the inflammation site using ultrasound. Upon exposure to sound waves, these gas vesicles generate ultrasound contrast, thereby facilitating the quantification of GV expression levels. Here, we implement the acoustic reporter genes to create bacterial biosensor capable of detecting kynurenine, while concurrently improving the existing thiosulfate sensor. We explore diverse strategies such as changing the origin of replication, reducing the operon size, incorporating recombinase base switch, as well as utilizing a T7 polymerase feedback loop, to refine the sensor performance.

Using Machine Learning to Classify Autism From Oculomotor Features
Audrey Lai
Mentors: Ralph Adolphs and Na Yeon Kim

Quantifying gaze behavior through eye tracking has unveiled distinct patterns in autism, offering potential for screening and diagnosis. However, it has been difficult to identify reliable visual features that can be used to distinguish autism across different studies. This project investigates whether autism can be classified using oculomotor features obtained over a sufficiently long and diverse set of stimuli, without needing to decompose the stimuli into specific objects such as faces. Participants with autism (N = 13) and control participants (N = 19) completed a series of tasks using a Tobii eye tracker. These tasks consisted of well-validated measures to prompt specific eye movements, as well as naturalistic viewing of images and movies. We established an optimal method for characterizing oculomotor events (e.g., fixations, saccades, and smooth pursuit) through the application of a machine learning-based algorithm. We then compared properties of those events, such as duration, velocity, and acceleration, between the autism and control groups. The findings will advance our understanding of oculomotor signatures in autism, and have the potential to enhance early detection of autism.

On-chip Sample Interactions in LNOI
Tze King Lam
Mentors: Scott Cushing and Emily Hwang

To realize on-chip sample interactions for fully integrated entangled photon spectroscopy, inline spectral filters and sample interaction architectures must be developed to distinguish pump photon excitations from entangled photon light-matter interactions and facilitate measurable on-chip sample interactions. Using ANSYS Lumerical, we have computationally explored a long-pass filter design based on directional couplers (DC) in the lithium niobate on insulator (LNOI) platform. This DC filter design can theoretically attenuate the pump light (406 nm) by 15 dB while enabling near 100% transmission at the downconverted entangled pair center wavelength (800-830 nm). A linear taper (LT) was also optimized to combine the filter with an on-chip spontaneous parametric down conversion (SPDC) source on the same material platform. Finally, simulated transmission spectra for polymethyl methacrylate (PMMA) doped with indocyanine green (ICG) on a straight waveguide suggested the viability of sample interaction mediated by the coupling of the fundamental TE mode with the cladding.

Developing Adaptive Optics Techniques and Instrumentation Implemented for Direct Imaging and Characterization of Exoplanets
Luke Lamitina
Mentors: Dimitri Mawet and Jorge Llop Sayson

While many methods for studying exoplanets exist, direct imaging provides many new possibilities. Direct imaging gives many insights into the characteristics of a planet, especially its atmosphere. While this technique provides much insight, we must go to great measures to ensure that we are only receiving light from the desired exoplanet. Since the planets that are being studied are so close to their host stars, it is exceedingly difficult to discern the planet from stray starlight. To do this, the Exoplanet Technology Lab at Caltech employs techniques such as wavefront control and coronagraph technologies to observe exoplanets at a high contrast level. In this project, I worked on an environmental control system for the HCST testbed and analyzed data taken from telescopes such as Keck Observatory and Palomar Observatory.

Exploring HP1-Mediated Heterochromatin Silencing and the Role of SUMO and PxVxL Motif Interactions
Dillan Lau
Mentors: Alexei Aravin and Qing Tang

Heterochromatin, a highly condensed form of chromatin, plays an important role in gene silencing. Epigenetic markers, modifications which do not alter DNA sequences, can initiate and perpetuate heterochromatin. In particular, histone 3 lysine 9 trimethylation (H3K9me3) is known for constitutive heterochromatin formation and the repression of repetitive DNA elements. Histone methyl transferases catalyze H3K9me3 deposition, while HP1 proteins read this mark, prompting chromatin condensation. This project investigates the model behind HP1-mediated silencing. Unexpectedly, the protein SUMO emerges as vital for H3K9me3 deposition. Additionally, HP1-binding proteins have a consensus PxVxL motif that binds to HP1's chromoshadow domain, but when HP1 is mutated at W174A, the PxVxL interaction is killed and HP1 loses its silencing ability. The theorized model proposes an unknown protein containing the PxVxL motif that can bind to HP1 and interact with SetDB1 in a SUMO-dependent manner. TRIM24, CAF-1, and ATRX were selected as potential candidates and subject to Co-IP assays with and without NEM to test for these qualities. The results have yet to ascertain a definitive model, and further work needs to be done investigating additional complexity and alternative models. For example, SetDB1 can be SUMOylated, which was explored through plasmid transfection and Western Blotting.

Generating Realistic and Safety-Critical Traffic Scenarios for Autonomous Driving Systems Testing Using Conditional Diffusion With Compositional and Classifier-Free Guidance
Jonayet Lavin
Mentors: Baishakhi Ray, Ziyuan Zhong, and Steven Low

Generating safety-critical traffic scenarios using traffic simulators is fundamental for comprehensively evaluating modern autonomous driving systems (ADSs). Due to the substantial costs from the increasing number and complexity of embedded systems in modern ADSs, as well as the risks associated with running large-scale real-world tests, ADS developers rely on extensive testing in simulations. To achieve traffic simulations that are both realistic and safety-critical, recent advances from diffusion modeling and differentiable logic were used to develop a conditional diffusion model, which was guided with compositional objectives to perform controllable traffic simulation testing (CTST). By using a hierarchical reward function for rule composition, multiple objectives were achieved in tandem, not just criticality (near-collision situations). Due to the inherent tradeoff between rule satisfaction and trajectory realism, CTST was implemented with classifier-free guidance to leverage these two components. Additionally, CTST was extensively evaluated on the nuScenes dataset, establishing the first scalable testing framework for generating highly realistic and critical traffic scenarios with respect to strong baselines, and marking the first usage of conditional diffusion for ADS testing with scalable compositional and classifier-free guidance.

Cross-Talk and Higher Order Computations in Nuclear Receptors
Jordan Lay
Mentors: Michael Elowitz and Yodai Takei

Nuclear receptors (NRs) are ideal drug targets since they act as both signal receptors and transcription factors. They are of great interest medically and biologically due to their involvement in various physiological functions and diseases. Understanding the architecture of receptor interactions and the resulting cellular changes will enable improved drug design and inform biological programming efforts. Despite this importance, a detailed understanding of cross-talk between receptors is lacking, as previous studies primarily focused on individual components in isolation rather than an interacting network. Thus, this project explores how NRs as a system compute "inputs" by sensing multi-dimensional ligand environments and perform the appropriate "outputs" by executing transcriptional programs that determine cell fate. We induced human liver hepatoma cell lines, an ideal model system exhibiting high NR activity, with various combinations of receptor agonists and analyzed the resulting transcriptomic changes with barcoded bulk polyA mRNA sequencing followed by identification of differentially expressed genes. To generate a more comprehensive understanding of combinatorial NR systems, future work involves expanding the methodology to single-cell technology, incorporating information from receptor binding locations on the genome, and developing high-throughput nascent RNA sequencing methods to improve temporal resolution.

Appearance of Entropy in the Growth of Cardinalities of Orbits of Flags
Ryan Leal
Mentor: Juan Pablo Vigneaux Ariztia

For certain groups, parabolic subgroups appear as the stabilizer of flags under some action that the group takes on a vector space. The cardinalities of these orbits asymptotically reveal entropies of certain systems. Interpreting their quotients as multinomial coefficients, the multiplicative chain rules that occur in these cardinalities appear as additivity of entropies asymptotically. Symmetric groups are particular instances of finite reflection groups; we study the aforementioned quotients for such groups and their asymptotic behavior in connection with entropic functionals. Their Dynkin diagrams provide a more unified description of the multiplicative chain rules that appear. We also introduce flags of vector spaces as natural objects on which the groups act on and that are stabilized by the parabolic subgroups. We also investigate the asymptotics for the Symplectic and Orthogonal groups. For these finite Chevalley groups we investigate the chain rules that appear from interpreting their quotients as multinomial coefficients. Further research could include a general construction of the asymptotics for quotients of arbitrary finite Chevalley groups.

Using Supervised Machine Learning to Predict the Regioselectivity of C–H Oxidation Sites in Complex Molecules
Gina Lee
Mentors: Sarah Reisman, Jules Schleinitz, and Alba Carretero

Targeted C–H oxidations, which split C–H bonds into C–O bonds, can derive complex molecules from other pre-existing molecules rather than synthesizing them *de novo*. As a result, they allow for greater efficiency in the synthesis of complex molecules. However, due to the multitude of existing sites where oxidation may occur, it is extremely difficult to manually pinpoint the most effective site to create the product. Thus, this project aims to utilize supervised machine learning to predict the most reactive sites within a complex molecule, where the desired product will be created. A Random Forest model, which utilizes a “wisdom of the crowd” method by generating numerous decision trees, is used, and a set of electronic descriptors are generated through quantum chemical methods for each carbon atom in the data set. The model is then tested and run through the data set of 288 unique reactions using their descriptors, with the reactions split between the testing and training sets. The accuracies are then compared to a baseline established by a method based on the atoms’ Gasteiger charges, and the model is improved based on its performance with numerous proportions of testing and training data splits.

A Compact and Efficient Chemical Boltzmann Machine That Learns
Inhoo Lee
Mentor: Erik Winfree

Biological cells make decisions based on signals from their environment, demonstrating the ability of small chemical systems to process information and motivating the interpretation of a model of chemistry as a model of computation. A model of interest is the Stochastic Chemical Reaction Network (SCRN), which can capture aspects of the chemistry at scales where cells exist: chemical states specify integer counts of molecules, and the trajectory of the system is nondeterministic. SCRNs have already been shown to be capable of complex computation. In recent times, advances in synthetic molecular computers and growing research into the molecular basis of learning have spurred investigations into constructions of abstract chemical systems that can learn and perform probabilistic inference. We propose two improved variants of Chemical Boltzmann Machines (CBMs), mappings of Boltzmann Machines (BMs) onto SCRNs. A BM is a completely recurrent stochastic neural network that is capable of inference and learning. Stochastic neural networks are naturally implemented in SCRNs because of the nondeterminism of the model and the connectivity between molecules. Prior work has demonstrated constructions of CBMs that exactly simulate BMs but only at the cost of utilizing an impractical, exponential number of reactions, as well as constructions that use a more feasible quadratic number of reactions but at the cost of only poorly approximating the BM distributions. Our first CBM has similarities to gene regulatory networks and maintains the quadratic order of reactions, but better reflects the state probabilities of a classical BM. Our second CBM has a mutable, molecular count encoding of the weights and has additional reactions that can perform a wake-sleep-inspired learning scheme. Our work suggests that small scale chemical systems need not be less powerful. The nondeterminism allows us to draw from the field of stochastic learning algorithms and develop surprisingly efficient constructions for learning. The pursuit of efficient SCRN implementations of learning models not only raises deep questions about the power of randomization and its role in biology but also may provide insight into the processes of the cell and physical implementations in synthetic cells.

Production of HIV-1 Env Proteins for Screening Anti-Caldera Antibodies
Natalie Lee
Mentors: Pamela Björkman and Luis Caldera

After four decades, HIV-1 remains a global health challenge as the virus evades vaccine efforts and other therapeutic treatments through its high mutagenicity and morphological characteristics. HIV virions are heterogeneously decorated with few spike glycoproteins called Env, which the virus uses to infiltrate $CD4^+$ T cells. These Env trimers are positioned sparsely across the virion's membrane, making it difficult for antibodies to bind to and neutralize HIV. An effective strategy, therefore, might require intra-spike binding of highly conserved regions within the same spike trimer. The aim of this project is to create an antibody-based reagent that would neutralize HIV-1 more effectively by targeting conserved residues in what we call the "caldera" region, which is accessible only in the Env protein's pre-fusogenic "open" conformation after it binds to its target, CD4. If successful, our antibody-based reagent, an anti-caldera antibody fused with soluble CD4, would be used to target Env with high affinity and high avidity. To this end, we engineered and produced SOSIPs, soluble versions of HIV-1 Env, to be used in anti-caldera antibody screening using molecular cloning, bacterial transformation, mammalian transfection, and protein purification methods.

Engineering TEV Protease to Increase Auxin Sensitivity in a Macrophage-CAR-T Two Cell Circuit
Mengziang Lei
Mentors: Michael Elowitz and Kaiwen Luo

Numerous attempts have been made to circumvent the challenge of antigen heterogeneity in CAR T cell therapy. Nevertheless, these attempts typically rely on a single-cell design, which does not address T-cell infiltration issues, and may have a potential inability to achieve complete tumor killing. A macrophage-CAR-T two cell circuit has been conducted in mammalian cells with the bio-orthogonal auxin to amplify signals from rare tumor-exclusive antigens. The TEV protease in the T cells constantly cuts the CAR and can be inhibited by the auxin. However, the current system exhibits limited responsiveness to the auxin. In this study, to increase CAR-T cells' sensitivity to the auxin signal, we engineered the TEV protease to possess reduced stability or decreased efficiency by introducing mutations, improving the auxin-inducible degron, and attaching additional degron. Even though introducing new mutations into the TEV protease did not improve auxin sensitivity, in the end, we produced a TEV protease with a DHFR tag that led to 49% CAR-T cell activation rate in response to the auxin and are ready to test it in the killing assay.

Flexible Flying Surfaces for Dynamic Multi-Modal Flight
Steven Lei
Mentors: Morteza Gharib and Ioannis Mandralis

Unmanned Aerial Vehicles (UAVs) are quickly gaining in popularity in a range of fields such as search and rescue, exploration, as well as package delivery. However, the rigid design of these systems limits the possible flight modes that can be explored. By loosening these restrictions, we can hope to design flying vehicles that can achieve more agile and energy efficient flight. In this work, we utilize a set of embedded brushless motors, inertial measurement units, and thin mylar sheeting to produce a flexible flying surface that flies in both a folded and unfolded configuration. This mechanism possesses the ability to achieve multi-modal flight (flapping and hovering) while also allowing freedom for shape manipulation. We investigate the controls necessary for this mechanism, with current results showing that a modified proportional-integral-derivative (PID) controller can achieve basic flight. More experimentation will be conducted to produce stable flight with smooth shape control.

Hydrothermal Alteration of the Ocean Crust and on Other Planetary Bodies Through Imaging Spectroscopy: Quantifying Chlorite, Prehnite, Epidote, and Calcite
César León
Mentors: Bethany Ehlmann and Rebecca Greenberger

Earth's ocean crust covers around 60% of the surface of the planet and hydrothermal systems are very common on Earth and other planetary bodies. Yet, geochemical interactions which form, cool, and alter oceanic crust are not entirely understood. Additionally, access to samples is not easy or cheap. In this project, we are looking at (~1.2 km; 3 holes which are ~400m each, GT1A, GT2A, GT3A) drill core samples of the ocean crust from the Oman ophiolite recovered by the ICDP Oman Drilling Project. This region of oceanic crust is particularly interesting because it is an area where ocean crust and parts of the upper mantle outcropped onto the surface (ophiolite) which provides easier access. These cores were measured with imaging spectroscopy, in the visible-shortwave infrared (VSWIR), and samples were selected for scanning electron microscopy (SEM). We classified minerals using existing spectral mineral maps derived from absorption features in spectra and correlating them with elemental maps from SEM measurements. Classification maps show more detailed and higher resolution mineral groupings compared with the spectrally derived maps. Using the classification maps, we are quantifying and characterizing end member minerals. The results are important for quantifying mineral abundances and improving interpretation of imaging spectroscopy data.

Simultaneous Velocity and Temperature Measurements Applied to Combustion Processes
Kyle Lethander
Mentors: Joseph Shepherd and Charline Fouchier

Understanding thermal ignition is critical for safety and performance in aviation and process industries. However, the standard method of autoignition testing (ASTM E-659) is limited to visual observation and pointwise temperature measurements. Recent work has demonstrated the promise of thermographic particle image velocimetry (TPIV) for obtaining full-field velocity and temperature measurements in high-temperature flows. This technique is applied to study thermal ignition by seeding a test volume with BAM:Eu^{2+} phosphor particles, illuminating the flow with a combined 532/266 nm pulsed light sheet, imaging the scattered light for PIV analysis, and detecting the luminescence intensity of two emission bands for temperature measurements. The spectral response to temperature was investigated for particles on a heated surface, and a temperature calibration using two-color thermography achieved better than 20 °C accuracy for surface temperature measurements over 20 °C – 550°C. A luminescence imaging system was designed to capture 2D intensity fields of two emission bands, and a similar calibration was performed on BAM:Eu^{2+} particles suspended in a gas flow. Finally, the temperature calibration was applied in conjunction with a previously developed PIV system to provide full velocity and temperature fields inside a combustible mixture preceding thermal ignition.

Closed Geodesics on Genus 0 Triangular Unitary Shimura Curve
Guanxi Li
Mentor: Elena Mantovan

Shimura varieties have become the center of the study of number theory in recent years. In this project, we will explore the number-theoretic properties of closed geodesics on triangular unitary shimura curves. Sarnak has shown that the geodesic on the projected upper half-plane that connects real points has a compact image under projection onto the modular curve if and only if it has non-trivial stabilizers generated by one element. Additionally, Sarnak has shown the number-theoretic property of the length and multiplicity of closed geodesics on shimura curves. Bekki later generalizes the statements regarding endpoints and stabilizers of the modular curve to quaternionic shimura curves and the (2,3,7)-shimura curve. In this project, we generalized these statements for triangular unitary shimura curves, specifically for the case of (2,3,10) triangle group, for which we obtained the explicit representation of the group and also the expression for the endpoints of the geodesics. We generalized Sarnak result regarding length and multiplicity to the (2,3,10)-unitary shimura curve, which states that the length of the closed geodesics is $2\log(\epsilon)$, where ϵ is the fundamental relative unit of $Q(\zeta_5)(\sqrt{D})/Q(\zeta_5)$, and we conjectured the multiplicity of the geodesics to be $h^{o}_{Q(\zeta_5)}(D)$, the narrow class number of the field $Q(\zeta_5)(\sqrt{D})$. This conjecture could be potentially proven by establishing one-to one correspondence between primitive hyperbolic elements in the triangle group and equivalent classes of quadratic forms.

Magnetic Field Dependence of Excited State Dynamics in Nickel–Bipyridine Photoredox Catalysts
Melody Li
Mentors: Ryan Hadt and David Cagan

Carbon–heteroatom bond-forming reactions via transition metal photoredox cross-coupling catalysis can bring revolutionary changes to the pharmaceutical field. By utilizing light for chemical potential and replacing the use of precious metals that are relied upon heavily today, transition metals provide a more sustainable and cheaper alternative. In particular, nickel–bipyridine (bpy) complexes pose themselves as promising candidates. These photoactive molecules can undergo one electron chemistry, presenting alternate electronic states that allow for new reactivity prospects in the drug discovery process. However, these prospects may not be utilized to their full potential without first understanding nickel's complex excited state electronic structure. Low quantum yields for productive Ni(I) formation prohibit direct ultrafast spectroscopic studies of the key excited state Ni(II)–C(aryl) bond homolysis step, and it is also unclear if this elementary step is chemically reversible. Furthermore, these Ni(I)–bpy halide $3d^9$ complexes are paramagnetic, and their magnetic properties have yet to be explored. To further understand the nickel ultrafast dynamics leading to catalytically active species, we have designed magnetic field-dependent optical transient absorption (TA) experiments using a tandem Cryomagnetics superconducting magnet (0 – 5 T) and a Helios TA spectrometer. The underlying kinetics of the intersystem crossing (ISC) from the long-lived ^{3}(d-d) excited state to the ground state were perturbed by the magnetic field. The addition of Kessil LEDs to the TA magnet set-up was used to observe any magnetic field dependence of the photogeneration of Ni(I). The combination of obtaining the ultrafast kinetics of the excited states and discovering possible magnetic field-impacted photogeneration may pave the way for developing more effective and facile C–X bond reactions.

Proteomics Examination and Structural Elucidation and Phospholipase A2 Activating Protein Mutant and Interaction With Valosine-Containing Protein (P97)
Xuan Li
Mentors: Tsui-Fen Chou and Katelyn Radford

PLAA is a regulatory element that modulates phospholipase (specifically PLA2) and its disease mutant was linked to lethal neurodevelopmental disruption and autism spectrum disorder. This project seeks to uncover PLAA mutant structure as potential therapeutic target and further the understanding of PLAA regulated ubiquitination processes, which have been lowly characterized during mammalian neurodevelopmental processes. Additionally, proteomics examination will reveal binding confirmation PLAA and P97, a cancer therapeutic target valosine-containing protein, and trace out related co-factors. Lastly, Cryogenic Electron Microscopy and computationally assisted folding models was adopted to characterize the binding moiety between PLAA-P97 and mutant structure of PLAA.

Nickel-Catalyzed Enantioselective α-Alkenylation of Amides
Yuxuan Li
Mentors: Gregory C. Fu and Asik Hossain

Developing more efficient and robust methods for carbon-carbon bond formation is one of the long standing challenges for synthetic chemists. Specifically, carbonyl groups that bear an α-stereocenter are a common motif in biologically active molecules. Enantioselective α-functionalization methods of carbonyl compounds are potentially useful approaches in the syntheses of target molecules in academia or industry. Herein we describe the progress on enantioselective α-alkenylation of amides, demonstrating that a nickel-BOX ligand complex can accomplish desired transformation using racemic Reformatsky reagents and vinyl bromides. Systematic optimization of reaction condition with investigations of all possible reaction parameters was performed, followed by ligand modification aiming at achieving further improvement in yield and enantioselectivity. Preliminary substrate scope study was carried out to test the compatibility of the method for substrates with diverse functional groups and structural motifs. Mechanistic experiments will be conducted in due course, to gain insight into key intermediates and steps involved in the catalytic cycle.

The Abundances of CO, H_2O, and OCS in Venus's Atmosphere From Observations and Modeling
Ting-Juan Liao
Mentors: Yuk. L. Yung, Eliot Young, and Mark Bullock

Scientific investigation into Venus's atmosphere has spotlighted gaps in photochemical models' ability to explain the trace gas species distribution. Key elements such as CO and OCS are essential to Venus's sulfur cycle and cloud formation. To understand the abundance and variability of these trace gases before the DaVinci probe's descent, we launched an observational study using NASA's IRTF telescope equipped with the ISHELL high-resolution spectrometer. From June 11 to June 30, 2023, we captured K, H, and J-band spectra of Venus's night side, utilizing the SMART software to calculate synthetic spectra across various gas abundances and emission angles. Our high-resolution spectral data ($R=\lambda/\Delta\lambda\sim25{,}000$) enabled the successful mapping of CO, H_2O, and OCS abundances in the equatorial region, revealing daily and latitudinal variations. We specifically examined the sensitive balance between chemistry and transport, as indicated by the anti-correlation between OCS and CO abundance with cloud opacity. Through near-IR observations, this study seeks to untangle the complex interaction between atmospheric dynamics and chemical reactions in Venus's cloud formation. We contribute insights into the observed cloud patterns and the relationship between atmospheric chemistry, dynamics, and cloud creation on Venus, thereby providing vital parameters to refine photochemical models.

Scalable Learning of Non-Gaussian Graphical Models
Sarah Liaw
Mentor: Ricardo Baptista

In recent literature, the Sparsity Identification in Non-Gaussian Distributions (SING) algorithm has been used to identify conditional independencies of a collection of non-Gaussian random variables. The SING algorithm utilizes the relationship between the sparsity of a probabilistic graphical model and the sparsity of a transport map representing the distribution of the random variables to achieve this task effectively. When dealing with high-dimensional distributions, however, the computational cost of the SING algorithm becomes intractably high. In our study, we propose a localized SING algorithm, which aims to learn the conditional independencies of a large number of random variables using neighborhood selection methods. For Gaussian distributions, we demonstrate the relationship between neighborhood selection with the Lasso and linear transport maps. For non-Gaussian distributions, we extend the neighborhood selection method to develop the localized SING algorithm. We will compare the computational runtime and performance of the localized SING algorithm with the original SING algorithm. Finally, we will assess the algorithm's theoretical and experimental consistency in recovering the true graph with high probability as the sample size of the underlying distribution increases. The evaluation includes non-Gaussian datasets like the butterfly distribution and Lorenz-96 dynamical system.

Profiling of Synthetic Transcription Factors to Uncover Design Principles of Combinatorial Gene Regulation
Emily Lin
Mentors: Michael Elowitz and Evan Mun

Multicellular complexity requires the cooperation of thousands of specialized cell states derived from a singular genomic template. Each cell state is characterized by its distinct combination of transcription factors (TFs) which uniquely regulate the genome for that state. While traditional approaches to understanding natural gene regulation demonstrate the necessity of many individual TFs, they lack fundamental models of how a set of TF binding sites proximal to a gene produce a precise regulatory outcome. To uncover the rules that could underly a fundamental model of *cis*-regulation, we utilized a synthetic TF design to modularly recruit combinations of transcriptional effector domains, which are the components of TFs that dictate how the TF impacts the transcriptional output of a gene it is recruited to. Specifically, we examined how TFs respond to a controlled perturbation of the positioning, co-recruitment, and timing of regulatory events. Our initial results quantified an efficacy decay that transcriptional effectors undergo over a shared length scale. Ongoing work intends to characterize synergistic and antagonistic transcriptional effector domain combinations. Our findings highlight the rules and limitations within eukaryotic *cis*-regulation, informing optimal design for synthetic regulatory schemes and providing the core of a fundamental model for predicting regulatory outcomes.

Regioselective Aryl Amination With Hydroxylamine
Ethan Lin
Mentors: Frances Arnold and Kathleen Sicinski

Primary arylamines are found in a range of valuable compounds from pharmaceuticals to organic semiconductors. Although there exist chemical methods to synthesize arylamines, many strategies use rare and expensive transition metals or toxic organic compounds to achieve site-selective amination. Enzyme biocatalysts present a greener alternative for site-selective synthesis of anilines, as enzymatic reactions occur in gentle aqueous conditions. Enzymes catalyze numerous diverse reactions in nature and have high chemo- and regioselectivity stemming from their innate three-dimensional and chiral active site. However, no native enzymes have been discovered to catalyze primary aryl amination with hydroxylamine in nature. Herein, we discovered a class of enzymes, protoglobins, that show basal activity towards amination of an activated arene, aniline. We then utilized reaction optimization to boost the yield of a thermostable *Aeropyrum pernix* protoglobin for regioselective aryl amination of substituted arenes. We found that addition of an iron reducing agent, sodium dithionite, improved the enzymatic yield of *p*-phenylenediamine (2-fold) and *o*-phenylenediamine (1.3-fold). Additionally, altering the reaction buffer from nitrogen-free minimal salt medium (pH 7.2) to potassium phosphate buffer (pH 8) improved yield 1.3-fold. Utilizing optimized reaction conditions, we are performing error-prone PCR and site saturation mutagenesis to generate mutations of our lead biocatalyst.

Utilizing General Vision Language Models for Animal Action Recognition
Jonathan Lin
Mentors: Pietro Perona and Markus Marks

Accurate animal action recognition holds significant implications across diverse fields such as bioengineering, nature conservation, and pharmaceutical experimentation. A multi-species action recognition model offers distinct advantages over single-species models due to its versatile applicability and out-of-the-box capabilities. The current challenge with multi-species action recognition is the variety of ways different species of animals can accomplish the same action, such as climbing. We present a method for multi-species action recognition by utilizing Contrastive Language-Image Pre-Training (Radford et al., 2021) and X-CLIP (Ma et al., 2022). CLIP encodes a latent space between an image and a set of captions, while X-CLIP encodes a latent space between several images, across the temporal setting, and a set of captions. In this project, we present the results of action recognition by utilizing CLIP and X-CLIP with the general pre-trained weights. Our findings underscore the insufficiency of generalized pre-trained CLIP and X-CLIP models for precise atomic action recognition in the animal domain, emphasizing the necessity of custom pre-training to achieve heightened accuracy.

Diffusion Models for Brain-Machine Interfaces
Christina Liu
Mentors: Pietro Perona and Markus Marks

Latent models are frequently used to model neuronal activity from neural spike trains. This form of modelling allows for better estimation of the underlying neuronal manifold, which in turn can be the input source of downstream tasks such as the decoding of motor activity based on recorded neural activity. In this study we will explore how diffusion models can be used to estimate the latent neural state space from noisy samples of neural activity spikes. We build upon the existing diffusion model to represent a time-dependent score-based generative model that contains an additional epsilon variable that marks the minimum diffusion time for perturbing data in the forward stochastic differential equation (SDE) process. From this model design, we evaluate the modified diffusion model’s ability to denoise and learn the distribution of noisy data without knowing the ground truth data.

Engineering Synthetic Allostery for Phosphorylation-Based Protein Circuits
Meryl Liu
Mentors: Michael B. Elowitz and Dongyang Li

Phosphorylation is a ubiquitous post-translational modification, encoding information reversibly and dynamically in cellular signaling pathways. Synthetic protein circuits can reprogram cellular behaviors to function as sensors, switches, and amplifiers. In contrast to protease-based designs, kinase-driven phosphorylation promises to enable fast, reversible protein circuits that can sense and respond to various inputs, including endogenous signaling states and environmental stimuli. Current approaches include split-protein reconstitution and domain insertion, which require extensive fine-tuning for targets while the repertoire of engineered kinases is limited. However, mutating negatively-charged allosteric hotspots to phosphorylatable residues in physically contiguous, co-evolving sectors has previously achieved successful rewiring of yeast MAPK pathways. Here, we extend this strategy to expand the protein circuit toolbox by engineering allosterically-controlled human kinases. We developed a computational pipeline to conduct statistical coupling analysis and identify sector-connected solvent-accessible D/E residues throughout a eukaryotic kinome-wide sequence alignment. We then adapted imaging-based kinase translocation reporters for high-throughput kinase activity profiling using flow cytometry. We are conducting an alanine scan to distinguish functionally-coupled candidate residues for introducing phosphorylation motifs of an input kinase. Our work provides insights into allostery design principles and opens up avenues for the systematic development of phosphorylation-based protein circuits with composable engineered mammalian kinases.

Analyzing the Effect of Transpiration on the Propulsion of a Spinning Origami Millirobot With the Immersed Boundary Lattice Green Function Method
Charles Liu
Mentors: Tim Colonius, John Sader, and Wei Hou

Immersed boundary (IB) methods are numerical techniques that use immersed surfaces described by Lagrangian structures to solve PDEs on Eulerian grids and are implemented by adding forcing terms without modifying the underlying PDE discretization. We use a lattice Green function technique to discretize and solve the incompressible Navier–Stokes equation on an unbounded Cartesian grid. The differential algebraic equations describing the temporal evolution of the discrete momentum equation and incompressibility constraint are numerically solved by using an integrating factor technique for the viscous term and a half-explicit Runge–Kutta scheme for the convective term.

We use the Immersed boundary lattice Green function method to study the propulsion mechanism of a novel rotation-enabled amphibious milli robot designed by Zhao et al. that utilizes the geometrical features of the Kresling origami, a hollow cylinder with tilted triangular panels. A unique feature of its design is an improved swimming speed after adding radial cuts on side panels and a hole on its front plate. To uncover the flow physics behind its enhanced propulsion, we have run 2D and 3D CFD simulations with various boundary conditions to emulate its transpirating velocity and obtained visualizations of the flow field and computations of its corresponding drag.

Knowledge Distillation for Jet Tagging at the LHC
Ryan Liu
Mentors: Maria Spiropulu, Jennifer Ngadiuba, Abhijith Gandrakota, and Jean-Roch Vlimant

The challenging environment of real-time systems at the Large Hadron Collider (LHC) strictly limits the computational complexity of algorithms that can be deployed. For deep learning models, this implies only smaller models that have lower capacity and weaker inductive bias are feasible. To address this issue, we utilize knowledge distillation to leverage both the performance of large models and the speed of small models. In this paper, we present an implementation of knowledge distillation for jet tagging, demonstrating an overall boost in student models' jet tagging performance. Furthermore, by using a teacher model with a strong inductive bias of Lorentz symmetry, we show that we can induce the same bias in the student model which leads to better robustness against arbitrary Lorentz boost.

Tracking Erosion and Channel Morphologies of Single-Threaded Rivers in Permafrost Flume Experiments
Zhuo (Andy) Liu
Mentors: Michael P. Lamb and Maria N. Schmeer

Permafrost environments are particularly vulnerable to climate change, and thawing of permafrost may significantly influence the dynamics of Arctic river systems. In single-threaded rivers, lateral erosion into floodplains and deposition of sediment in point bars alters the distribution of sediment and nutrients. However, no one has yet performed experiments of a single-threaded channel through a sand and ice mixture to study how permafrost distribution may change with riverbank erosion. We perform controlled laboratory experiments to maintain a single-threaded channel that can erode and deposit at both of its banks, with flow conditions of a natural river. We design a setup that allows us to examine the effects of sediment transport and riverbank erosion on river geometry in both unfrozen and frozen cases. We quantify sediment inputs and outputs using a sediment feeder at the head of the experimental channel and a sediment trap at the end. In addition, we use images from an array of cameras to measure channel geometry (slope, width, depth) and location during the experiments to obtain the erosion rate of the riverbanks and describe the evolution of the channel. We run an unfrozen experiment that tests our setup and data and image processing techniques. The unfrozen results will be used to describe the behavior of a dynamic river channel under unfrozen conditions in the lab and allow us to prepare future frozen experiments. Overall, these results have implications for experimental work on river channel evolution, ultimately contributing to the advancement of climate-resilient strategies for fluvial systems in permafrost environments.

Tipping Point Forecasting in Non-Stationary Dynamics on Function Spaces
Miguel Liu-Schiaffini
Mentor: Anima Anandkumar

Tipping points are abrupt, drastic, and often irreversible changes in the evolution of non-stationary and chaotic dynamical systems. For instance, increased greenhouse gas concentrations are predicted to lead to drastic decreases in low cloud cover, referred to as a climatological tipping point. In this paper, we learn the evolution of such non-stationary dynamical systems using a novel recurrent neural operator (RNO), which learns mappings between function spaces. After training RNO on only the pre-tipping dynamics, we employ it to detect future tipping points using an uncertainty-based approach. In particular, we propose a conformal prediction framework to forecast tipping points by monitoring deviations from physics constraints (such as conserved quantities and partial differential equations), enabling forecasting of these abrupt changes along with a rigorous measure of uncertainty. We illustrate our proposed methodology on non-stationary ordinary and partial differential equations, such as the Lorenz-63 and Kuramoto-Sivashinsky equations. We also apply our methods to forecast a climate system tipping point in stratocumulus cloud cover.

Whole-Cell Segmentation on Multi-Channel Images Using Self-Attention Mechanism
YuHsiang Lo
Mentors: Yisong Yue, Uriah Israel, Markus Marks, and Xuefei (Julie) Wang

The advancements in biomedical image segmentation have enabled a better understanding of spatial and functional relationships of cells in tissues. With the introduction of multiplexed imaging, the number of concurrently quantifiable protein markers has increased, resulting in multi-channel images that provide improved opportunities for precise segmentation. However, existing segmentation models depend on fixed-channel input images, which restricts the information richness of bio datasets, as these datasets frequently consist of varying and numerous channels.

To address these challenges, we introduce a foundational image segmentation model capable of accommodating input images with varying numbers of channels. To do so, we investigate how to incorporate multiplexed information as inputs in the Segment Anything Model(SAM). We intend to employ the self-attention mechanism on the embeddings produced by passing the multiplexed channels through the encoder, and the combined embeddings will then be used as inputs for the decoder. This approach will enable our model to perform whole-cell segmentation on multi-channel images.

Implementing the Smagorinsky-Lilly Eddy Viscosity Model Into the Climate Modeling Alliance's Large Eddy Simulation
Lana Lubecke
Mentors: Tapio Schneider and Haakon Ervik

Climate models are an important tool for studying climate change and may be used to predict changes in the statistics of the Earth system. Climate models provide data and evidence that inform policymaking, which means the reliability of these climate models is paramount. Clouds play a major role in regulating the temperature of the Earth, yet they are prohibitively difficult to model because their energetic turbulent dynamics occur on the scale of meters, while the resolution of numerical models is on the scale of hundreds of kilometers. Thus, the inter-institutional Climate Modeling Alliance (CliMA) relies on parameterizations to faithfully model the subgrid-scale dynamical processes. The Smagorinsky-Lilly eddy viscosity model is the canonical way to represent subgrid-scale turbulence. This model was implemented in the CliMA atmosphere model, and the performance was assessed against the Barbados Oceanographic and Meteorological Experiment test case.

Modeling Viscous Compressible Flow for the Diffuse Boundary Simulation of AP/HTPB Burn
Juan Luchsinger
Mentors: Brandon Runnels and Melany Hunt

The deflagration of solid composite propellants, particularly ammonium perchlorate embedded in a hydroxyl-terminated polybutadiene binder (AP/HTPB), can be complex to simulate. This project aims to develop a computational model that simulates and couples the solid and gas phases of AP/HTPB burn, with a focus on the simulation of the gaseous phase and the role viscosity plays in this process. The model utilizes the self-similar diffuse boundary approach and couples it with adaptive mesh refinement to improve upon traditional methods for simulating complex multiphase flows. This combination allows for the precise modeling of the complex geometries and topological changes while minimizing computational costs. By simplifying the flux boundary conditions of source terms such as Couette flow, we can apply these examples to the model to verify its accuracy.

Documenting and Visualizing the Vegetation and Soil Biogeochemistry Models in the CliMA Land Surface Model (ClimaLSM)
Vespera Qinwen Luo
Mentors: Christian Frankenberg and Alexandre A. Renchon

Earth system models (ESMs) are state-of-the-art climate models that account for feedbacks between managed and unmanaged land, the ocean, the cryosphere, and the atmosphere. Each component is developed separately, and the land processes are represented by land surface models (LSMs). Existing ESMs are legacy models from the 1960s and are written in the FORTRAN programming language. These models usually lack modularity, are difficult to operate, and are poorly documented. The Climate Modeling Alliance (CliMA) employs recent advances in computational and data sciences to build a more accessible ESM that provides a new level of accuracy in predicting climate change. In particular, CliMA employs a modular structure, assembling land process submodels like puzzle pieces. This summer project contributed to the development of a clear and comprehensive online documentation that incorporates interactive visualization tools for each submodels of ClimaLSM. I reconstructed and explained the parameterization and differential equations that set up the submodels, summarized variables, units, initial values, and ranges into tables, and created multiple interactive figures. Some of these submodels are: radiative transfer, leaf photosynthesis and stomatal conductance, heterotrophic respiration, and soil and plant hydraulics. This work will facilitate the communication of LSMs to the scientific community and the public.

Identifiability of a Class of Statistical Models With Latent Symmetries
Eric Ma
Mentor: Leonard Schulman

The workhorse of modern deep learning is the neural network, which are mathematical models parameterized by a large number of variables. Deep learning has achieved great success recently in fields like computer vision and natural language processing. Understanding this success requires a rigorous understanding of the mathematical properties of neural networks. The product of experts is one mathematical representation of one layer of a neural network. It is a directed bipartite graph consisting of latent nodes and observable nodes, all nodes being random variables (RVs) that take on one of two values. The observable nodes are binary RVs with moments that are polynomials in the values of the latent variables. We show a tight bound for the number of moments needed for identifiability when the number of latent variables is 2 or 3 and make progress towards a general method for showing identifiability using methods from algebra and number theory.

Assessing Cell Motility of *Escherichia coli* Using the Subtractive Photonics Process in 180 nm CMOS
Antônio Victor Machado de Oliveira
Mentor: Ali Hajimiri

This study explores the optogenetic manipulation of bacterial motility using an integrated circuit for targeted applications such as pathogen elimination and drug delivery. The research relies on the controllable movement of *E. coli*, a widely studied model organism, which exhibits distinctive run and tumble states. Prior efforts using chemotaxis for motion control have highlighted limitations in spatial precision. To overcome this, optically regulated genetic circuits have been introduced, employing a phosphoprotein phosphatase to govern flagella rotation. With previous studies demonstrating complex pattern formation on a petri dish, bacterial motility is shown to be controlled in microchip environments using integration of photonics and fluidics in a CMOS chip. The chip's design, employing subtractive photonics, facilitates optical illumination control in specific zones. A bifurcated fluidic path, when illuminated, induces swimming or tumbling bacterial behavior, enabling differential measurement of concentration through biofluorescence encoded in genetically engineered *E. coli*. Successful outcomes hold potential for broader optogenetic applications, including in vivo bacterial manipulation for therapeutic purposes.

Improved Deep Learning-Based Reconstruction for 2D Phase Contrast MRI
Ishaan Mantripragada
Mentors: Shreyas S. Vasanawala, Matthew J. Middione, Julio A. Oscanoa, Daniel B. Ennis, and Lior S. Pachter

Magnetic Resonance Imaging (MRI) is a non-invasive imaging technique to produce detailed soft tissue anatomical images without exposing the body to ionizing radiation. The measured MRI signal can be represented as complex numbers which generate magnitude (real component) and phase images (imaginary component). Typically, MRI images are presented as magnitude images, which generally offer a qualitative view of the patient's anatomy and structure. On the other hand, PC-MRI stores valuable information about the velocity of flowing blood. 2D PC-MRI oftentimes requires patients to hold their breath for up to 20 seconds during a scan, to eliminate the effects of respiratory motion. However, this poses challenges for both sick and older patients. To reduce breath hold durations, we propose a solution that involves undersampling the data collection, which shortens the scan time but produces inaccurate image reconstructions with conventional reconstruction approaches. We plan to use fully sampled 2D PC-MRI images and a Convolutional Neural Network to generate a deep learning-based reconstruction that learns how to reconstruct accurate PC-MRI images from undersampled images. Similar techniques have already been demonstrated in the literature and offer ≤12x reduction in scan time for magnitude images and ≤ 8x reduction in scan time for 2D PC-MRI.

Experimental Determination of the Nitrogen Isotopic Fractionation During Core Formation in Rocky Protoplanets and Planets
Darius Mardaru
Mentors: Paul D. Asimow and Damanveer S. Grewal

Knowing the origin and evolution of nitrogen and other life-essential volatiles in rocky bodies is key to understanding the formation of habitable worlds in our Solar System. One way to track their journey in the planetary nebula is by using their isotopic composition in iron meteorites, the remnants of the metallic cores of the earliest formed planetesimals in the Solar System. Because different groups of iron meteorites sample different regions of the early Solar System, reconstructing the $^{15}N/^{14}N$ of their parent bodies can provide valuable insight into the dynamics of the nitrogen budget of the Solar System. To study the nitrogen isotopic fractionation, we performed high pressure-temperature experiments at conditions relevant to core formation (1 GPa, 1200-1400°C) using a metallic mixture, analog for the core composition of the earliest planetesimals. We measured the solid and liquid composition of the quenched experiments using an Electron Probe Microanalyzer, which helped us adjust future experiments to explore most of the relevant compositional parameter space. Then, we will measure the nitrogen fractionation using a Secondary Ion Mass Spectrometer and backtrack the isotopic ratio of the parent bodies of iron meteorites.

Relationships Between Nighttime Light, Economic Variables, and Covid-19 in the United States
Katherine Marquis
Mentor: Pawel W. Janas

Covid-19 has caused over 1 million deaths in the United States by May 2022 (WHO). Nighttime light (NTL), as used as an indicator of human activity, may reflect Covid-19 transmission and severity. This study attempts to assess the relationship between NTL and Covid-19 by assuming that high NTL radiance levels indicate a large amount of human contact to spread Covid-19 and that significant drops in NTL radiance levels correspond to quarantine or deaths due to Covid-19. In order to examine this relationship, NTL monthly composite satellite images from 2018-2023 were collected from NASA, county information was collected from the U.S. Census Bureau, Covid-19 case and death statistics at the county level were provided by Johns Hopkins, Covid-19 vaccination information was collected by the CDC, and economic variables were collected by Opportunity Insights. After preprocessing this data, various machine learning models were applied to the data to analyze relationships.

Bayesian Active Sensing and Planning Applied to Attitude Dynamics and Spacecraft Control
Arnauld Martinez
Mentors: Soon-Jo Chung and Jimmy Ragan

Modern spacecraft must be equipped with a high degree of fault tolerance to ensure safe and successful system operation during critical moments in the spacecraft's mission. To combat total system failure, engineers implement redundancy to allow multiple failures to occur without compromising vehicle performance or objectives. However, if a redundant system fails, the source of the failure reduces to a family of potential problems that requires significant time to analyze and repair. To combat this, the ARCL lab developed FEAST (Fault Estimation via Active Sensing Tree Search), a novel algorithm that identifies failing sensors and actuators in a redundant system. The accuracy of FEAST has been verified on planar spacecraft models. In this paper, we extend FEAST to consider the attitude/orientation of the spacecraft about its center of mass. We model the spacecraft using quaternions and vary its orientation using reaction wheels. Additionally, we build a more realistic sensing model to simulate known failure modes in monocular cameras. By designing a procedure to identify faulty sensors and actuators, we aim to increase spacecraft reliability and crew safety.

The Role of Solvent Reorganization in Aqueous Ion-Ion Interactions
Jose Martinez
Mentors: Zhen-Gang Wang and Alec Glisman

When ions are placed into a polar solvent, the finite solvent dipole results in a highly ordered solvation shell forming around the ion. Depending on the size and charge of the ion, the molecules in the solvation shells are more tightly held, limiting the rotational and translational entropy. It has been shown that ion-solvent interactions cause the overall ion pairing event to be driven by entropy gain due to solvent release, which is surprising as it is expected that ion pairing would be driven by energy for ions in a vacuum. Since ion-solvent interactions can dominate the pairing process, an all atom molecular dynamics (MD) simulation must be used to resolve these interactions. Building upon prior research, we analyzed the free energy of ion pairing as a function of separation distance and decomposed the free energy into entropic and enthalpic contributions. Utilizing all-atom MD simulations, we studied solvated systems of NaCl and $CaCl_2$ and drew conclusions on the role of entropy in ion pairing. A greater understanding of the role of solvent entropy in ion interactions can lead to advances in rational pharmaceutical and material design, with applications in medicine, water treatment, and battery engineering.

Asymptotic Growth Rate for the Number of Tilings of a Regular Dodecagon
John Griffith Mattson, Jr.
Mentor: Nets Katz

In this paper, we try to compute $S(n) := |T_n|$, where T_n is the set of all tilings of an n-sided dodecagon out of equilateral triangles and rhombi with small angle 30º, both of side length one, with equivalence up to rotational symmetry. First, we present an algorithm for finding all possible ways of tiling an arbitrary outline, and then we apply this algorithm to compute $S(1)$. This algorithm essentially involves finding all the ways to tile the boundary, and then use a sequence of a few tricks to split the space of all possible solutions into further-refined disjoint subsets of that space. To compute $S(n)$, we present a few more algorithms, including: one, a procedure for "ballooning" a solution in T_n to a solution in T_{kn}, where k is a positive integer; two, a procedure for completing a solution in T_n to a solution in T_{n+1}; and, three, a procedure for making a solution in T_n that contains at least $(3n^2 + 1)/4$ dodecagons of side-length one, where n is any odd number. We begin by using the first algorithm to establish that there are, in fact, solutions in T_n, where n is greater than 1. We then use the second algorithm to establish that the sequence $\{|T_n|\}_{n\in\mathbb{N}}$ is exponentially increasing. Finally, we use the third algorithm to establish that this same sequence is $\Omega\left(S(1)^{\frac{3}{4}n^2}\right)$.

On a Counterexample to the Milnor Conjecture in Dimension 7
Haydn Maust
Mentor: Antoine Song

Measures of the curvature of a Riemannian manifold can be used to derive strong results concerning the structure of the manifold. In this project, we are interested in sectional and Ricci curvature. Milnor conjectured in 1968 that every complete manifold with nonnegative Ricci curvature has finitely generated fundamental group. This conjecture has been proved for manifolds of dimension ≤3, but recently Elia Brué, Aaron Naber, and Daniele Semola discovered a counterexample in dimension 7. Their paper constructs a universal cover manifold with a group action by the group $\mathbb{Q}/\mathbb{Z}$ so that the quotient space has fundamental group $\mathbb{Q}/\mathbb{Z}$, which is infinitely generated. The universal cover is constructed using a very complicated gluing procedure which is made possible by proving novel results on the mapping class group $\pi_0\mathrm{Diff}(S^3 \times S^3)$. We provide an exposition explaining the innovations used to construct this counterexample manifold, including the requisite study of $\pi_0\mathrm{Diff}(S^3 \times S^3)$.

Curating a Retrospective Art Exhibit for the Caltech/JPL Data to Discovery Program
Ethan McFarlin
Mentors: Santiago Lombeyda and Hillary Mushkin

Melding the spirit of scientific inquiry with foundational research in human-computer interaction and visual perception, Caltech's Data to Discovery (D2D) Initiative aims to demystify complex data sets through the design of interactive visualization systems. Past projects launched by the initiative vary precipitously not only in their means of visualization but also their underlying scientific focus— from tracking the movement of the Mars' Exploration Rover to simulating glacier flow in Antarctica. The wide breadth of projects undertaken combined with the 10 year anniversary of the program engenders the opportunity to revisit unexpected parallels and insights uncovered by D2D. This paper describes the development of a comprehensive retrospective to revisit and communicate those visual and scientific insights in a manner that is widely digestible to those outside the field. The process of creating the retrospective involves curating raw material for an interactive art exhibit and thematically analyzing connections between projects.

CP Violation in Neutrino Oscillations: Examining the Statistical Behavior of Neutrino Beam Experiments
Jude McLean
Mentor: Ryan Patterson

Current neutrino beam experiments such as Fermilab's NOvA and Japan's T2K have worked to observe muon neutrino to muon neutrino and muon neutrino to electron neutrino oscillations. Both have attempted to quantify the parameters governing these flavor changes using data fitting techniques. In doing so, each has produced a set of best fit values in disagreement with one another. Moreover, many of these best fit models point towards maximal CP (Charged-Parity) violation, but with the limited data we have and the experimental constraints of the two beams, it is hard to trust the validity of these results. By simulating both experiments thousands of times we've quantified how often we fall into these maximal regimes, and by extension how trustworthy or untrustworthy our current fits are. Ultimately, we've been able to better understand the behavior of each experiment in conjunction with the relevant fitting techniques. As the next generation of neutrino beam experiments, including DUNE and Hyper-K – the respective successors of the two current beams – continue to take shape our research will necessarily provide insight and guide our interpretations of the best fit results we produce.

Distinguishing Experimental Groups of Animals Through Unsupervised Learning
Cameron McNamee
Mentors: Pietro Perona and Markus Marks

Understanding behavior is crucial for understanding the brain. Manually distinguishing behavioral patterns is labor-intensive, time-consuming and potentially prone to human biases.. Using machine learning (ML) we can overcome each of these shortcomings. Training ML models in a supervised setting requires vast amounts of annotated data, which do not exist for animals and collecting this data is costly. Instead, we employ XCLIP, a large vision-language model, to derive video embeddings of animal movements. We try to learn the differences in behavior across experimental groups by analyzing these video embeddings. We utilize an Autoregressive Hidden-Markov-Model (AR-HMM) to temporally cluster these embeddings into behavioral states. We use the number of occurrences of those states and their transition matrices to describe behavioral differences across experimental groups. Specifically we validate our approach by describing behavioral differences in sheep that underwent neurosurgery.

Kinetic Inductance Detector Analysis and Simulation
Mira Menezes
Mentor: Sunil Golwala

Low mass dark matter, with masses in the MeV range, will only deposit energy on the eV scale in a detector. We are developing Kinetic Inductance Detectors (KIDs), which are able to sense phonons deposited by these low energy interactions. Each detector consists of a superconducting aluminum LC circuit. When phonons hit a detector, they break the cooper pairs in the detector into quasiparticles, making it superconduct less well. This can be easily read out in a change to the LC circuit's quality factor and frequency. KIDs are easily multiplexed on a single wafer, and this allows for improved screening of background noise. To be able to interpret results from an array of KIDs, we must understand how the array reacts to various inputs. We analyze the results of various experiments, including behavior where highly energetic devices lose their energy much faster than other devices. We have also created models to understand the behavior of phonons moving through the array as a whole.

Thermal Imagery of Callisto From ALMA Calibrator Data
Cole Meyer
Mentors: Katherine de Kleer, Xander Thelen, and Maria Camarca

Compared to more active satellites, Callisto, one of Jupiter's four Galilean satellites, is understudied and there exist few spatially resolved thermal images of its stable and relatively unaltered surface. Thermal images at different wavelengths probe varying subsurface depths of cold, icy bodies like that of Callisto and therefore can inform us about its composition, thermophysical properties, and history of impact craters. The relatively inactive surface of Callisto makes it a popular flux calibrator for observatories such as the Atacama Large Millimeter/submillimeter Array (ALMA) with thermal continuum data across multiple frequency bands, including those for which we do not have science data. Many of these data have not been evaluated for science merit and could inform us about whether future science runs in those unexplored frequency bands may be valuable. We identify nine calibration observations of Callisto between 7/16/2012 and 11/4/2012 within the 602 GHz to 720 GHz frequency band (0.4 mm to 0.5 mm) with spatial resolutions sufficient to resolve major craters on the surface. We present high-quality thermal images for three of the nine observations. Future work will include generating thermal images for the remaining six observations and searching for geologic surface features.

Impact of Topography on the Pressure Diffusion Into an Aquifer
Lucie Michelin
Mentor: Xiaojing (Ruby) Fu

In recent years, CO_2 capture and storage (CCS) has gained significant attention as an effective method for mitigating atmospheric CO_2 levels. While underground reservoirs are considered ideal sites for CO_2 storage, concerns persist about potential seismic events and surface deformations resulting from reservoir exploitation. To address these concerns, we propose an efficient two-phase flow model based on the vertical flow equilibrium (VFE) hypothesis by considering negligible vertical flow. Through the application of the VFE hypothesis to the laws of mass conservation and Darcy, we achieve a highly efficient model using the FEniCS library in Python. Nevertheless, the influence of topography on reservoir pressure distribution has remained unexplored. Given that natural reservoirs may not exhibit flat characteristics, it becomes crucial to understand the impact of topography on pressure distribution to ensure safety during CCS activities. To address this gap, we have modified the VFE model's pressure distribution equations to incorporate topography terms. This enhanced model enables us to compare the effects of topography in different CO_2 injection scenarios, including single-phase and multi-phase models, and apply it to reservoirs with complex geometries. The results underscore the significance of considering topographical variations when predicting pressure distribution, providing valuable insights for optimizing CO_2 storage and underground activities.

Using the Novel Neural Network SPANet to Study HH4b Decays
Caden Mikkelsen
Mentors: Harvey Newman and Javier Mauricio Duarte

Studying the cross section of di-Higgs production at the Large Hadron Collider (LHC) is a challenging, but accessible way to measure the trilinear self-coupling constant. We use the novel Symmetry Preserving Attention Network (SPANet), a modified transformer, to study di-Higgs events that decay into $b\overline{b}b\overline{b}$ ($H\!H\to$ 4b decays). Because $H\!H\to$ 4b decays are currently one of the most sensitive channels to measure the trilinear self-coupling constant, we wish to test if SPANet is able to improve the reconstruction of these events enough to further restrict the possible range of values of the constant. We generate a number of different SPANet models trained on different datasets and inputs in order to optimize our model's reconstruction abilities. We find that our best model's reconstruction efficiency is approximately 116\% of the current leading $H\!H\to$ 4b reconstruction technique.

Designing an Optimized Robotic Ankle for a Bipedal Robot
Julian Millan
Mentors: Aaron Ames and Adrian Ghansah

This project aims to redesign a proper ankle for a bipedal robot built by Caltech's AMBER Lab. Moving on from stick feet, this new design will have a motorized ankle allowing for rolling and pitching motion. The design will also include a passive toe joint that would allow the robot to have a more efficient walking gait. This form of ankle design will allow for greater balance and efficiency and will also allow the robot to travel rougher terrain than the smooth and soft lab floor. The primary goal of our work this summer is to create a fully fleshed out 3D model in an application such as SOLIDWORKS that includes all of our motorization, attachments, and main body of the ankle. At the end of the summer, a 3D printed model will be created to better demonstrate the mechanism of the ankle. The proper creation of this design will allow further progress to be made on the robot and further ankle design iterations to be made.

Physically Informed Machine Learning Emulators of Aerosol Activation Trained on a Lagrangian Particle-Based Model
Mikhail Mints
Mentors: Tapio Schneider and Anna Jaruga

A significant part of the uncertainty in climate change forecasts arises from microscopic interactions within clouds, which occur on a scale that is much smaller than the resolution of current climate models. Since it is too computationally expensive to directly simulate these processes, climate models must rely on microphysical parameterizations. This project focuses on modeling aerosol activation – the process by which water vapor condenses onto aerosol particles to form cloud droplets. Climate models approximate aerosol populations as a set of lognormal modes, and thus the competition between aerosol particles for the available water vapor needs to be parameterized. The Abdul-Razzak and Ghan (ARG) parameterization, currently used in many climate models, makes approximations that cause it to produce inaccurate results in certain conditions. The goal of this project is to construct a data-driven aerosol activation emulator trained on PySDM – a detailed Lagrangian model that represents the interactions within a population of particles from first principles using the Super-Droplet Method. Existing physical approximations based on ARG are added to the training data, and the performance of several machine learning techniques is evaluated against PySDM. Previous work is extended by constructing emulators for more generalized, multimodal aerosol distributions.

Effects of Autism Spectrum Disorder-Associated Mutations on Endosomal Sorting Functions of p97
Bertha Mireles
Mentors: Tsui-Fen Chou and Mengcheng "Windy" Wu

Ubiquitous ATPase p97, also known as valosin-containing protein, is involved in the regulation of a wide range of integral cellular functions, including the regulation of signal pathways and proteostasis. Due to its involvement in the governing of proteostasis, mutations in p97 are directly linked to a variety of neurological diseases, such as amyotrophic lateral sclerosis (ALS) and frontotemporal dementia. One aspect of proteostasis regulated by p97 is endosomal sorting, a step in the endosomal pathway involving endocytic sorting of lipids and receptors. Previous studies have determined the endosomal pathway is crucial for adequate neural function and linked its dysregulation to autism spectrum disorder (ASD), which is characterized by repetitious sensorimotor behavior and social communication impairment. In this study, I use liquid chromatography mass spectrometry and proteomic analysis to investigate the effect of ASD-associated mutations in p97 on binding of relevant cofactors involved in endosomal sorting regulation. This investigation allows for better insight into the link between p97, endosomal sorting dysfunction, and the genetic etiology of ASD.

SQUID as an Amplifier for Sensitive Barkhausen Noise Measurements
Shanya Mishra
Mentors: Thomas Rosenbaum and Daniel Silevitch

The use of a Superconducting Quantum Interference Device (SQUID)-based amplifier can drastically improve the sensitivity of magnetic measurements, enabling the detection of events that involve very few spins, with the challenge that mechanical vibrations in closed-cycle cryostats can drown out the signals of interest. We demonstrate that a SQUID can be used as an amplifier in such a system. Vibrations in the cryostat were mitigated by the installation of air bearings and wrapping a sheet of Sorbothane (a material specifically for shock absorption and vibration damping) around the pulse tube cryocooler. We wound a matched pickup coil for the SQUID with a room-temperature operational range demonstrating a flat response between 3 Hz and 20 kHz. The assembly of the SQUID and pickup coil was then characterized at 2 K by measuring the background noise spectrum and the frequency response to an applied ac magnetic field. The background noise amplitude showed an improvement by a factor of around 4 in comparison to the noise amplitude measured in a previous SURF project prior to the vibration mitigations. The frequency response of the SQUID-based amplifier was flat below 10 Hz but varied at higher frequency, so further work is needed to optimize the parameters of the feedback loop to linearize the response. The sensitivity of the SQUID-based amplifier will be tested by performing measurements on a sample of permalloy. In the future, the SQUID-based amplifier can be mounted on a helium dilution refrigerator and be used to make extremely sensitive Barkhausen noise measurements on quantum ferromagnets.

Exploring Human Magnetoreception: Examining How Magnetosensory Information Influences Behavior and Modulates Multisensory Integration
Maxwell Montemayor
Mentors: Shinsuke Shimojo and Lara Krisst

Magnetoreception is a sensory modality whose existence is well established in animals, but is not well researched in humans. Our research builds upon a 2019 study that found that some people exhibited a neural response to a magnetic field that mimics the earth's, although participants did not consciously perceive it. To further probe the existence of this sense, we carried out a series of tests to see how magnetosensory information may influence behavior and how it is integrated with other sensory modalities. In experiment 1, participants chose which of 4 dixie cups contained a magnetized disk underneath. In experiment 2, participants chose which of 4 buttons had a powered electromagnet underneath. In a third EEG experiment, subjects were exposed to a magnetic field sweep moving left or right horizontally, then were asked to report the direction of the sweep, while EEG data were collected. In an additional set of studies which examined the cross modal integration of implicit and explicit information, participants reported the direction of perceived visual motion of dots moving on a screen, while concurrently being exposed to a directional but implicit audio cues. We aimed to measure how implicit auditory, visual, and magnetosensory information integrate.

Molecular Mechanism of Nucleocytoplasmic Transport of p38α and cGAS
Frida Moreno
Mentors: André Hoelz and Chia Yu Chien

Nested between the inner and outer lipid layers of the nuclear envelope, nuclear pore complexes (NPCs) are the sole gateways that mediate the bidirectional macromolecule transport between the cytoplasm and nucleus. One of the macromolecules that relies on the NPC for intracellular transport is mitogen-activated protein kinase 14 (MAPK14), also known as p38α. MAPK14 is critical for directing cell growth, differentiation, and apoptosis in addition to stimulating immune responses against external stressors. Thus, the hyperactivity of MAPK14 in the nucleus carries detrimental health implications ranging from mild inflammatory disorders to autoimmune diseases and cancers. By researching the route taken by MAPK14 into the nucleus, it becomes possible to explore the nuclear transport inhibition as a solution to the negative effects of dysregulated MAPK14. Alongside the research being conducted on MAPK14, the transport of the primary immune sensor of cytosolic DNA, cyclic GMP-AMP synthase (cGAS), is also under investigation. Progress on recombinant protein purifications and pull-down technique has allowed for further pathway analysis with the hopes of identifying the critical transport factors for p38α and cGAS.

Geometric Optimization of Mesh Spacer Gaskets Used in Electrodialysis for Direct CO_2 Capture From Ocean Water
Cameron Morgan
Mentors: Chengxiang Xiang and Monica Hwang

As climate change threatens the world and human life, new technology able to remove carbon dioxide from the atmospheric and oceanic environment is necessary. Capturing CO_2 from ocean water using an electrodialysis cell processes is an exciting but challenging prospect, currently having economic and energy limitations. To reduce energy consumption within the cell, each component must be optimized for mass and ion transport. In this project, geometric optimization of membrane mesh spacers used to direct the bulk fluid flow was investigated. A new system was designed to isolate the effect different spacer geometries have on an applied voltage to maintain a desired current. Rectangular, hexagonal, and oval shapes for the mesh, at 90- and 45-degree attack angles were investigated and related to literature. By experimenting with different redox coupled electrolyte solutions in the new system, we were able to increase the sensitivity for evaluating the different geometric effects on energy consumption—successfully isolating parameters for mesh spacer optimization within an electrodialysis cell.

Measuring Ice Grain Growth Rate in the Caltech Dusty Plasma Experiment From Size and Wavelength Dependent Laser Extinction
Robert Morgan III
Mentors: Paul Bellan and Andre Nicolov

The Caltech Ice Dusty Plasma Experiment studies the dynamics of ice grains suspended in a weakly ionized plasma at T=80-150 K. In one to two minutes, water vapor forms elongated fractal-like ice grains that can grow up to 750 microns. While there is substantial research on the ice grains once they stabilize in size, the growth rate is unexplored. One possibility for tracking growth rate is by measuring the attenuation of light passing through the dusty plasma. A laser beam emitting two wavelengths at 532 nm and 1064 nm passes through the plasma, and the exiting beam is split by a wavelength-dependent beamsplitter and measured using two photodiode detectors. When the grain sizes are comparable to the wavelength, Mie scattering occurs. The degree and direction of scattering depend on the incident angle, particle size, grain number density, and wavelength. As the grains grow, scattering from 532 nm will differ from the 1064 nm. This difference will indicate the growth rate and changes in other parameters such as number density.

Validation of Thermophilic Eukaryotic Model Organism Through the Reconstitution of Cytoplasmic Filament NPC Complex
Anna Mortari
Mentors: Andre Hoélz and George Mobbs

Nuclear pore complexes (NPCs) regulate the transport of macromolecules in and out of the nucleus, which is essential for controlling gene expression and cellular homeostasis. Using X-ray crystallography, the structures of many nucleoporins, the protein constituents of the NPC, have been resolved at atomic resolution. *Alvinella pompejana*, a species of extremophile thermophilic worms that live in deep sea vents, have been shown to have NPC sequence and structural similarity to the *Homo sapiens* homolog. Through protein purification and X-ray crystallography, the structure and the biochemical complexities of the apNup88^{NTD}•apNup214^{Tail}•apNup98^{APD} complex are elucidated. Additionally, the thermophilic nature of the protein complex is shown through thermostability assays of the constituents of the complex. These conclusions will allow for broader knowledge of the NPC and confirmation of potential biochemical interactions in homologous species.

Optimization of Non-Linear Optical Waveguide Parameters to Generate Single-Mode and Spectrally Uncorrelated Photon Pairs
Shivam Mundhra
Mentors: Alireza Marandi, James Williams, Elina Sendonaris, and Robert Gray

Photon pairs have a vast array of applications in quantum information science, from quantum communication protocols to photonic quantum computing. Single-mode pairs are the most desirable for such applications due to the pair exhibiting spectral uncorrelation, where the measurement of one photon projects the other onto a pure quantum state, and multiple independent sources can be made to demonstrate quantum interference. Thin-film lithium niobate (TFLN) has recently emerged as a promising platform for integrated nonlinear photonics, but current waveguide designs still lack the phase-matching conditions for type-0 spontaneous parametric down-conversion to produce photon pairs limited to a single temporal mode. We utilize a machine-learning framework to optimize for waveguide dimensions, poling design, and input pump pulse structure to achieve high spectral purity, a measure of spectral uncorrelation between photon pairs. We further demonstrate the applications of our engineered waveguide through nonlinear time-domain simulations which show that the outputted single-mode photons can be utilized for an ultra-fast quantum random number generator. The results from our optimization framework and nonlinear optical simulations show promise for the use of the TFLN platform in a variety of quantum information and photonics applications such as quantum key distribution, sensing, metrology, and computation.

Nitrogen Fixation via Proton-Coupled Electron Transfer Using a Pyrene-Based Mediator
Ramona Wanjiru Murugu
Mentors: Jonas C. Peters and Catherine G. Romero

In the quest for efficient electrochemical ammonia synthesis, the hydrogen evolution reaction (HER) often outcompetes the nitrogen reduction reaction (N_2RR) due to the limited stability and selectivity of current catalysts. To address the HER dominance, recent efforts have focused on tandem catalysis, which involves a molecular complex for reduction combined with a co-catalyst for photocatalytic proton-coupled electron transfer (*pe*PCET), which can be electrochemically recycled at comparatively mild potentials. This innovative approach harnesses light to provide additional driving force without resorting to harsh potentials. By utilizing a modified ferrocene complex with an amine base and an anthracene photosensitizer, irradiation induces intramolecular electron transfer, yielding a high-energy anthracene radical anion colocalized with a proton on the amine base, able to deliver H-atom equivalents to N_2RR intermediates. To further enhance the process, switching to a pyrene-based mediator with an extended excited state lifetime of 89.39 ns is proposed to improve stability and quenching yield of the charge separated state. We discuss the synthesis of this novel pyrene-based mediator, characterize the new compound, and compare its performance to previously studied cobaltocene and anthracene-based mediators.

Denoising Three-Dimensional Bacterial Biofilm Images Using Machine Learning
Mia Mutadich
Mentors: Dianne K. Newman and Georgia R. Squyres

Over the last two decades, the development of high-resolution, three-dimensional imaging has been instrumental in unveiling the structural and dynamical complexities of biofilms, enabling researchers to better understand their development and functions. However, direct observation of individual cell behavior within biofilms has been limited by the low signal-to-noise (SNR) of fluorescence microscopy images. We are applying deep neural networks for image restoration to three-dimensional images of biofilms to reduce noise without blurring the underlying signal – a limitation of previous techniques that I aim to overcome. To develop a neural network for this task, we started with a simpler 2D data set with a known ground truth. Because SNR in 3D biofilms varies with depth, we represented this by acquiring 2D images at various SNR levels. We trained a number of existing neural networks architectures on these images and wrote an algorithm to compare their performance, selecting one that performed best on the full range of representative SNR values and optimizing it accordingly. Finally, after developing a method to simulate noise in three-dimensional biofilm images, we aim to be able to retrain our optimized neural network on our semi-synthetic dataset so that it can denoise three-dimensional images.

Formal Compositional Design of an Automobile System Using Pacti and Contracts
Jack Myles
Mentors: Richard Murray and Inigo Incer

An important aspect of systems engineering is identifying the specifications of the various components that are needed to facilitate the design, integration, and management of a complex system. Contract-based design is a recently developed methodology that complements other system design approaches for effectively managing high-complexity systems, using assume-guarantee specifications, expressed as linear inequalities, to model the components of the system. Pacti is a recently developed open-source Python package for carrying out compositional system analysis and design. We explore the ability of Pacti to create a system model for an electric automobile. We have developed various contracts to represent the components of the system, and have used them to identify estimates of the capabilities of the vehicle in a variety of real-world scenarios. Multiple different viewpoints can be analyzed, including the efficiency of the automobile in converting energy to distance traveled and the effect of components' cost with varying performance on efficiency. These viewpoints can be useful in analyzing the model from both a business and engineering perspective. Our utilization of Pacti to apply contract-based design to an electric automobile defines the potential for applying Pacti and contract-based design methods to model-based systems engineering of other complex electromechanical systems.

A Joint-Sentiment Topic Modeling Approach to Examining the Effect of Social Media Discussions on Gaming Activity
Shreya Nag
Mentor: Michael Alvarez

This research project aims to investigate the relationship between discussion on social media and real-world events in the context of online gaming, with a specific focus on the game *Call of Duty*. The primary objective is to explore the connection between online sentiment and game updates. Leveraging Python, we will collect and preprocess data from Reddit and Activision's proprietary sources, enabling us to visualize posting patterns and keyword trends. We will utilize joint-sentiment topic modeling to estimate sentiment and topics in daily social media posts, revealing insights into player experiences, including issues such as abuse and harassment. Our work provides a systematic approach to uncovering the relationship between social media conversations and online gaming engagement. The project's conclusions offer valuable insights for game developers and researchers alike, shedding light on the dynamics between player sentiment and usage patterns. The research aims to contribute to understanding how online communities influence gaming behavior and to measure players' exposure to negative experiences.

Theoretical Model for Two-Level Systems (TLSs) and Finding Their Microscopic Origin
Manas Nagda
Mentor: Marco Bernardi

The field of quantum computing has witnessed remarkable advancements, with superconducting qubits emerging as a promising platform. However, the performance of these qubits is often hindered by decoherence induced by two-level systems (TLSs) present in the surrounding environment. The recent work on TLS physics in superconducting circuits has focused on finding ways to understand and remove TLS within metal oxide surfaces and junctions. Hence, knowing what a TLS is necessary, not just how it behaves. The primary objective of this research is to model the interaction between TLSs and superconducting qubits and determine the microscopic origin of TLSs. By analysing and studying different models and going through the literature, it was theorized that the high-frequency noise is primarily due to the localized TLSs. Further study on the density of these localized states by looking at the Urbach tails of increasingly disordered SiO_2 with oxygen vacancies implied the same. Further research aims to understand the role of electrons, these localized states, and the resulting TLS behaviour.

Euler-Kronecker Constants and Cyclotomic $\mathbb{Z}_p$-extensions
Kenji Nakagawa
Mentor: Anna Szumowicz

For any number field, there is an analog to the celebrated Riemann zeta function associated with it, referred to as the Dedekind zeta function. The Euler-Mascheroni constant can be realized in several ways, such as the constant term of the Riemann zeta function or as an error term of an arithmetic approximation of the natural logarithm. Analogously, the Euler-Kronecker constants show up in similar fashions for number fields, as well as in a variety of other contexts. Some work has been done on computing the Euler-Kronecker constants for particular families such as cyclotomic fields and their maximal real subfield in connection to some conjectures by Ihara and a few have recently been shown to be almost true or true on average. We generalize some of the theoretical work done by Ihara on the first level of $\mathbb{Z}_p$-extensions from Iwasawa theory to hold for other finite levels of $\mathbb{Z}_p$-extensions as well as use some computational methods previously developed to compute the associated constants of these levels.

Generalization Properties of Deep Learning Models Trained With Regularizer Mirror Descent Using Different Regularizer Functions
Gustav Nauclér
Mentor: Babak Hassibi

Despite modern deep learning models being highly over-parametrized they can often generalize well to unseen data. It is understood that this is partially due to implicit regularization given by the learning algorithm. In cases where additional regularization is required, for example when data is corrupt, explicit regularization such as weight decay is often used. The problem with these methods is that they do not come with any convergence guarantees. A novel method has been proposed to solve this problem, Regularizer Mirror Descent, which utilizes convergence properties of Stochastic Mirror Descent to minimize the sum of training loss and an additional regularizer function of the weights. In this project we train a ResNet-18 architecture on the Cifar-10 dataset with various levels of corruption using the Regularizer Mirror Descent algorithm with different l_q norm regularizer functions. We investigate the generalization results together with the characteristics induced on the weights of the models.

Analysis of Higgs Boson Pair Production in the Bottom Quark-Antiquark Pair and Two Fully Hadronic Vector Bosons Final State Using Proton-Proton Collision Data in CMS at the Large Hadron Collider
Andres Nava
Mentors: Harvey Newman and Nan Lu

The Higgs boson, postulated in 1964 and discovered in 2012 at CERN's Large Hadron Collider, is fundamental to understanding how elementary particles acquire mass. Since its discovery, significant attention has been directed towards the study of Higgs boson pair production, providing insights into vital parameters of the Higgs field. Our research builds on a current analysis searching for standard model nonresonant double Higgs production, targeting the bottom quark-antiquark pair and all-hadronic final vector boson pair states in the scenario where both Higgs bosons are highly Lorentz-boosted by investigating the vector boson fusion production channel. By employing the latest machine learning techniques, including ParticleNet and Particle Transformer, we achieve a heightened accuracy in identifying jets indicative of Higgs decays, crucial for enhancing signal sensitivity and suppressing potential backgrounds. Initial investigations have been conducted on simulated data, with plans to extend our research to real datasets.

Impact of Pancreatic Adenocarcinoma on the Duodenum Microbiome in Mouse Models
Paulina Naydenkov
Mentor: Rustem F. Ismagilov

Abstract withheld from publication at mentor's request.

Quantum Corrections and the Single Copy of Worldline Operators in Gravitational Theories
Vinicius Nevoa
Mentor: Clifford Cheung

Inspired by the well known BCJ double copy, this work attempts to push the mapping between gravity and gauge theories beyond the level of amplitudes to the level of extended operators in flat space. We devise a way of mapping the color structure of a Yang-Mills Wilson loop to the corresponding gravitational holonomy that holds up to quantum corrections to order $1/M_{pl}^3$. Following the amplitude level double copy, we use the action of N=0 supergravity to compute correlators on the gravitational side, and the matching fixes the coupling of the dilaton, graviton and Kalb-Ramond two-form field to a spin 1 decorated worldline. In order to decorate the worldline with more degrees of freedom, we explore the mapping $F_{\mu\nu}{}^{a}$ --> $\omega^{ab}{}_{\mu}$, which motivates the discussion of curved backgrounds with non-trivial spin connection holonomy in this formalism.

Variation of Protic Ligand in Well-Defined Sm^{II}-based PCET Donors: Thermochemistry and Selectivity
Bao Nguyen
Mentors: Jonas C. Peters and Emily Boyd

The well-defined Sm^{II} complex with a dimethylcyclam-derived multidentate ligand is a powerful reducing agent. Recent work by Boyd and Peters has demonstrated that pairing the Sm^{II} complex with a protic ligand, such as methanol or 2-pyrrolidone, yields useful proton-coupled electron transfer (PCET) reagents with remarkably weak O-H and N-H bonds. Herein, we investigate the thermochemistry and reactivity of various other protic ligands with the Sm^{II} complex. We determine the effective pK_a of tert-Butanol and the $[Sm^{III}]^+$ complex to be 21.0 and explore the reactivity of the Sm^{II} complex and 2-oxazolidinone derivatives with chiral auxiliaries as possible asymmetric hydrogen atom transfer reagents.

Kanerva Networks as Models of Syntactic Parameters
Thanhthanh Nguyen
Mentor: Matilde Marcolli

In the field of linguistics, the "Principles and Parameters" model of syntax suggests that natural languages' grammars are guided in terms of vectors of binary variables, known as "syntactic parameters". These parameters are thought to be responsible for global language properties such as word order, negation, etc. Some criticisms of this model include its inability to produce a complete set of such parameters across languages, the lack of clear relations between parameters, and whether or not a clear set of independent variables exists among the known parameters.

Using a mathematical model developed by Pentti Kanerva in 1988, which is a network designed to represent human memory, this project aims to test the rigor of the "Principles and Parameters" model. The Kanerva network, also known as sparse distributed memory (SDM), is responsible for modeling how the human brain stores syntactic parameters and deriving dependence relationships between them. This project builds off of prior work done under Professor Marcolli's direction, which investigated the reoccurrence of certain syntactic parameters in different languages and the level of "recoverability" of certain parameters as a function of others using associative memory.

Machine Learning Based Approach to Comparing Gene Variant Detection Methods
Ali R. Niazi
Mentors: Ashish Mahabal and Lisa Guan

Understanding gene variants is fundamental to understanding the mechanisms that drive cellular function, inheritance, and molecular development of diseases. Many traditional sequencing methods result in inaccurate variant calling and remain limited in detecting variants at lower sample percentages, variant sizes, and other genomic features. We used Genome Editing samples from Amplicon Sequencing (AmpSeq) data (n = 25), and from Duplex Sequencing (DuplexSeq) data (n = 5) and evaluated comparative variant calling performance. We found that both methods largely inaccurately called variants, with low True Positive Rates (TPR), with the majority of variants not being called at all. We designed a Machine Learning (ML) based framework that takes in binary alignment and map (BAM) files in pileup format and uses a Ridge Classifier to predict variant calls. Thus, we hope to provide a data-driven, ML-based solution to variant calling inaccuracies to improve existing methods of next-generation sequencing technologies.

Testing the Preservation of Cells and Organics in Soda Lake and Putative Mars Conditions
Emily Nikas
Mentors: Alex Sessions and Makayla Betts

There are many different ways in which evidence for early microbial life on Earth can get preserved. However, there are significant unknowns in the pathways to microbial fossilization. This leads to the question of what environments and diagenesis conditions can preserve organic material and other microfossils. Therefore, this project aims to identify what pH and salinity conditions of the environment will still allow for the preservation of cell structure and biomarkers. We will also analyze the effects of mineralization on the organic matter. This will be tested by incubating our biomass with different clay types, the differing structures of which can influence the bonding to organic matter. The results of these incubations will allow for a better understanding of organic matter preservation in the extreme environments of early Earth and putative Mars conditions.

Identifying and Classifying Misinformation About Cryptocurrencies on Twitter
Jamal Omosun
Mentor: R. Michael Alvarez

Misinformation on Twitter, especially around cryptocurrency, has long been a topic of conversation on the platform. There has been a long history in the crypto community on Twitter of bot accounts, spam, scam, and misinformation. Recently there have been incidents where misinformation has had an effect and actively influenced crypto trading and market prices such as in the case of the currency Ripple. The goal of our project is to train models that can accurately identify misinformation involving cryptocurrencies and classify them. We gathered a large dataset of thousands of tweets and then tested them against a preselected selection of misinformation key phrases and other such identifiers. The results of this analysis give us an idea of how likely any given tweet is to be misinformation, a scam, or from a bot account.

Investigating Decision-Making Processes Through Gambling Choices
Ella Onderdonk
Mentors: Antonio Rangel and Brenden Eum

The primary focus of this study was understanding decision-making processes using a simple choice model involving gambling. We utilized a Standard Drift Diffusion Model (DDM) to explore the decision-making thresholds of participants, providing valuable insights into their cognitive processes. Through this analysis, we aimed to gain a better understanding of the factors influencing participants' choices and the dynamics behind their decision-making. During our experiment, we presented participants with a series of trials in which they had to make choices based on circles of different sizes and colors (red representing a loss, green representing a gain, and the size of the circle representing the magnitude of the potential gain or loss). As anticipated, our results revealed a significant correlation between the likelihood of participants choosing to play a trial and the average presentation of positive stimuli, as well as an increased reaction time when stimuli were more ambiguous or neutral. These observations highlight the impact of emotional valence and risk aversion on decision-making behavior.

Synthesis and Thermochemical Characterization of *ortho*-Carborane Derivatives as a Proton Coupled Electron Transport Mediator
Matthew Ong
Mentors: Jonas Peters and Enric Adillon

The sustainable activation and reduction of small molecules including CO_2 and N_2 into useful products has been a field of ongoing interest. One such method to achieve this conversion is through *proton coupled electron transport* (PCET) using a molecular mediator. Previous work in the Peters group has shown the potential of *ortho*-carboranes as a platform for PCET mediation in the reduction of model substrates. We investigate how changes to the *o*-carborane structure will impact its thermochemical properties, in particular the $E_{1/2}$ and pK_a, which in turn, affect its competency in reductive reactivity. Here, we present the thermochemical characterization of two novel o-carborane derivatives: one containing an electron-donating anisole and the other featuring an electron-withdrawing pentafluorophenyl group. These modifications were selected as ways to tune the electronic properties of the carborane. We find that, in addition to impacting the $E_{1/2}$ of the carborane, the pK_a is also impacted significantly, demonstrating coupling between aromatic groups on the o-carborane platform. Current efforts are underway to evaluate the potential for these novel carboranes in the reduction of model substrates.

Developing Custom Software for a Miniature Potentiostat With Functionalized Aptamer Based Sensors
George Ore
Mentors: Ellis Meng, James Yoo, Emmanuel Ramirez, Christopher Larson, and Alireza Marandi

In the realm of biomedical MEMS technology, the demand for compact, adaptable instrumentation has surged, particularly for wearable applications necessitating real-time electrochemical analysis. This abstract underscores the imperative to develop software tailored for a miniaturized potentiostat, primed for wearable deployment, and specifically geared for continuous square wave voltammetry (SWV) measurements. The development of the software involves several key stages. Initially, comes the planning phase. First, a comprehensive analysis of the potentiostat's hardware specifications and capabilities is conducted to determine the required software features. Next, the graphical user interface (GUI) is designed to provide an intuitive platform for researchers to define experimental parameters, such as applied potentials, scan rates, and data acquisition intervals.

During the proceeding implementation phase, programming languages such as Python are employed due to their versatility and extensive libraries for scientific computing and graphical representation. Low-level communication protocols are established between the software that users access and the code on the potentiostat's hardware components to enable real-time parameter adjustments and data retrieval.

The customizability of the software is imperative as the requirements of the lab evolve through successive iterations, the software is continuously refined and expanded. The resulting software serves as a vital tool for researchers to conduct their work and the ever-fluctuating demands of the electrochemical research community.

Uniformly Rotated Mondrian Tessellations for Random Feature Models
Calvin Osborne
Mentors: Houman Owhadi, Ricardo Baptista and Eliza Watson O'Reilly

First proposed by Rahimi and Recht, random features are a technique to accelerate the performance of kernel machines in solving regression problems. The Mondrian kernel is one such example of a fast random feature approximation to the Laplace kernel. In this work, we study a variation of this technique through uniformly rotated Mondrian tessellations. First, we classify the isotropic limiting kernel of the uniformly rotated Mondrian tessellation. Second, we classify the convergence of the uniformly rotated Mondrian tessellation to its limiting kernel, using techniques from stochastic geometry to study Poisson Manhattan mosaics. Third, we compute a theoretical bound for the performance of uniformly rotated Mondrian tessellation in kernel regression. Finally, we demonstrate the high performance of the uniformly rotated Mondrian tessellation in experimental kernel regression on isotropic datasets.

Electron-Phonon Interactions in the Density Matrix Formalism
Vibha Padmanabhan
Mentors: Marco Bernardi and Ivan Maliyov

Understanding transport in semiconductors is important to improve the working and efficiency of devices like LEDs, transistors, and solar cells. A particularly important transport phenomenon is scattering: the deflection of electrons and holes from their original paths due to interactions with other particles, such as phonons, in the system. The Bernardi group at Caltech has developed PERTURBO, an open-source software which computes from first principles the scattering processes between charge carriers, defects and phonons in solid state materials using the Boltzmann equation. The Boltzmann equation is the semi-classical limit to the equation of motion for the density matrix of the system. In this project we derive the complete dynamics of the density matrix of an electron-phonon system. This will give us new information about coherences between states and the effects of optical pulses, which is important to better understand the optical and electronic properties of semiconductors. We also begin to develop a prototype implementation of the dynamics with the goal of extending the capabilities of PERTURBO.

Improving Repeatability in Minimum Autoignition Temperature Testing in Aviation Fuels
Isabella Pagano
Mentors: Joseph E. Shepherd and Charline Fouchier

The thermal autoignition of jet fuel poses substantial challenges to maintaining safety in the aviation industry. Currently, the ASTM-E659 test is the industry standard for determining the minimum autoignition temperature (AIT) of aviation fuels. This test consists of the injection of a small volume of fuel into a furnace heated to a controlled temperature; ignition is determined from visual observations and thermocouple data. We seek to improve the repeatability of the results from the ASTM-E659 test by automating the fuel injection into the ASTM furnace. We designed a machine which allows for the complete automation of the ASTM-E659 test by lowering a syringe into the testing furnace and injecting a set volume of fuel via a motorize slide, then raising this syringe component and rotating the assembly via a turntable connected to pneumatics. This mechanism allows for the control of the fuel volume injected and the rate of injection. It also minimizes the incidental heating of the syringe and fuel due to proximity to the furnace, providing more consistent results. The success of the machine was then determined by testing the ignition of hexane against existing test data.

Non-invasive, Computer-based Therapy to Reduce Tremors in Parkinson's Patients: StableHand2 Prototype
Sanvi Pal
Mentors: Joel Burdick and Drora Samra

Paradoxical Kinesia (PK) is the sudden ability of subjects with Parkinson's Disease (PD) to show reduced symptoms, such as reduced tremors. While the mechanism of PK is poorly understood, visual stimuli can induce PK. Leveraging these visual stimuli to create non-invasive therapy for PD subjects can significantly impact many lives because current treatment options for PD like Levodopa medication and Deep Brain Stimulators are expensive and inaccessible. This project aims to create an interface for PD subjects that displays various visual stimuli like moving chevron, sinusoidal, and checkerboard patterns while having the subject type displayed words. The keystroke timings and error rate is then analyzed and interpreted to gauge if the visual stimulus induced an improvement in typing significantly enough that it can be classified as PK.

An Investigation Into the Potential of Machine Learning for the Prediction of Regioselectivity of C(sp^3)–H Bond Functionalization
Amitesh A. Pandey
Mentors: Sarah Reisman, Jules Schleinitz, and Alba Carretero

C–H functionalization refers to the cleavage of a C–H bond and subsequent replacement of the hydrogen atom with a different (desired) atom. It is arguably one of the most commonly used techniques in organic synthesis. However, C–H functionalization is only a viable tool in organic synthesis when there is only one reactive site in the reactant (i.e. it is regioselective) which can be predicted with confidence. Currently, there is a great dependence on the prediction of C–H functionalization regioselectivities using a set of manually-intensive heuristic rules that fail on more complex molecules. In this work, we propose a machine learning-based pipeline for the prediction and validation of regioselectivities. We survey recent literature studies on C–H functionalization reactions using two specific reagents with an emphasis on C–H oxidation and leverage semi-empirical quantum mechanical descriptors to prepare the training set for the model. We conduct a hyper-parameter search to establish the optimal architecture of the model. Finally, we validate the model on over 288 reactions and develop an interface for regioselectivity predictions of user-accepted reactant molecules.

Design of a Qubit Module for High Fidelity State Transfer From Quantum Transducers
Ricky Parada
Mentors: Oskar Painter and Piero Chiappina

The transmission of information between remote nodes in a quantum network would expedite prospects such as quantum cryptography and distributed quantum computing. Due to their dominance in control and operating times, superconducting quantum circuits (SQCs) are primary candidates for realizing scalable quantum computers. However, cryogenic temperature dependencies render SQCs incompatible with long-range transmission. To overcome this issue, quantum transducers are being developed to convert microwave photons into optical photons better suited for network communication via optical fibers. Going forward, it is crucial to design a qubit module that can efficiently catch photons emitted from these transducers. We design an SQC module that facilitates efficient quantum information transfer from a transducer to a superconducting qubit using a directional photon catch scheme. We calculate the optimal temporal pulse shape of transducer-emitted flying photons through detailed state transfer simulations and determine the corresponding qubit parameters that emit such a pulse. We achieve an effective qubit-photon coupling rate of ~12 MHz as a result of optimizing the transducer to qubit fidelity subject to the numerous theoretical and physical constraints. Future work includes implementing the design on a standard qubit layout to experimentally realize quantum state transfer and remote entanglement mediated by quantum transducers.

Design and Fabrication of a Microwave Resonator to Measure the Cooper Pair Density in Twisted Bilayer Graphene
Pranav Parakh
Mentors: Stevan Nadj-Perge and Yiran Zhang

Bernal-stacked Bilayer Graphene (BLG) with tungsten diselenide (WSe_2) shows superconductivity at zero magnetic field. Characterizing this superconductivity and measuring the cooper pair density in the BLG is challenging. We present a method to use a microwave readout resonator capacitively coupled to a transmission line to measure the frequency spectrum of the BLG. Since BLG can be treated as an LC oscillator with a resonant frequency dependent on its kinetic inductance, measuring the resonant frequency of our sample allows us to track the kinetic inductance, which is inversely related to the cooper pair density of our sample. In this project, we detail the design and fabrication of a transmission line resonator and printed circuit board (PCB) chips to interface between the BLG sample and our readout mechanism. We first use Sonnet to simulate a transmission line resonator connected to our graphene sample and tune the parameters of the resonator so it is resonant at a frequency of 5.5GHz. Then, we provide a design of this resonator in AutoCAD. Finally, we design and fabricate two PCB chips to interface with the sample and the resonator, to be mounted in an Oxford Triton Dilution Refrigerator.

Analysis of Quantum Parity Detector Signal and Noise Sources for Phonon Detection
John Parker
Mentor: Sunil Golwala

Quantum parity detectors (QPDs) are a proposed class of quantum devices which use the tremendous sensitivity of superconducting qubits to quasiparticle (QP) tunneling events as the detector concept. Phonons in a silicon substrate generate QPs in a superconducting absorber. QP tunneling events switch the charge-parity of the sensitive region of the detector, which is measured as a frequency shift in a coupled microwave resonator. We simulate this two state, time dependent signal. We consider the effect of resonator response time as well as generation recombination, Fano, and telegraph (shot) noise. From simulated signal-noise traces, we reconstruct QP tunneling rates, and hence reconstruct deposited phonon energy. This procedure is repeated for various device parameters and deposited energies. We quantify the energy threshold and dominant noise sources for various device parameters. Simulations like these will help determine optimal device parameters for future QPDs.

Robust Accelerated MRI Reconstruction Methods for Complex Motion Types in Clinical Pediatric Imaging
Deepro Pasha
Mentors: Shreyas Vasanawala, Mikhail Shapiro, and Arjun Desai

Advances in deep-learning (DL)-based magnetic resonance image (MRI) reconstruction have substantially improved reconstruction quality and reduced inference times. However, these DL methods are sensitive to acquisition-related distribution shifts, such as patient motion. While newer DL reconstruction methods have been designed for robustness to these acquisition-related distribution shifts, these approaches have not generalized to complex distribution shifts, such as multi-dimensional patient motion. In this work, we generalize VORTEX, a semi-supervised consistency-based training strategy for MRI reconstruction models, to complex motion types, including rotation and 2D translation, which are typically observed among pediatric scans. We demonstrate that VORTEX reconstruction performance increases with this new training. We also show that VORTEX performs better than other baseline models that are also trained with 2D roto-translationally motion corrupted MRI scans.

Using Unsupervised Machine Learning to Extract Novel Information From Zwicky Transient Facility Light Curves
Avi Patel
Mentors: Dalya Baron and Matthew Graham

With the high volume of one million source detections, or alerts, per night, the Zwicky Transient Facility (ZTF) has observed hundreds of billions of transients down to a magnitude of 20.5 in the *g*, *r* and *i* filters. These transients include exploding stars, tidally-disrupted stars by supermassive black holes, stochastic accretion around supermassive black holes, and semi-periodic pulsations in stars to name a few. Developing the framework needed to support this incoming data is vital for making new scientific discoveries. We use a novel approach to search for finer sub-classes of transients and identify hidden trends in the data by applying the Uniform Manifold Approximation and Projection (UMAP) to reduce the dimensionality of the light curves. Since astronomical ground-based light curves are typically unevenly sampled, incomplete and come with many biases, we use magnitude-time histograms (DMDT-maps) to represent our light curves as a set of features. We test this methodology using a sample of one hundred simulated periodic and non-periodic light curves with different sampling and noise properties and find that our approach clusters light curves by their shape and properties into distinct groups. We intend on applying this to ZTF light curves.

Evaluation of the Mechanical Properties and Behaviors of Interlocked Knots
Payal Patel
Mentors: Chiara Daraio and Wenjie Zhou

Architected materials are materials with repeating geometries, sometimes consisting of periodic arrangements of unit cells. Introducing unit cells in structured materials arms researchers with new variables to modify, allowing for the creation of new mechanical, material properties. Most modern research concerning architected materials considers the evaluation of continuous structures or "strut-based lattices," where unit cells are placed adjacent to each other as fashioned by the traditional beam-and-junction model. While these structures typically have high stiffness- and strength-to-weight ratios, in conditions of constrained kinematics, these structures often fail catastrophically due to the accumulation of stress at their junctions. Here we propose an interlocking hierarchical structure that is formed by periodically linking prime knots. Interlocking knots eliminates the presence of conventional vertices while also permitting for unit cell manipulation. Due to the novelty of this type of structure, the goal of this project was to mechanically characterize various knot-based structures to attempt to understand how the knots can influence their behaviors and properties. Included in our methods were tensile and compressive tests on interlocking chain particles, cyclic shear tests on cubic specimens, and oscillatory amplitude sweeps on cylindrical specimens. The resulting data illuminates the complex behaviors displayed by knot-based structures. Particularly, they display tunable mechanical properties based on the direction and magnitude of forces applied and the presence of both liquid-like and solid-like behaviors simultaneously, offering profitable applications in soft robotics and energy-absorbing structures.

Enhancing Parkinson's Disease Therapy With StableHand 2: A Web-Based Visual Stimulus Platform
Sneh Patel
Mentor: Joel Burdick

Parkinson's disease (PD) is a debilitating neurological disorder affecting millions in the United States, imposing a significant healthcare burden. PD results from dopamine production reduction in the basal ganglia, leading to symptoms like tremors, stiffness, and impaired coordination. Current treatments, such as levodopa and deep brain stimulation, offer limited long-term relief. Dr. Drora Shevy's research explores the potential of Visible Moving Patterns (VMPs) to reduce dyskinesia in PD patients. Building upon this promising foundation, Caltech undergrad Sneh Patel, along with his partner Sanvi Pal, has developed StableHand 2, a user-friendly website which offers customizable visual patterns, including chevrons, squares, and sinusoids, underneath a typing display. Keystrokes, timestamps, and errors are logged; secondary data derived from these will evaluate the patient's dyskinesia severity. Monitoring the progress of the severity, and hopefully inducing a decrease, the parameters responsible for customization of the patterns will be fine-tuned to each patient, strengthening the VMP therapy's effectiveness. This research represents an innovative approach to improve the lives of PD patients by leveraging visual stimulus therapy through StableHand 2. The development of a user-friendly platform holds promise for advancing PD symptom management and therapy effectiveness.

Developing Disease Relevant Endogenous Nucleic Acid Detecting Conditional Guide RNAs for Mammalian Cell-Selective Regulation of CRISPR/Cas
Jean-Sebastien Paul
Mentors: Niles Pierce and Mikhail Hanewich Hollatz

Spatiotemporal selective regulation of CRISPR/Cas has been achieved with the use of conditional guide RNAs (cgRNAs), dependent on the presence or absence of a given nucleic acid trigger. This technology has potential uses in programmable cell-selective regulation sectors- such as developmental biology research and molecular medicines. However at present, cgRNA function has only been demonstrated with synthetic triggers, rather than with endogenous cellular inputs. Such inputs would make them more useful to bioengineers and scientists in the field trying to evoke synthetic responses when certain critical cellular features and events manifest in vivo. We have thus aimed to develop a C-Myc mRNA detecting ON-> OFF cgRNA in the context of mammalian HEK-293T cells. We present a high throughput ON->OFF cgRNA generation and screening process- from which we identified functional C-Myc detecting cgRNAs. This procedure provides a foundation for pursuing further engineering of endogenous nucleic acid detecting cgRNAs (so called endogenous cgRNAs) in future projects. Moreover, given C-Myc's status as a pertinent and widespread oncogene, we show the potential therapeutic relevance and applicability of cgRNAs.

Exploring the Future of Quantum Machine Learning in Astronomy
Autumn Pearce
Mentors: Matthew Graham and Ashish Mahabal

In recent years, telescope surveys have become an increasingly popular way of collecting astronomical data. As a result, the field has seen radical growth in the amount of data available. While this data has greatly aided research efforts, it has also introduced new challenges. In the past, researchers could visually identify and categorize objects, or they could apply time-consuming computer processes to each individual object. With so much data to analyze, this is no longer feasible. To address this issue, machine learning algorithms are being used to sort and analyze data. However, the computational complexity of machine learning algorithms increases exponentially with the number of parameters analyzed, which limits their usability in the face of exponentially large datasets. This study investigates the potential of quantum machine learning to prevent these constraints from limiting progress in astrophysical research. Quantum computing hardware is still in its infancy, but this new form of computing is already known to provide immense speedups to classical machine learning tasks. Thus, it holds promise for revolutionizing the way we process vast amounts of astrophysical information. Moreover, this project hopes to establish a bridge between astronomy and quantum computing, as the fields currently operate independent from one another.

Model Selection of Biological Systems Using Sparse Levenberg-Marquardt
Ava Penn
Mentors: Niall Mangan and Peter Schroeder

The dynamics of many biological systems are unknown despite their influence in governing critical processes such as enzyme activity, cellular signaling, gene regulation, and metabolic pathways. Understanding the nature of these systems poses challenges owing to their complex nonlinear dynamics, motivating our use for data-driven modeling techniques. In this project, we combine parameter estimation techniques from the Levenberg-Marquardt algorithm with a sparsity constraint that selects between terms. Implementing a numerical method for calculating geodesic acceleration, a term that has been found to mitigate challenges arising from parameter-effects curvature, has enhanced our use of Levenberg-Marquardt for parameter estimation in systems with differential equations. Further, we utilize an iterative thresholding framework on the parameters to choose model terms from a large function library that represents many possible hypotheses describing the dynamics of the system. These techniques have shown promise through testing on simulated data but require further testing for robustness to noise and increased model complexity. In subsequent work, adding functionality for unmeasured state terms would also allow the technique to be used on true biological data. A variety of thresholding methods may also be tested in future work by the Mangan Group.

Probing the Circum-nuclear Environment of an Accreting Supermassive Black Hole With X-ray Spectroscopy

Dylan Perez
Mentors: Fiona Harrison, Oluwashina Adegoke, Peter Boorman, and Edward Nathan

Active galactic nuclei (AGN) are extremely luminous galactic centers, originating from the accretion of matter around supermassive black holes (SMBH), which can be characterized by features in their X-ray emission spectra. Most AGN are obscured by a dusty torus that contributes to these features by absorbing, scattering, and fluorescing X-ray photons. The X-ray Baldwin effect is an observed anti-correlation between the equivalent width (EW) of the iron fluorescence line seen in AGN X-ray spectra and their X-ray luminosity. This effect has not been widely studied for individual heavily obscured sources that exhibit significant time variability in their luminosities. Since most AGN are heavily obscured and grow in this state, studying these sources can help illuminate the process by which SMBH grow in general. The aim of this project is to determine whether an X-ray Baldwin effect exists for the heavily obscured and variable AGN Mrk 3. Using 11 observations from the Nuclear Spectroscopic Telescope Array (NuSTAR), the first focusing hard X-ray space telescope, we extract spectra and perform fits of a phenomenological model designed to reproduce the underlying continuum and iron line profile simultaneously for accurate equivalent width measurements. By using novel Bayesian sampling algorithms, we are able to propagate uncertainties to derive EW and unabsorbed luminosity posterior distributions for each observation epoch. We then perform a statistical analysis on the relation between the two to determine to what confidence the X-ray Baldwin effect can be reproduced in Mrk 3 alone. Since the X-ray Baldwin effect is often purported to arise from a decrease in sky-covering fraction with increasing accretion power, our study will provide a potential new probe for the evolution of the obscurer surrounding supermassive black holes.

Simulating Time-Dependent Atmospheric Chemistry on Venus on a Diurnal Timescale

Marcos Perez
Mentors: Yuk Yung and Danica Adams

Research over the past several decades has identified three primary chemical cycles in Venus' atmosphere, but significant details about each cycle have proved elusive: the carbon or CO_2 cycle includes: production of oxygen due to photodissociation when carbon dioxide is exposed to UV radiation from the Sun on the dayside and the production of CO_2 via catalytic cycles involving chlorine species, the sulfur oxidation cycle includes the formation of sulfuric acid from sulfur dioxide as well as the decomposition of sulfuric acid into sulfur dioxide, and the polysulfur (S_x) cycle includes the photodissociation of sulfur compounds (SO_2 or OCS) into polysulfur as well as the production of OCS and SO_2 [Mills and Allen, PSS, 2007]. Most modeling to date has used either a one dimensional average photochemical model [Krasnopolsky, Icarus, 2012; Bierson and Zhang, JGR Planets, 2019; Bains et al, Astrobiology, 2021; Rimmer et al, PSJ, 2021] or a three dimensional global circulation model (GCM) with limited chemistry [Navarro et al. Icarus, 2021; Parkinson et al. Icarus, 2021]. Photochemistry simulations that explore expected diurnal variations are needed.

We will build upon and run previously written code, Caltech-JPL KINETICS [Yung et al., JAS, 1980; Allen et al., JGR, 1981], to simulate the atmospheric chemistry of Venus through a diurnal cycle. The results will be compared with spacecraft and Earth-based observations of SO_2, OCS, HCl, ClO, CO, and O_2 [Marcq et al, Sp Sci Rev, 2018; Vandaele et al, Icarus, 2017ab]. A subset of the photochemical model results will be compared with simulations from the Venus Thermospheric General Circulation Model (VTGCM) [A.S. Brecht et al. JGR Planets, 2021]. This project has the potential to bridge the current gap between the predictions made in chemical models and the measurements made through a plethora of spacecraft missions and Earth-based observing campaigns.

Investigating the Starspot Paradigm of T Tauri Stars in the Taurus-Auriga Star Forming Region

Facundo Pérez Paolino
Mentor: Lynne Hillenbrand

Accurate age and mass determinations for young stars are crucial for understanding their evolution. However, strong magnetic fields in these systems, causing phenomena like starspots and flares, make it difficult to achieve precise measurements. Low-mass stars with fully convective interiors and strong magnetic fields can experience significant convection suppression, leading to extensive starspot coverage. We present results from multi-epoch near-infrared spectroscopy of 32 T-Tauri Stars in Taurus-Auriga with the aim of studying spot-behavior. We constructed composite models of spotted stars by combining BTSettl-CIFIST atmospheres to represent the spots and the photosphere along with accretion and disk continua. Using a Markov-Chain Monte-Carlo algorithm, we derived best-fit spot and photospheric temperatures, spot filling factors, as well as disk and accretion filling factors, successfully reproducing stellar spectra. We find best-fit spot filling factors over 30% for all of our targets, with a constant spot-to-photosphere temperature ratio of 0.7, consistent with estimates for older types of spotted stars. Using K2 photometry, we are able to correlate spectral variability with photometric variability on rotational timescales. Using our best-fits, we calculate effective temperatures and luminosities and use the Stellar Parameters of Tracks with Starspots (SPOTS) models to derive corrected masses and ages for our sample.

High Throughput Engineering of Next-Generation Mammalian Acoustic Reporter Genes for Multiplexed Ultrasound Imaging
Anh Phuoc Nguyen Phung
Mentors: Mikhail Shapiro and Nivin Nyström

Genetically encoded ultrasound contrast agents in the form of biogenic gas vesicles (GV), which are air-filled protein nanostructures native to aquatic microbes, have revolutionized a new pathway for biomolecular imaging. The latest iteration of mammalian acoustic reporter genes (mARG), derived from *Anabaena flos-aquae*, enables heterologous expression of GVs that yield strong non-linear signals for real-time, non-destructive imaging in deep tissue. Building on this, the development of next-generation mARG with enhanced acoustic contrast is desired to realize ultrasound multiplexing, which permits unique differentiation of acoustic signals or spatial distribution from different GV populations. Here, we devised two approaches towards high throughput engineering of GvpA and GvpC – structural proteins that are responsible for GVs' mechanical and hence acoustic properties. First, two alanine and cysteine-scanning gvpA libraries were generated by site-directed mutagenesis, constituting 141 mutants for arrayed acoustic screen. Candidate positions that outperform the wild-type were then selected for further site-saturation and combined mutagenesis. In parallel, we developed a directed evolution pipeline for randomized screening of pooled gvpC libraries by monoclonal integration into AAVS1 landing pad cell line.

Effect of Epigenetic Machinery Disruption on Neural Function
Tessa Pierce
Mentor: Hans Tómas Björnsson

The Epigenetic Machinery (EM) are enzymes that regulate and interact with epigenetic features and control gene expression in cells. When different EM genes are mutated, it causes shared phenotypes of intellectual disability and growth dysregulation. The objective of the project is to gain insight into the mechanism by which dysfunctional EM components modify the epigenetic landscape in neurons and how these mutations cause common phenotypes. We examine the effect of six EM genes on DNA methylation by creating knockouts in murine hippocampal cells. The cells are isolated from $Cas9^{+/+}$ mice, and small guide RNAs are introduced by lentivirus vectors, guiding the CRISPR/Cas9 system to knockout the associated gene. The success of the knockouts are tested via PCR, qPCR, and western blot. All six viruses have been produced by transfection in HEK293T cells, and transduction efficiency tests have been conducted, with FACS indicating 85% maximum success rate. Mutant cells will be created using 30% transduction efficiency, and the resulting change in neural function will be evaluated with Oxford Nanopore Technology sequencing to observe changes in DNA methylation. Regions in which the epigenetic landscape is impacted by EM dysfunction may contribute to overlapping phenotypes of intellectual disability and growth dysregulation.

Late-time Chandra and eROSITA Observations of X-ray Selected Tidal Disruption Events
Vismaya Rajeev Pillai
Mentors: Shrinivas Kulkarni and Yuhan Yao

A star that passes too close to a massive black hole (MBH) will be disrupted by tidal forces in a tidal disruption event (TDE). As the disrupted stellar material falls back to form an accretion disk around the MBH, X-ray emission is produced in the central region. Sazonov et al. (2021) presented the first statistical sample of TDEs systematically selected in the X-ray band using the first two all-sky surveys conducted by the eROSITA telescope onboard the *SRG* satellite. However, without late-time observations, several key predictions of TDEs have not been tested. We obtained follow-up observations of five TDEs in the Sazonov et. al. (2021) sample using the Chandra X-ray telescope and later eROSITA surveys to characterize their late-time flux and spectral evolution. Two physically motivated spectral models—non-thermal power law and thermal disk emission—are used. We also examined light curves from optical sky surveys to better constrain the multi-wavelength evolution. This work aims to test whether the accretion rate follows that predicted by the fallback accretion model and investigate the frequency of late-time corona formation, and changes in the accretion disc geometry.

Characterization of Autism Spectrum Disorder Genes in Zebrafish
Juni Polansky
Mentors: David Prober and Jin Xu

Autism spectrum disorder (ASD) is a neurodevelopmental disorder found in about 1-2% of the global population, and it is estimated that heritability of the disease is about 60-90%. ASD is often marked by restrictive, repetitive behavior patterns, sensory hyperactivity or hypoactivity, and deficits in early social communication/interaction. The current research in the Prober lab aims to investigate the mechanistic basis for these phenotypes using zebrafish mutants that have mutations in identified candidate risk genes. As many of these genes' functions are unknown, such research is crucial in understanding why mutation of these genes results in phenotypes relevant to ASD. In this project, to generate new zebrafish mutants of a new batch of ASD risk genes, CRISPR Cas9 constructs targeting each gene were injected into zebrafish embryos to induce mutations. Subsequent PCR and T7 analysis identified several potential founders. Potential founders were out-crossed to obtain heterozygous offspring. These embryos were screened and confirmed for mutations by T7, and potential heterozygotes were raised in the system to establish stable mutant lines for future experiments. In preparation to comprehensively and effectively test mutants' phenotypes in the near future, hybridization chain reaction (HCR) and brain dissection techniques that will be critical to examine developmental deficits were practiced, and code was optimized to facilitate large-scale behavioral data analysis.

Analysis of the Relative Importance of *P. synxantha*'s Gluconate Pathway in Solubilizing Phosphate Minerals
Chris Pope
Mentors: Dianne Newman and Nate Glasser

Overfertilization is a global problem in agriculture. This is especially true for phosphorus, as it is readily consumed by bacteria in the soil, leading to frequent overcompensation in fertilization. An important example of this is the mobilization of phosphate in the soil by the genus *Pseudomonas* in wheat rhizospheres. Understanding more about how much phosphate these bacteria use and how important different gene pathways are to solubilizing said phosphate would help inform more responsible fertilization. To understand more about how a species of *Pseudomonas*, *P. synxantha*, uptakes phosphorus, a genetic approach was used to remove the glucose to gluconate pathway, an important cellular tool for solubilizing calcium phosphate. The mutant was then introduced to soil and plant root environments and the relative impact of the gluconate mutants on the bioavailable phosphate was quantified and compared to wildtype strains of *P. synxantha*. The gluconate mutants were also compared to mutants in the phenazine biosynthesis pathway, another cellular method for solubilizing phosphate minerals that targets iron phosphate in soil. The relative contributions of the phenazine and gluconate pathways for solubilizing phosphorus in the wheat plant rhizosphere were determined.

Investigating the Impact of Fluid Accumulation on the Mechanical Properties of 3D Printed Alveoli Models Mimicking Lung Tissue
Sophie Polidoro
Mentors: Kaushik Bhattacharya and Jin Yang

Respiratory gas exchange hinges upon dynamics of alveoli, minute and elastic air sacs within the pulmonary system. With each breath, these microstructures undergo cyclic expansion and compression, facilitating gas exchange. However, diverse pathological conditions disrupt this process causing mucus and anomalous fluids to accumulate, leading to pulmonary edema. This study aims to understand the interplay between fluid accumulation and alveolar mechanical characteristics, to elucidate underlying mechanisms for prompt diagnosis and intervention. To identify how periodicities and geometries affect mechanical attributes of lung tissue, we 3D-printed soft elastic resin models based on this architecture in various sizes. The samples are characterized using uniaxial tension and compression experiments at different loading rates to compare their material mechanical behavior. Next, we explore effects of fluid accumulation on alveolar behaviors by filling 3D-printed alveoli samples with different liquids and hydrogels in different viscosities and conducting needle-induced cavitation experiments to investigate how mucus impacts alveolar responses. Additionally, we plan to integrate Digital Image Correlation to enable full-field spatiotemporal measurement of dynamic deformations during the expansion-compression cycles. By converging these avenues of inquiry, this research endeavors to enhance the scientific community's comprehension of pulmonary edema etiology and progression, ultimately advancing expedited diagnosis and targeted therapeutic interventions.

Looking for Dwarf Carbon Stars Using Low-Resolution Spectra From Gaia DR3 XP Spectra
Evan Portnoi
Mentors: Kareem El-Badry and Ben Roulston

For decades, scientists have had both convincing theories and conclusive proof that small stars incapable of producing their own carbon can still have carbon-rich atmospheres by matter accretion from a nearby giant carbon star that is a binary companion. However, they are rare and not easily distinguishable from normal oxygen-rich stars without detailed spectroscopy, looking at each spectrum by hand to find carbon features. Because of this, there are still very few documented dwarf carbons. However, machine learning methods such a Support Vector Machine can be used to identify carbon stars en masse using the training set derived from Gaia DR3. The algorithm takes color, spectral indices quantitatively representing features in the spectrum, and a series of coefficients from the Hermitian polynomial. Testing and cross-validation have shown scores of 95% accuracy. The set data tables can be created for the entire Gaia DR3 dataset of over 200 million sources. Initial tests have shown a predicted carbon star rate of .01%. If this proves to be correct, the machine learning pipeline can be applied to the whole dataset and cross-referenced with parallax data to determine the size of the stars, creating a large catalog exclusively containing dwarf carbon stars.

Accelerating ELISA Protocols Using Heat and Microwaving Techniques
Camilla Power
Mentors: David A. Prober and Naomi R. Lee

Despite their effectiveness, current FDA-approved vaccines for HPV remain fairly limited. Most notably, the available vaccines require two injections within a period of six months to achieve maximum protection, and easily degrade if not stored in the proper conditions. As such, next generation HPV vaccines that are both accessible and highly immunogenic are needed to protect populations against HPV-associated cancers. One approach to broaden immunity and lower costs is the use of self-assembling peptides to increase the immunogenicity of displayed HPV peptide antigens. We have chosen fibrils as a vaccine platform because they can withstand varying temperatures, solvents, and pH, unlike current HPV vaccines that are fairly volatile and can degrade even while refrigerated. After immunization, a method to measure immunogenicity is needed. ELISA (enzyme-linked immunosorbent assay) is an accessible, simple, and accurate plate-based technique to detect and quantify the antibody response to a disease after vaccination. However, ELISA assays take between seven and twenty hours to produce results. As a result, we attempt to establish an accelerated ELISA protocol by using heat, such as incubating at a higher temperature, or using a microwave to apply heat directly to the plate.

The Role of Kinetochores in Mammalian Neural Development
Aditee Prabhutendolkar
Mentors: Thomas Schwarz, Guoli Zhao, and Joseph Parker

The kinetochore is a protein complex found at the centromere of chromosomes. It plays an essential role in mitosis, but our lab is investigating the role of the kinetochore in a surprising post-mitotic setting. Specifically, we are focusing on the presence of kinetochores in the synapses and axons of mammalian nerve cells, implying that kinetochores play a key role in neural development.

Here we have engineered strains of mouse embryonic hippocampal nerve cells with certain kinetochore-encoding genes knocked out, and then fluorescently imaged their axonal growth cones. To quantify the change in dynamicity of the growth cones after gene knockout, we used image classification and machine learning techniques and found statistically significant results between the knockout and wildtype strains of nerve cells, indicating that kinetochores are essential to functional axon growth.

Development of a Coherent Optical Receiver for Fiber Optic Communication Applications
Olivers Prānis
Mentors: Ali Hajimiri and Samir Nooshabadi

Fiber optic technology has already proven to be a vital part of the modern world. Whether it is establishing a high-speed Internet connection for a single household or entire countries, using light to transmit information is currently the fastest way to communicate across short and long distances. However, with the increasing demands for ever faster speeds and higher bandwidths, there is a need for improved designs for optical receiver systems to translate the optical signals into electronic ones. This research project focuses on developing and characterizing a new type of integrated optical receiver utilizing coherently modulated light waves.

Single Nucleus RNA Sequencing Data Set of Enteric Neurons in the Alpha Synuclein Overexpressing Mouse Model of Parkinson’s Disease: Overcoming Obstacles
Christopher Pukszta
Mentors: Sarkis Mazmanian and John Bostick

In addition to the motor symptoms associated with the death of dopaminergic neurons in the substantia nigra pars compacta during the progression of Parkinson’s disease (PD), there are well documented gastrointestinal (GI) symptoms. Several studies have investigated the enteric nervous system (ENS) of human patients but have not been able to sample from the Myenteric Plexus (MP) which directly controls GI tract contractions. Here we look to assess the transcriptional state of MP neurons via single nucleus RNA sequencing. Using an adeno-associated viral vector (AAV) to deliver a nuclear pore protein fused with GFP under the control of the human synapsin 1 promoter, neuronal nuclei are sorted from other extracted nuclei. This report describes the major hurdles associated with packaging and verifying full expression of a novel AAV genome in the ENS, carefully extracting and preserving nuclei for downstream sequencing, and analyzing the transcriptomic profile of a rare population of cells. Subsequent work with this transcriptomic profile will be to examine protein expression levels and investigate new potential links between the gut microbiome, the immune system, and PD pathology.

Simulating the Spin of Stellar Mergers With Magnetic Braking and Angular Momentum Transport

Kecheng (Stephon) Qian
Mentors: James Fuller and Nicholas Rui

Stellar mergers are high-occurrence events that may leave rotational signature on the surviving stars. In this research, we study spin evolution of low mass stars ($\lesssim 2M_\odot$) that undergo merger events during red giant branch (RGB). We model merger events as rapid accretion onto the stellar surface, and use 1-D star evolution code \mesa to track the envelope and core rotation rates of the stellar model after merger events with implementation of angular momentum transport (\cite{2019MNRAS.485.3661F}) and several different prescriptions for magnetic braking. We find that the merger event may significantly spin up the star on the red clump (RC) and the white dwarf stage (WD) as long as the secondary star mass $\gtrsim 0.01M_\odot$ and the primary star is moderately close to the tip of RGB during merger. The rapid rotation of these remnants can be identified using astroseismic measurements, which enables us to identify merger remnants from single stars. We also find that MB prescription that does not has a saturated regime may lead to faster rotation rate on RC and WD.

Blowup Analysis for the Weak Convection Hou-Li Model

Xiang Qin
Mentor: Thomas Y.Hou

We study the a-parameterized weak advection version of a 1D model proposed by Hou-Li. This model is based on an approximation of the axisymmetric Navier-Stokes equations in the r direction. By considering the fixed-point problem of some nonlinear map, we show that the weak convection model admits exact self-similar finite-time blowup solutions with smooth profiles for $2/3<a<1$. We also verify and visualize our theoretical results using a direct numerical iterative method. Our work reproduces the previous results in a purely analytic approach, and obtain more properties of the profiles.

Carbon Isotope Fractionation During Core Mantle Differentiation in Rocky Protoplanets and Planets

Mithil Rajput
Mentors: Francois Tissot, Paul D. Asimow, and Damanveer S. Grewal

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

Multi-Robot Cooperation to Accomplish a Sequence of Tasks Using Deep Reinforcement Learning

Sreeyutha Ratala
Mentors: Maria Gini, Nabil Khan, and Chris Umans

Many real-world problems mandate teamwork, where multi-robot systems accomplish complex tasks through cooperation and decomposition. We study whether robots can learn cooperation to accomplish a sequence of complex tasks in a simulated environment inspired by a factory warehouse. A deep reinforcement learning approach, particularly Q-Learning and a multi-layered neural network, is used for the multi-agent system. The specific task the robots learn is to find bulky artifacts and move them to their destination, which requires cooperation in pairs. Our prior experiments reveal robots can learn to cooperate to perform complex tasks, but the scalability of this approach is limited in terms of the number of robots and tasks, and training time efficiency. The previous approach allocated artifacts to robots prior to training. In our novel approach, however, robots must learn to allocate subtasks themselves to move artifacts not specifically assigned to them. Methods include introducing explicit and implicit forms of communication, which is important for ad-hoc teamwork. We use robot simulations to empirically analyze how well the robots complete the sequence of tasks and evaluate the performance of various approaches through success rates, computing time, scalability, and generalizability.

Eliciting the Mechanism of Action of mGlu4, a Class C GPCR

Mahi Ravi
Mentors: William Goddard III and Soo-Kyung Kim

GPCRs (G protein-coupled receptors) are the largest group of membrane receptors that activate responses to odorants, hormones, and neurotransmitters. Since 30% of current drugs act on GPCRs, understanding the mechanism of action of GPCRs and how their ligand binding elicits signaling is of great use in drug development. The human genome encodes 850 GPCRs, half of which are considered potential drug targets.

There is a wealth of research investigating metabotropic glutamate receptors (mGluRs) in the treatment of neurodegenerative diseases, since these class C GPCRs regulate neuron excitability and control synaptic functions in the central nervous system. In this project, we focus on mglu4, a potential mGluR target for Parkinson's disease. The current mglu4 cryoEM structure contains only 80% of all residues present and has a low resolution of 4 angstroms, both of which have inhibited the development of selective agonists against mglu4 till date. We used molecular dynamics to complete the mglu4 structure and elicit the atomistic mechanism underlying the action of the mglu4 GPCR. Characterizing this mechanism could allow for the development of a selective agonist of mglu4, mitigating off-target effects on similar proteins such as mglu5 that are known to cause harmful side effects.

Dualities as Sequential Quantum Circuits
Vibhu Ravindran
Mentors: Xie Chen and Robijn Vanhove

Dualities in physics are mappings that relate two different looking theories that actually describe the same physics**.** They are ubiquitous as quantities on one side of the duality are often easier to compute than quantities on the other side. They are significant in condensed matter physics as they can map between different phases of matter. It is known that sequential quantum circuits (SQCs) are the minimal class of quantum circuits that can map from one phase to another. Broadly speaking, this project attempts to understand the relation between these different objects.

We investigated dualities between categorically symmetric 1D systems and showed that they correspond to SQCs changing the boundary of a 2D topologically ordered system. Understanding this mapping in more generality and in higher dimensions will allow us to get a new perspective on dualities as well as systematically construct new ones.

Actuator Communication Attempts for AMBER Lab's Bipedal Robot ADAM
Juan Renteria
Mentors: Aaron Ames and Adrian Boedtker Ghansah

From helping in labor intensive jobs to helping individuals with mobile disabilities, humanoid robots have the tremendous potential for supporting humans in a vast number of ways. The AMBER Lab at Caltech is working on developing ADAM, a humanoid robot, where the goal is to create generalized dynamic 3D walking algorithms that can be transferred to other humanoid systems. The first step in creating the electrical system that will lie inside ADAM is to establish communication with the actuator that would be used. Communication with the actuator used for ADAM would occur through a communication line that includes a microcontroller and a transceiver embedded in the system. The primary actuator discussed is the A1 Unitree Actuator. After exhausting all the paths for communication with no success, and due to lack of information from the company, it was decided to halt more attempts at communication with the A1 Unitree Actuator. The next actuator chosen is the CubeMars T-Motor AK-Series, which is currently going through another testing stage.

MITF-Mediated Melanoma Phenotype Switching Through Gene Tagging and Knock-In Studies
Rachel Reyes
Mentors: Eiríkur Steingrímsson and Evangeline B.Raja David Isac

Melanoma, a lethal form of cancer originating from melanocytes, presents a complex challenge due to its cellular heterogeneity and resistance to conventional treatments. Recent studies indicate that the Microphthalmia-associated transcription factor (MITF) plays a pivotal role in the regulation of CDH1 and CDH2 genes, which are associated with phenotype switching and drug resistance. However, the precise mechanisms underlying this switching was incompletely understood. Here we employed Mir-SkMel28-MITF cells for two CRISPR-based experiments. These cells allow us to modulate MITF expression by inducing miRNA that targets MITF expression.CDH1 was tagged with eGFP, while CDH2 was marked with mCherry, enabling real-time expression tracking and following MITF manipulation.This will be achieved using CRISPR technology, involving the transfection of cells with a guide RNA (sgRNA), Cas9 enzyme, and a vector containing fluorescent protein markers flanking the respective genes.The primary objective of tagging these cells was to facilitate the monitoring of CDH1 and CDH2 expressions and the manipulation of MITF levels through knockdown techniques. This tagged cell line will serve as a valuable resource for future genome-wide knockout studies and help identify genes that regulate CDH1 and CDH2, thereby contributing to a deeper understanding of melanoma biology and the development of innovative therapeutic strategies.

Testing the Efficacy of Isotopic Clumping Data When Applied to Temperature Dependent Sex in Modern Day Reptiles
Martha Richmond
Mentor: John Eiler

The isotopic clumping of 13-C and 18-O observed in carbonate mineral lattices can be used to determine the temperature at which that carbonate formed, without independent knowledge of the 13-O and 18-O contents of water. We tested whether eggshell clumped isotope abundance data could be used as a basis for reconstructing egg shell growth temperature, and thereby constrain sex distributions among modern-day reptiles known to show temperature-dependent sex determination (TSD). This study could shed light on the impacts of warming global temperatures on sex ratios and reproductive capacities. The data was obtained using the 'paleothermometer' developed by Eiler et al. We studied the reproducibility and accuracy of our results by replicate analysis of samples with known incubation temperatures via mass spectrometry. We are now exploring whether these values represent the internal temperature of the mother or of the external environment. The latter has the potential not only to be used as a non-invasive technique to study TSD but also to challenge various publications regarding gigantothermy propositions from fossilised eggs. Future directions of this study may involve generating a comparison between herpetological species or testing the efficacy with differing age of samples, even exploring TSD in Mesozoic gigantotherm eggs.

Implementing Property-Based Testing in NetworkX
Nilo Rivera
Mentors: Chris Umans and Ross Barnowski

Currently, most software is tested with a set of example inputs and expected outputs. A newer approach is property-based testing, in which many example inputs are generated, and the outputs are tested for specific properties they are expected to have, such as commutativity. NetworkX, a Python package for graph data structures and algorithms, could benefit from this form of testing. However, as property-based testing is not yet prevalent, I had to develop an algorithm for generating random graphs to use as test cases. This algorithm had to be capable of ensuring specified characteristics in its output, such as connectedness, and finding the simplest graph that fails a test. I will continue this work for the remainder of the summer by determining which properties each algorithm in NetworkX should have and writing tests for each of these properties, improving the efficacy, development time, and readability of the NetworkX test suite. Accompanied by an analysis and research paper, this work will contribute to the adoption of property-based testing in software used across the many industries where graphs play a vital role.

Exploring and Mitigating Social Bias in LLM Question-Answering Systems for Clinical Decision-Making
Ashlyn Roice
Mentors: Tina Hernandez-Boussard, Madelena Ng, and Joel Tropp

The application of large language models (LLMs) in healthcare has the potential to redefine the norms of clinical care and delivery. Research has shown that LLMs present embedded biases in multiple contexts, especially towards minority social groups. However, there is limited empirical evaluation of the unique biases that exist in LLMs applied for healthcare purposes. Our study aims to ascertain and mitigate the hidden biases in GPT-3 when used to determine whether a patient should be treated (yes/no) for clinical conditions. We used validated clinical vignettes in pain management (n=55), cardiology (n=60), and dermatology (n=75) to enable the assessment of these LLMs in diverse clinical contexts. To assess social bias, we examined how the LLMs respond in their treatment decision for each clinical vignette across rotating patient identities of race, gender, religion, and sexual orientation. Bias in the GPT-3 treatment decision output was detected across various individual and intersectional identities. We then applied our debiasing protocol to mitigate these identified social biases. We hope that our debiasing and analysis framework will be applied to future language models created for healthcare question-answering models, fostering fairer guidance for clinical outcomes.

Feedforward Frequency Stabilization of 2-Micron Lasers Using Optical Delay Homodyne Interferometry
Hannah Rose
Mentors: Rana Adhikari and Aidan Brooks

The proposed post-O5 LIGO Voyager upgrade as well as some proposed third-generation gravitational wave observatories center on a cryogenic silicon optics system for reduced thermal noise. This requires a shift of the laser wavelength further to the infrared using the comparatively noisy 2-micron technology to compensate for the high absorption of the current 1064nm laser in crystalline silicon. To meet the tight frequency noise requirements for desired sensitivities of these interferometers, we demonstrate a feed-forward frequency noise reduction system at 2050nm in fiber. Additionally, we characterize the sources of noise limiting the degree of noise reduction and the sensitivity of the interferometric measurement of the reduced frequency noise, allowing for the targeting of future improvements to the system.

To Develop an Artificial Uterus-Like Platform to Support Embryogenesis *in vitro*
Silas Ruhrberg Estevez
Mentor: Magdalena Zernicka-Goetz

Abstract withheld from publication at mentor's request.

Deep Generative Modeling for Safe Control Using Conditional Variational Autoencoders
Igor Sadalski
Mentors: Aaron Ames and Ryan Cosner

In safety-critical contexts, ensuring robust behavior in the presence of external disturbances is of primary concern. The existing literature outlines controller architectures designed for this purpose, contingent upon a priori knowledge of the disturbance distribution. While uncertainty and complex nonlinear-effects present in the real-world render analytical modeling (e.g., based on fluid dynamics modeling) unfeasible there are various learning methods, including Bayesian Neural Networks and Gaussian Processes, that could potentially predict the disturbance with its associated uncertainty. Unfortunately, practical implementations of these demands substantial computational resources, resulting in operation at reduced frequencies. To address this challenge, we propose a novel approach utilizing conditional variational autoencoders which is a learning framework built on variational inference. By adopting this approach, we can learn properties (mean, variance-covariance matrix) of complex disturbance's distribution. The subsequent integration of this learned model with a Control Barrier Function (CBF)-based controller ensures the safety of the system. We demonstrate the efficacy of our method in simulation and deploy it on a hardware system.

Non-Intrusive and Inexpensive Current Measurement System: Development of a Low Power, Bluetooth, Time-Synced Network for Proprietary Current Sensors
Subham Sahoo
Mentor: Axel Scherer

The future of powering households lies in moving away from centralized power plants and moving towards distributed power grids. The main challenge with a distributed power grid system is devising a system that allows each household to know how much power they're consuming at any point during the day. Currently, this is done by paying an electrician thousands of dollars for hours of labor and installation of very intrusive current measuring tools (oftentimes cutting into the wires themselves). It's also quite difficult to get a reading out on the instruments. As such, we have utilized the topology of power carrying multi-core wires and emergent properties of phase differences between different currents to non-intrusively measure the current going through the wire. Since we want multiple sensors around the house for accurate readings and want it all to read out to some central display on the user's phone or a website, all the sensors need to be able to communicate with one another on a network. If the sensors are networked, we need to ensure that it consumes very little power (longevity of product) and that all the sensors are on the same clock at the current measurement is time dependent. The results and conclusions we've come to is that a network like this is feasible, but we just need to make it functional for all kinds of wire topologies.

Modeling Seismicity Induced by CO_2 Injection at the Decatur Site, Illinois
Guillaume Salha
Mentor: Jean-Philippe Avouac

CO_2 emissions grow increasingly today, threatening our ecosystems. To mitigate the impact of CO_2, many projects of carbon capture and storage (CCS) have been undertaken. However, CO_2 injection may induce seismicity which can lead to devastating earthquakes.

Therefore, assessing the risk of seismicity induced by CO_2 injection in deep reservoirs is a crucial step to scale these CCS projects. In this regard, the Decatur project, that consisted in injecting one million metric tons of CO_2 in a 2000m deep reservoir, proves very insightful. Measurements of induced seismicity were performed, and much data is available as regards physical parameters.

Given geological parameters and injection data, numerical models can predict the evolution of the seismicity rate very accurately, both in time and space. This means that seismicity as an obstacle to CCS projects may be mitigated efficiently.

Random Utility Model With the Network Flow Technique
Alec Sandroni
Mentors: Kota Saito and Yi Xin

Random utility model is one of the fundamental models of choice in economics. The recent literature has increasingly seen use in the “graphical” or “network flow” formulation of random utility. Using these techniques we study the nature of random utility models. Falmagne (1978) proved the necessary and sufficient conditions for a complete system of choice probabilities to be induced by rankings. However there is much work to be done in the case where some information is not available to the analyst. A common tool in econometrics is to aggregate alternatives into a single outside option. We study the rationalizability of such datasets. We also study changing preferences.

Discovering Social Bias in Text-To-Image Models Through Likelihood Estimation
Adhithya Prakash Saravanan
Mentors: Anima Anandkumar and Rafal Kocielnik

Text-to-image diffusion models have already been adopted into key commercial workflows. Characterising the implicit biases they exhibit is a necessary first step in avoiding discriminatory outcomes. Existing bias testing methods rely predominantly on external models, such as CLIP or attribute classifiers, that often exhibit their own biases. Our novel framework directly probes the text-prompt conditioned image generation distribution, by leveraging an evidence lower bound to approximate the intractable generating distribution. The key idea is that a diffusion model's ability to denoise a noised image, given a text-prompt, is a proxy for that prompt's likelihood. Using our framework, we recover expected and significant inter-sectional social biases in Stable Diffusion v2.1, a state-of-the-art open-source text-to-image model. Our findings caution against the uninformed adoption of text-to-image foundation models for downstream tasks, including classification.

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

Nitrogenase is an enzyme that fixes dinitrogen to ammonia, an essential compound for living organisms. We can further investigate the nitrogenase enzyme by identifying conserved regions of nitrogenase protein structures across a variety of diazotrophic microbes. However, structures of the MoFe- and Fe-proteins of nitrogenase are currently limited to the proteins of a few model diazotrophs. In this project, we optimized the expression and isolation of endogenous MoFe and Fe- proteins from *Rhodopseudomonas palustris* by eliminating extraneous sources of carbon and sulfur from the media. We utilized cryoSPARC to analyze single-particle cryo-EM data and create a preliminary model of the *R. palustris* MoFe- protein. Not only will this workflow allow us to compare isolated nitrogenase proteins, but it can be adapted to study nitrogen fixation *in vivo* in *R. palustris*.

Bio-inspired Underwater Propulsion: Advancements in Fin Mechanisms
Jacob Schuster
Mentors: Morteza Gharib and Meredith Hooper

Modern marine thrusters have revolutionized underwater propulsion, reaching impressive levels of efficiency and power. Yet, some aquatic animals are able to propel themselves at much higher energy efficiencies than even the best human-made propulsion systems. Taking inspiration from the propulsion of aquatic creatures, The Gharib Research Group aims to create a bio-inspired alternative to traditional marine thrusters by mimicking the movements of fish fins. To achieve this, we are developing a fish robot that can achieve collinear flow, while executing trajectories determined by a machine learning algorithm. The robot uses a central motor and a swash plate mechanism connected by a universal joint to complete these trajectories. In the future, we hope to optimize the design of the fish robot and fin trajectories in order to improve underwater propulsion methods around the world, making them both more efficient and eco-friendly.

Characterizing Hazardous Near Earth Asteroids With Thermal Infrared Data From NEOWISE and Reporting Previously Missed Detections to the Minor Planet Center
Elena Selmi
Mentor: Joseph Masiero

Near Earth Asteroids (NEA) are of great interest to the scientific community due to their proximity to Earth, making them both potential hazards and possible targets for future missions, as they’re relatively easy to reach by spacecraft. The Wide-field Infrared Survey Explorer (WISE) has scanned the sky since 2010 at different wavelengths, discovering hundreds of new NEOs and expanding the observation dataset of previously known ones. In this project, we recover all observational epochs for a list of asteroids and run a thermophysical model utilizing Monte Carlo Markov Chain (MCMC) simulations to fit diameter, albedo, thermal inertia and period. Results for most targets are used in conjunction with those obtained by other groups utilizing polarimetry data and improved measurements of the H absolute magnitude, to build comprehensive assessments of these asteroids. In parallel,

we search for previously missed detections of NEAs in NEOWISE's Year 9 data and report them to the Minor Planet Center (MPC). This helps to expand further the database of epochs available for future research on NEOs and allows to fully take advantage of the data already collected by WISE.

Preparation for NEMS-MS With Ultra-Thin Si Resonators
Samuel Senzon
Mentors: Michael Roukes and Mert Yuksel

Mass Spectrometry (MS) is used as a technique for identifying proteins through quantitative measurements of charge-to-mass ratio. Nonetheless, traditional techniques rely on pure solutions with a high number of the same samples and lack the high sensitivity necessary for detection of small proteins which can have crucial biological functions. Due to their small scale and high quality factor, nanoelectromechanical systems (NEMS) resonators provide a promising platform for high-resolution MS, working on the single-molecule level and achieving higher sensitivity. The Roukes group has developed such systems, achieving imaging of a single protein's inertial mass distribution in real time by monitoring shifts in vibrational modes upon adsorption of the protein. Yet, attaining high mass sensitivity remains a challenge in NEMS-MS. In this project, the goal is to implement an LC network tailored for achieving impedance matching in an ultra-thin silicon film NEMS resonator, with the aim of optimizing signal transfer and thereby enhancing achievable mass sensitivity. Additionally, a electrometer mapping PCB is to be designed and implemented for a more efficient method of system alignment.

Assembly Test Stand for Construction of Barrel Timing Layer (BTL) in CMS at CERN
Kristina Ann Sevier
Mentors: Maria Spiropulu and Jason Trevor

This project involves constructing an Assembly Test Stand to help with the proper installation of the scintillator silicon photomultipliers (Scintillator SiPMs) to a tray that will be installed into the Barrel Timing Layer of the Compact Muon Solenoid in the Large Hadron Collider at CERN. I have referenced the CAD file of the Assembly Test Stand provided by engineers at CERN and used it to order the necessary parts for its construction from McMaster and manufacture parts via metal working equipment. I built the Assembly Test Stand from these parts and modified parts as necessary for the build. During the assembly process, there was a lack of communication with the design, so I consulted with the engineers at CERN who created it. I have also manufactured parts incorrectly, therefore, I noted my mistakes and bought new stock to recreate the parts correctly. Even with these difficulties, the overall construction of the test stand was a success. The Assembly Test Stand successfully holds the tray, but the installation of the Scintillator SiPMs has not started, so its success is still undetermined. The next steps are to work on the installation and improve the Assembly Test Stand as needed.

MagnetoFilter: Manufacturing Magnetic Nanoparticle Capture Devices via Hydrogel Infusion Additive Manufacturing (HIAM)
Faiza Shabibi
Mentors: Julia Greer and Sammy Shaker

A non-surgical approach to advanced liver cancer treatment, transcatheter arterial chemoembolization (TACE), utilizes chemotherapeutics with significant off-target adverse events. Chemotherapeutic capture could mitigate this risk; however, currently proposed high surface area-functionalized capture filters can induce blood flow stagnation. Functionalized magnetic nanoparticles could provide improved capture of therapeutics, but require architected magnetic lattices to avoid the same stagnation issue that is often difficult to manufacture with traditional metal manufacturing techniques. A novel synthetic method, hydrogel infusion additive manufacturing (HIAM), allows for the creation of intricate 3D structures using magnetic metal alloys without the limitations of traditional manufacturing methods. We explored the synthesis of magnetic Fe-Co alloys of a range of compositions via HIAM for potential use as capture filters. The synthetic process was characterized using thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC). Powder X-ray diffraction (pXRD), scanning electron microscopy (SEM), and energy-dispersive X-ray spectroscopy (EDS) were used to analyze the composition and structure of the intermediate metal oxides and metals, and the magnetic properties of the samples were determined via vibrating sample magnetometer. These values were compared with respect to composition and the Fe-Co phase diagram and represented a further extension of the HIAM method to magnetic alloys.

Exploring Ruthenium Photosensitizers for Photodriven N_2 Reduction
Sanjana Shah
Mentors: Jonas C. Peters and Christian Johansen

Nitrogen (N_2) is reduced to ammonia (NH_3) by the energy intensive Haber-Bosch process. It is crucial that a more efficient process is developed. Previous work from our group has demonstrated a photodriven N_2 reduction using a molybdenum precatalyst, iridium photocatalyst, collidine/collidinium buffer and the Hantzsch ester (a dihydropyridine) as a source of 2 protons and 2 electrons. We explored the possibility of N_2 reduction using other photocatalysts, specifically ruthenium compounds. We were interested in ruthenium photosensitizers because of their ability to perform green light reductions and expand the scope of H+/e- donors. We investigated photocatalysis with these photosensitizers: $Ru(bpy)_3(PF_6)_2$, $Ru(bpy)_3(BAr^F)_2$ and $Ru(bpy)_2(PIm)(PF_6)$. We have observed the best catalysis with $Ru(bpy)_3(BAr^F)_2$ which can produce up to 9.1 equiv. NH_3/Mo. We have also explored the molybdenum speciation during catalysis and have studied the quenching steps of the ruthenium photosensitizers.

Investigating Leakage-Resilient Hardness Equivalence to Logspace Derandomization
Yakov Shalunov
Mentor: Chris Umans

Randomization is often a critical aspect of algorithm design, and one of the central open questions in modern complexity theory is whether random algorithms can be "efficiently" (polynomial composition and multiplication overhead) derandomized. I.e., whether there exists an approach to converting random algorithms (which are also allowed to produce incorrect answers some small fraction of the time) into deterministic algorithms with "small" overhead. It is known that an exponential time (in time-bounded setting) or quadratic space (in space-bounded setting) factor allows for derandomization. It has been known for several decades that the existence of certain types of hard functions allows for efficient derandomization. A recent result by Lui and Pass identifies a new class of hardness assumption under which it is possible to perform time-bounded derandomization efficiently, that of "leakage-resilient hardness." They identify an assumption which is equivalent to efficient derandomization. We investigate reapplication of this result to the logarithmic space setting, where we attempt to find an equivalence with additive logarithmic space overhead derandomization.

Photometric Template Re-fitting of High Redshift Galaxies From James Webb Space Telescope
Arden Shao
Mentors: Charles Steinhardt and Melany Hunt

With the initial release of the James Webb Space Telescope, an abundance of studies purportedly found ultra-high-redshift galaxy candidates that were later debunked. However, in this current regime of more deep field information and improved redshift determination based on inferred properties reconciled with ΛCDM, we attempt to re-probe for the highest redshift galaxy. We use a set of high-redshift optimized synthetic templates as a first-order correction on top of models distributed with the EAZY software to derive the best fit redshifts. Some of the photometric redshifts are then cross-checked by taking confirmed spectroscopic measurements from NIRSpec in the relevant redshift range. The resulting constrained catalog at $z > 10$, with contaminants discarded, offers a glimpse into the early universe.

The Hunt for Binary Stars in the Darkest Galaxies: Investigating the Bias in Dark Matter Measurements
Domani Sharkey
Mentors: Josh Simon and Lynne Hillenbrand

Dark matter comprises 80% of all mass in the universe, and yet is still one of the largest gaps in scientific understanding today. Ultra-faint dwarf galaxies (UFDs), as the most dark matter-dominated systems known, are uniquely valuable for investigating this mysterious substance. However, their inferred dark matter content depends on their velocity dispersions, which are derived from the velocities of stars assumed to be in single-star systems. This process therefore presents the danger that the calculated velocity dispersions may be erroneously inflated by binary stars. Here we investigate this potential measurement bias by examining a sample of spectra from 15 stars in 8 local UFDs. We fit each spectrum with an empirical template spectrum to extract a radial velocity and perform a Chi-Square analysis on each star's velocities to test for velocity variability. For the discovered binaries, we also compute the orbital period and binary mass function. We find that 86.7% of the stars show no evidence of binarity, which places a constraint on the fraction of binary stars contained in the UFDs. Moving forward, the identification of these binaries and the subsequent calculations from them will be used to more precisely measure the dark matter in UFDs.

Analysis of Di-Higgs Decaying to Two Bottom Quarks and Two Photons Using Proton-Proton Collision Data in CMS at the Large Hadron Collider
Joseph Sheeran
Mentors: Harvey Newman and Irene Dutta

In the Standard Model of particle physics, the Higgs field associated with the Higgs Boson, discovered in 2012 at the Large Hadron Collider, generates the intrinsic masses of fundamental particles. By studying the cross section of the process Di-Higgs to two bottom quarks and two photons ($HH \rightarrow b\bar{b}\gamma\gamma$) we can measure the strength of the Higgs boson self-coupling which is related to the shape of the Higgs potential. Using simulated data of varying energies, we can build convolutional neural networks to better discriminate between background and signal events in the data collected by the Compact Muon Solenoid, and as a result, improve on the constraints on the self-coupling relative to the previous analysis of this channel. We have begun training our model on simple background data and will gradually incorporate all of the main backgrounds along with the simulated signal data in order to build an improved analysis. This will potentially allow us to obtain stronger bounds on Di-Higgs production when implemented on real data.

Combining Model-based Controller and Machine-Learned Advice via Convex Reparameterization

Junxuan Shen
Mentors: Guannan Qu, Adam Wierman, and Steven Low

Nonlinear control problems frequently rely on machine-learned black-box policies, which have achieved great success but often lack worst-case guarantees. On the other hand, the classical model-based control provides policies with provable stabilities and robustness guarantees but are usually outperformed by the black-box policies. To achieve the best of both worlds, our work focuses on combining an ML controller with a model-based controller for nonlinear control problems by using Disturbance Response Control (DRC) parameterization. We proved that by using DRC parameterization, the space of stable controllers becomes convex for nonlinear controllers for Linear Time-Invariant (LTI) systems and their generalizations. For each of the LTI system, Linear Time-Variant (LTV) system, and LTI system with a model mismatch, we propose self-tuning policies with adaptively chosen confidence parameters based on the performance of the RL controllers. We provide theoretical analysis for the safety guarantees and the sublinear regret bounds of the combined controllers. We show that there is a tradeoff between the safety and the regret bounds of these policies.

Understanding XP Codes From Quantum Lego

Ruohan Shen
Mentors: John Preskill and Charles Cao

The Quantum Lego framework is a powerful approach for constructing large quantum error correction codes by combining smaller codes. By representing encoding maps as tensors and contracting them, we obtain the encoding map of the larger code. While this framework has shown efficiency for Pauli stabilizer codes on qubits and qudits, its expressibility is limited in the vast many-body Hilbert space. To address this limitation, we propose replacing the atomic Legos with XP codes, which is a lately proposed non-stabilizer code. Surprisingly, we find that the operator matching rule still produces the new stabilizers, as long as we match the logical identity group. Additionally, we establish the condition that the traced code remains an XP code. Our results demonstrate that the Quantum Lego framework can be successfully extended to XP codes, offering new possibilities for error correction in quantum systems. In future work, we plan to explore numerical methods to discover exotic examples of XP Legos. Moreover, we aim to leverage tensor enumerators, a by-product of the Lego framework, to design efficient decoders for XP Legos.

Exploring Misinformation in Twitter's Musk-era

Siddhartha Shendrikar
Mentors: Michael Alvarez and Jacob Morrier

This project aims to detect the changes in climate misinformation after Elon Musk acquired Twitter. There have been previous studies specific to this goal, however we are going to look deeper into the underlying data and draw conclusions aimed at finding the reasons for the increase in misinformation. We will use hashtags with high misinformation rates to gather the data, measure the differences, and interpret them using a method called causal inference. In the early stages of the project, we gathered hundreds of millions of tweets from the past year that are related to climate. Subsequently, we cleaned up the data, and found the coherence of the topics and started topic modeling to identify trends. The upcoming stages are to create visuals and dive into the realm of misinformation.

Deploying the "Galactic Radio Explorer"

Priya Shukla
Mentors: Shrinivas Kulkarni and Liam Connor

The GReX is an upcoming low-cost radio telescope that will search for the brightest fast radio bursts in the universe. The GReX box comprises a comprehensive assortment of hardware components, including Low-Noise Amplifiers (LNAs), SNAP boards, Front-End Modules (FEMs), Raspberry Pi, Field-Programmable Gate Arrays (FPGAs), and sources of power. The rationale behind housing all these components within an aluminum box is to provide effective shielding against environmental factors such as rain, snow, and Radio Frequency Interference (RFI). In our study, we present detailed methodologies for the assembly, programming, and testing of the FEM within the GReX box. The box is deployed in an open-sky environment for prolonged durations. To address thermal management concerns associated with the operational electronics inside the box, we employ a heat sink design and incorporate thermal fans.

Dependence of Carrier Mobility on Pseudopotential and Exchange-correlation Functional in Semiconductors
Shreya Shukla
Mentors: Austin Minnich and Tomi Esho

Semiconductors are important in condensed matter physics and for technological applications. Charge transport in these materials plays a key role in electronics, optoelectronic, photovoltaics, and photocatalysis[1]. Understanding the microscopic processes that govern charge dynamics in these materials is of fundamental interest. Ab-initio calculations, where no adjustable parameters are needed to predict material properties, have been shown to possess strong predictive accuracy[2]. These calculations are based on density functional theory (DFT), where electron-ion and electron-electron interactions are approximated with pseudopotentials (PP) and exchange-correlation (xc) functionals. Since there are various pseudopotentials and functionals to choose from, it is important to evaluate the effect of these choices on charge carrier properties. Therefore, this project aims to calculate the mobility of electrons and holes in different semiconductors while varying the pseudopotentials (PP) and exchange-correlation (xc) functionals. By employing ab-initio calculations based on DFT, the project seeks to gain insights into the microscopic processes governing charge dynamics in semiconductors. Additionally, the project investigates the influence of lattice parameters on carrier mobility and compares the results with experimental data. The approach involves computing electronic band structures, phonon dispersions, and electron-phonon matrix elements using Quantum Espresso. Furthermore, Perturbo is utilized to calculate charge carrier mobility by considering scattering processes with phonons. The results will be evaluated for various choices of PP and xc to assess their impact on charge carrier properties.

Resources
[1]Zhou, Jin-Jian, and Marco Bernardi. 2016. "*Ab Initio*Electron Mobility and Polar Phonon Scattering in GaAs" 94 (20).
[2]Bartlett, Rodney J, Victor F Lotrich, and Igor Schweigert. 2005. "*Ab Initio*Density Functional Theory: The Best of Both Worlds?" *Journal of Chemical Physics* 123 (6): 062205–5.

Measuring Fast Radio Burst (FRB) Scintillations Using CHIME Catalog1 Data
Anant Singh
Mentors: E. Sterl Phinney and Dongzi Li

Fast Radio Bursts (FRBs) are millisecond-duration bursts of radio waves that mostly originate from outside our galaxy. Although their exact causes remain uncertain, astronomers are now beginning to use these bursts as tools to probe the cosmos. One of the remarkable properties of these radio transients are their scintillations, which are variations in brightness caused by the scattering due to the irregularities in the intervening medium. These scintillations can be used as a tool to study the properties of the intervening medium and the FRB source itself. We develop a pipeline to measure the scintillations for some of the brightest FRBs using CHIME Catalog1 Data. The result will be used to compare with the scintillation model in the Milky way and constrain the origin of the scattering of FRBs.

Combination Genomic and Epigenomic Analysis of Plasma Cell-Free DNA Identifies Stemness Features Associated With Worse Prognosis in High-Risk Metastatic Castration-Resistant Prostate Cancer
Savar Sinha
Mentors: Aadel Chaudhuri and Jared Leadbetter

Prostate cancer is the second leading cause of cancer death among American men, causing 34,700 deaths annually. While localized prostate cancers are highly responsive to androgen-directed therapies, some patients develop metastatic castration-resistant prostate cancer (mCRPC), which is resistant to these treatments. Previous tumor whole-genome sequencing studies highlighted aberrations in both the androgen receptor (AR) locus and the recently discovered *AR* enhancer region as genomic hallmarks of mCRPC. The Chaudhuri Lab sought to replicate these results using cell-free DNA (cfDNA) analysis as a less invasive alternative to tumor sequencing, developing the EnhanceAR-Seq liquid biopsy assay to detect alterations in the *AR* locus/enhancer in post-treatment mCRPC plasma samples, which were found to portend primary resistance to treatment with high accuracy. In this study, we perform epigenomic analysis of pretreatment patient cfDNA samples, including genome-wide methylation sequencing, nucleosome profiling, and stemness analysis via EM-Seq, Griffin, and CytoTRACE, respectively, to elucidate the underlying biology of mCRPC. We illustrate that pretreatment plasma cfDNA analysis can be used to risk-stratify patients, mCRPC transcriptional profiles can be predicted from cfDNA epigenomics, and higher-risk mCRPC patients have more stem-like signature profiles that correlate with worse survival outcomes.

Terrain Aware Adaptive Control
Emilia Sjögren
Mentors: Soon-Jo Chung and Sorina Lupu

Developing robust algorithms for robots is essential to ensure reliable and efficient motion capabilities. We are exploring how we can integrate information about the terrain into control algorithms in order to take the environment into account. By extracting images in real time that the robot is taking, we are utilizing machine learning models, specifically a vision transformer called DinoV2 from *Meta AI*. By analyzing the feature vectors and performing dimensionality reduction using principal component analysis, the most important properties can be extracted. The ground properties together with depth images can be visualized as point clouds and elevation maps. These representations can then be used as inputs into adaptive control algorithms running on the robot.

Designing Reconfigurable Architected Materials for Thermal Applications: A Numerical Study
Alemayouh Snyder
Mentor: Julia R. Greer and Cyrus J.B.M. Fiori

Reconfigurable materials allow for the rapid change of material properties, which can have exciting applications in emergency cooling technologies. By breaking lattice connections, an architected material could be transformed from a conductor to an insulator. We use the pore network modelling approach to examine the transient and steady state changes in temperature and conductance while the connectivity of the architected material changes during fracture. Multiple simulations were run with different crack paths and crack propagation rates. Pillar defects were designed to best guide fracture through the lattice while maintaining a similar thermal response to a lattice without defect pillars. Four defect geometries were modeled and simulated to determine the effective diffusivity, then the lattice was simulated with these specific defect pillars. Simulations show that small edge-notch defects result in the smallest change in the temperature profile. After fracture, a large temperature jump is observed at and around the crack. When compared to a crack perpendicular to the initial temperature gradient caused by the boundary conditions, cracks that are diagonal or have sections both perpendicular and parallel to the gradient disrupt the temperature profile more. This makes these configurations more effective for manipulating lattice thermal conductivity.

Testing of Mechanical Optical Fiber Switches for Use by the High-Resolution Infrared Spectrograph for Exoplanet Characterization (HISPEC) Instrument
Svarun Soda
Mentors: Dimitri Mawet, Nemanja Jovanovic, and Ashley Baker

The HISPEC project is an experimental spectrograph device, planned for the Keck Observatory in Hawaii. The purpose of the project is the detailed characterization of exoplanets in our universe. A crucial part of the HISPEC assembly is a Mechanical Optical Fiber Switch, which requires extensive verification testing prior to implementation, as the resultant data from HISPEC entirely depends on the proper operation of the Switch device. The testing of the Switch device was carried out by measuring the output power from a light source on a power meter, via a pair of fibers connected by the Switch connectors. The power was measured over the course of many repeated connections on a single Switch port, and this allowed us to acquire power throughput data over a set of many connections. From the acquired data, we can conclude that cleanliness is of absolute importance. Occasional cleanings of the fibers inside the switch is a necessity to avoid power drops due to dust accumulation. While we were able to extract some conclusions from the data, further testing is required to find out exactly what cleaning intervals would be the most efficient.

GPS-Guided Thermal Image Annotation via Orthorectified RGB Aerial Imagery
Saraswati Soedarmadji
Mentors: Soon-Jo Chung and Connor Lee

Unmanned Aerial Vehicles (UAVs) have found widespread use in a variety of applications, ranging from agriculture and defense, to remote sensing and entertainment. To enable nighttime operations, UAVs are typically equipped with long-wave infrared cameras that can capture live thermal images for aiding in navigation and scene understanding. Today, deep neural network-based models can provide scene understanding for RGB imagery through the forms of 2D/3D object detection and image segmentation. However, applying such models to perform similar analysis in the thermal domain presents a challenge due to the lack of available thermal scene-specific training data. Unlike RGB cameras, thermal cameras are not ubiquitous, thus making data collection expensive. Even when such datasets are available, most are not annotated as they look very different from what people often expect, thus requiring experience and expertise to annotate. In this work, we focus specifically on developing a method using machine learning segmentation models to automatically annotate thermal data for training semantic segmentation models. After developing the thermal segmentation model, we will use the model on various thermal image segmentation tasks to help aid navigation and scene-understanding of UAVs during their nighttime operations.

Reinforcement Learning for Exoskeleton Gait Generalization With Variable Mass Distribution
Widyadewi Soedarmadji
Mentors: Yisong Yue and Kejun Li

Nearly 60% of neurological patients suffer from gait disorders or lower body paralysis. Wearable lower-limb exoskeleton devices aim to serve as a means of restoring mobility to people with lower-body paralysis or gait disorders. Users of exoskeleton devices may have different height and weight causing the exoskeleton and user system to have different mass distributions. Currently, the exoskeleton gait generation is performed using a control theory approach and requires many user-specific parameters to be provided for calculation of a gait. However, the generated gait is not generalizable to users with different body properties and the system could easily be thrown off balance when subject to perturbation forces such as user movement within the exoskeleton. We present a solution using reinforcement learning and privileged learning methods to learn a general and robust policy for exoskeleton gait generation for users of variable mass distributions requiring minimal personalized configuration.

Neural Theorem Proving in Lean 4
Peiyang Song
Mentors: Anima Anandkumar and Kaiyu Yang

Large Language Models (LLMs) have shown promise in Neural Theorem Proving (NTP) using Interactive Theorem Provers (ITPs) such as Lean, especially after our recent release of LeanDojo, an open-source Lean playground that extracts fine-grained data from Lean proof files and facilitates interaction with the proof environment programmatically, and ReProver, the first LLM-based prover augmented with retrieval for selecting premises from a vast math library. Built on top of these advances, this work on one hand upgrades LeanDojo with full support for Lean 4, the latest enhanced version of Lean to be official released, in order to preserve LeanDojo's relevancy in the future and arm it with more high-quality data from Lean 4 proofs. On the other hand, this work also creates LeanONNX, a complementary tool to LeanDojo that leverages the power of LLMs back to assist with ITPs, by enabling LLM inferencing in Lean 4 as a copilot for theorem proving. Those two directions together establish a roundtrip between the potent instruments of LLMs and ITPs, fostering a beneficial loop that automatically advances the field of Neural Theorem Proving (NTP) in the long run.

Rock Magnetic Studies and Dirac Magnetic Monopole Search on Primitive Material Returned From Asteroid Ryugu
Michael Sowell
Mentor: Joseph Kirschvink

To elucidate the history of the early Solar System and early Universe, we studied the magnetic properties of three Ryugu samples: A0397, C0006, and C0085. We attempted to constrain magnetic field conditions early in the history of Ryugu's parent body using paleomagnetic methods such as AF demagnetization, ARM, IRM, and an accidental multi-conglomerate test. Contrary to earlier articles on this topic, the weakness of the calculated paleointensities at medium-to-high coercivity ranges implies that these samples may not record the magnetic conditions of the early Solar System. However, the different directions of magnetization of the broken samples C0085a and C0085b conflict with this conclusion. In addition, we searched for Dirac magnetic monopoles (DMMs) in these samples. By passing asteroidal material through a 2G SQUID rock magnetometer, a theoretical DMM trapped within ferromagnetic grains would return a change in measured magnetic flux ($\Delta\Phi$) by a value of 4 magnetic flux quanta – 8.23 fWb. We measured $\Delta\Phi$ as -0.3 ± 0.2 fWb for A0397, 0.3 ± 0.5 fWb for C0006, and 0.4 ± 1.1 fWb for C0085. We detected no magnetic charge consistent with Dirac's predictions.

Advancements in Land Surface Modeling: Integrating a Two-Stream Radiative Transfer Scheme Into CliMA LSM and Performing Site Level Validation
Edward Speer
Mentors: Christian Frankenberg and Renato Braghiere

Earth system modeling is a computational approach seeking to simulate the fluxes of water, carbon, and energy through various Earth components, including the land, atmosphere, and oceans, to understand and predict climate over long time scales. The Climate Modeling Alliance (CliMA) is developing a next generation, data-driven Earth system model, whose land component model is called CliMA LSM. In order to improve the modeling of radiative transfer through vegetation canopies in CliMA LSM, the two-stream scheme presented in Sellers 1985 was integrated into the model and used to compute absorption of both photosynthetically active and near-infrared radiation. Site level validation of the model was performed by running simulations driven by flux tower data from the US-MOz, US-Ha1, and US-NR1 FLUXNET sites. Model usability was enhanced through structural modifications and additional usage tutorials.

Vortex Excitations in Box Trapped Bose-Einstein Condensates

Vishvesha Sridhar
Mentors: Nir Navon, Olexei Motrunich, and Songtao Huang

The study of trapped atomic gases has traditionally been done in harmonic traps. However, in recent times, optical boxes have emerged as an attractive method of probing the properties of these systems. In this project, we numerically solve the Gross-Pitaevskii equation to dynamically simulate vortex line excitations in atomic gases trapped in an optical box. We present methods to excite and detect Kelvin waves and varicose waves of a desired mode that can be experimentally implemented. We perform spectroscopy of various excitation modes and calculate the dispersion relations for Kelvin and varicose waves. Additionally, we present analyses of their lifetime and decay processes. We find these excitations have much longer lifetimes than in previous work.

Manipulating the Band Gap of a Mott Insulator Using Floquet Engineering

Aditya Srinivasan
Mentors: David Hsieh, Ryo Noguchi, and Carina Belvin

Floquet engineering, the process of using a periodic driving force, like a laser, can be used to control quantum systems by changing their electronic structure. In this project, a femtosecond IR laser was used to drive a Mott insulator (specifically La_2CuO_4) into transient states. Mott insulators are quantum materials which have a partially filled electron band, causing them to be insulators at low temperatures due to electron-electron correlation. Understanding their properties is of great interest as they potentially have wide-ranging applications from quantum storage devices to optical switches. Using a pump-probe technique, the La_2CuO_4 crystal was driven out of equilibrium by the femtosecond laser pump beam with varying energies intended to limit the heating of the Mott sample by the pump. The transient reflectivity was then probed using a white-light spectrum generated by a sapphire crystal of wavelengths comparable to the band gap. In addition, a DFT code, Quantum Espresso, was used to model the electronic structure of La_2CuO_4 and calculate various quantities such as the Fermi Energy and band gap. These transient reflectivity measurements and related spectra will be analyzed and interesting properties such as the optical conductivity can potentially be inferred.

Identifiability of Statistical Models With Latent Symmetry and Non-Uniform Priors

Andrei Staicu
Mentor: Leonard Schulman

Consider a statistical model consisting of a set of binary latents, where each binary latent has a non-uniform prior and the model is fixed under permutation of the latents. We show that for 2 and 3 latents it is only necessary to observe the first 5 and 7 moments respectively for this model to be identifiable. We provide the framework to generalize such results to arbitrarily many binary latent variables.

Monte Carlo Tree Search on a Graphics Processing Unit in the Context of Online Robotic Decision Making

Felix Steinberger Eriksson
Mentors: Soon-Jo Chung and Benjamin Rivière

Effectively leveraging parallel computation on graphics processing units (GPUs) is a promising direction for speeding up online robotic decision making and planning algorithms. Monte Carlo Tree Search (MCTS) is an established method with well-known empirical results. Since it was first described, MCTS has been adapted to areas beyond turn-based games with full observability, expanding its domain of applicability to areas like control and robotics. There are also recent theoretical results on the non-asymptotic convergence properties of MCTS. Although there exist parallel implementations of MCTS, parallel MCTS implementation is underexplored in the context of robotics. Furthermore, several recent methods for online robotic decision making make use of MCTS as a subroutine to obtain solutions to decision problems, or generalize it to explore the sample complexity of Markov Decision Processes (MDPs). We provide parallel implementations of some variants of MCTS and related newly proposed tree search algorithms. These parallel implementations are used in empirical analysis of a newly proposed anytime tree search-based planning algorithm that provides insight into new sample complexity measures for finite deterministic tabular MDPs.

Inferring a Population-Level Hot Jupiter Age Distribution by Stellar Rotation Period Measurements From TESS Transit Data

Elin Stenmark
Mentors: Andrew Howard and Luke Bouma

The detection of Hot Jupiter (HJ) "51 Pegasi b" established a new field of astrophysics, dedicated to investigating extrasolar worlds. In-situ formation of HJs is prohibited by several astrophysical limitations, and nearly 30 years after the first exoplanet discovery, the process by which HJs enter their close-in orbits of <10 days remains inconclusive. As different migration models produce HJs at different stellar ages, by measuring the distribution of host star ages, we discover which migration processes are most common. Stellar rotation periods increase over time, and can thus be used to infer stellar ages. We prepare a sample of 528 candidate stars from the NASA Exoplanet Archive and construct a Python pipeline to measure their stellar rotation periods, with 77% of stars successfully producing candidate rotation periods. We then use photometric data to confirm stellar rotation periods, a significant fraction of which were previously unknown. Finally, we convert confirmed stellar rotation periods to gyrochronological ages, to obtain a population-wide HJ age distribution, and compare this data set against predictions from two competing models: disc migration and high-eccentricity migration, in hopes of discerning their respective accuracy in describing HJ migration.

Moment Estimation Correlated Random Coefficient Linear Panel Data Models: A Comprehensive Analysis
Yelyzaveta Strulieva
Mentor: Robert P. Sherman

Panel data offers insights by observing the same units across multiple time frames, making it pivotal for understanding relationships between variables over time. Existing research, like Graham and Powell (2012), has delved into correlations within single panel data periods, yet there remains a void in comprehending correlations spanning multiple time frames, crucial for grasping the evolving nature of data.
The challenge lies in estimating relationships between the dependent variable and multiple independent variables over time, considering the fluctuating coefficients across individual sections and time periods. This complexity necessitates a more adaptable and precise model to capture these intricate data structures. We introduce a linear regression panel data model that permits random coefficients to correlate with regressors both within and across periods. These coefficients are shaped by a combination of independent, variably distributed past and present shocks. This design facilitates feedback, where future regressors can associate with all previous shocks, and incorporates all prior dependent variables as regressors. Through this, we pinpoint the marginal first moments of these random coefficients, which bear causal implications. Our findings, rooted in a unique functional fixed-point rationale, pave the way for intuitive estimators of these moments.

Quantitative Evaluation of CLIP Model Performance and Complexity Handling
Manal (Noreen) Sultan
Mentors: Robert Pless and Steven Quartz

Deep learning approaches to image retrieval are important in a variety of application domains, including image provenance detection in journalism, image localization in intelligence investigations, and aiding medical diagnosis through matching and retrieving relevant medical imagery. Purely image-based queries, where the input is an image and the task is finding images that are visually similar in some way, often fail to align to human-in-the-loop needs and intuitions, especially when the image retrieval models do not focus on components of the image that the human wants to focus on, or when results key on aspects of the image that the user wants to ignore.
Recent advances in text-based image retrieval present an opportunity to provide the user with flexibility to use natural language to describe exactly they want to focus on. Contrastive Language-Image Pretraining (CLIP) is the most common approach for text-based image retrieval. CLIP learns aligned image and text models by taking a huge number of pairs of images and their associated captions and pushing them to have similar representations in their respective models. These models support text-based image retrieval: a human provides a text query, that query is mapped into CLIP space, and a system returns images with similar representations in CLIP space. Unfortunately, existing CLIP models often fail for queries where a human writes specific or complex queries, limiting the utility of CLIP for many real world applications of text-based image retrieval. For example, a query that says ``find images of rooms with green carpet'' may return reasonable images, but a query that says ``find images of grungy rooms with stained green carpet, a dark wooden table, a striped couch, and an air conditioner on the wall'' typically does not. In this paper, we present a quantitative evaluation of CLIP model performance on queries with varying levels of complexity, and qualitative evaluation of CLIP-based image generation models for image generation from prompts with varying levels of complexity.

We additionally release our image dataset and human-written prompts, annotated by level of complexity, to support further evaluation of CLIP models for real world image retrieval uses.

Physics-Informed Neural Operator for Learning Schrödinger Bridges
Jeff Sun
Mentors: Anima Anandkumar and Julius Berner

This study delves into the capabilities of physics-informed machine learning methodologies for tackling the Schrödinger Bridge (SB) Problem, a mathematical problem centered on the evolution between two probability distributions. Originating from Erwin Schrödinger's 1931 proposition, the SB problem has recently gathered attention due to its significance in contemporary machine learning as a generative model. Traditional methodologies often encounter difficulties in high-dimensional contexts, leading to the exploration of physics-informed neural networks (PINNs) and physics-informed neural operators (PINOs). These methods leverage physical knowledge embedded in partial differential equations (PDEs) to enhance modeling accuracy. Additionally, the study is investigating the use of Gaussian process representation to model PINOs, offering a computationally efficient solution for high-dimensional problems. This research extends its experimental scope to n-dimensional Gaussian Mixture Models and high-dimensional synthetic datasets, such as the Funnel problem and Double Well problem. Preliminary findings underscore the potential of PINNs in approximating solutions across varying complexities and dimensions. Though the findings are encouraging, they highlight areas needing refinement and the potential of PINOs in advanced modeling for high-dimensional datasets. This exploration lays the groundwork for future research in the domain of physics-informed learning and its implications for generative modeling.

Exploiting Non-Convergent Dynamics in GAN Training
Bharathan Sundar
Mentors: Stefanie Jegelka, Nisha Chandramoorthy, and Houman Owhadi

It is well-studied that generative adversarial network (GAN) training can suffer from instabilities due to the challenge of finding a Nash equilibrium for the zero-sum game. Here, we are interested in studying GANs with non-convergent training dynamics, and exploiting their statistical properties to achieve robust generalization. We first explore the toy setting of learning Gaussian mixtures, and deliberately induce unstable behaviors such as oscillation. Under these dynamics, we introduce ensembling (time-averaging over training) as an approach to handle, or even exploit, non-convergence, along with multiple ensembling schemes. We show various empirical results where ensembling of models outperforms a single model, including even some simple, low-dimensional toy settings. These results present a promising direction for GAN research, as they imply convergent dynamics are not necessary to achieve strong performance in practice.

Evaluating Open-set Recognition Approaches for Re-identification
Avirath Sundaresan
Mentors: Serge Belongie, Nico Lang, and Pietro Perona

Re-identification, or re-ID, is a computer vision task that involves recognizing individuals across images. Re-ID techniques can be used for a variety of scenarios, from matching human fingerprints and faces for use in biometric recognition systems to identifying individual animals from natural body markings for biodiversity monitoring. In real-world re-ID scenarios, the set of possible identities is an open-set, where query images encountered during test time may not be represented in the database of known identities. Recent studies in visual recognition have shown that the ability for a classifier to recognize that a query image belongs to an unseen class is correlated with the performance of the classifier on known classes. In this research, we adapt these “familiarity-based” open-set recognition approaches for human and animal re-ID tasks, evaluating different feature extraction methods in their ability to generate meaningful ID representations that can be used for both closed-set re-identification and open-set ID recognition. Our work shows promising results for familiarity-based open-set ID recognition for both human and animal ID datasets.

Machine Learning Model to Predict Patient Fatigue Using Data From Wearable Sensors
Ashwitha Surabhi
Mentors: Wei Gao and Changhao Xu

Wearable sensors have become an increasingly popular area of research due to their ability to transform the medical industry by allowing the measurement of a patient’s physiological signals in constant time. In this project, we are measuring the pulse, GSR (Galvanic Skin Response), and temperature data from patients and using this data to predict patient fatigue, which becomes important for a patient as they are able to monitor their own health and energy levels throughout the day. Using data processing techniques, we are able to analyze the raw data from the patient and create more metrics such as systolic upstroke velocity time for pulse data and weighted moving average data for temperature and GSR data. Then, using machine learning techniques, specifically a transformer model using GPT 2, we will be able to take this data from the wearable sensor as an input to predict patient fatigue levels.

Studying Infrared Transients and Variables With WINTER and PGIR
Aswin Suresh
Mentors: Mansi Kasliwal and Viraj Karambelkar

The Palomar Gattini-IR (PGIR) is a robotic survey designed to observe variable stars in the Near Infrared J band. With a large field of view and a cadence of 2 days, PGIR has produced lightcurves of over a million variable stars, including Long Period Variables (LPVs), over four years. This project aims to create a high-purity catalogue of LPVs and characterize them. LPVs are pulsating variable stars that exhibit periodic expansions and contractions of their surfaces, resulting in brightness variations. PGIR's long baseline and infrared observations provide valuable data for characterizing LPVs and studying dust-obscured stars in the galactic bulge. Additionally, a subset of non-periodic or very long-period variable stars, such as R Coronae Borealis (RCB) variables that display unique properties, will be classified separately. The primary goal of this study is to employ a machine learning classifier to distinguish between LPVs and non-LPVs, with the potential for spectroscopic follow-up on interesting non-LPV candidates.

The lessons learned from this study will be applied to hunt for elusive transients such as kilonovae with the new IR telescope WINTER, surveying the infrared sky in the NIR Y, J and H bands up to a depth of 21 AB mag. Using transient alerts produced from WINTER, we will build a deep learning classifier to classify between real astrophysical sources and bogus alerts.

Improving Methods to Enhance Porous Ceramic Conductivity With Carbon Nanotubes
Matthieu (Finn) Sutcliffe
Mentors: Katherine Faber and Kevin Yu

The Faber group has developed a method to grow directionally porous ceramics by freeze-casting preceramic solutions. Silicon oxycarbide can be formed in this manner with a high degree of control over pore size, morphology and fraction, making it suitable for mass transport applications such as sensing and battery electrodes. However, the samples produced are electrically insulating, so the group has explored ways combine these ceramics with conductive carbon nanotubes. From these processes, specimen conductivity has been successfully increased by 10 orders of magnitudes up to around 0.01Scm^{-1}. Further increases in conductivity require the investigation of methods that can achieve higher CNT loading. This work seeks to refine three such methods, namely dispersing nanotubes in the pre-ceramic solution, growing nanotubes from nickel dispersed in the pre-ceramic solution, and growth from nickel deposited after casting. For the first method, it was found that nanotube dispersion by ultrasonication is mechanically limited to no more than 12wt.% due to solvent saturation leading to a gel-like consistency. The second method remains limited by the formation of Ni_2Si during pyrolysis, which does not oxidise in air below 1100°C. In the post-pyrolysis deposition method, it is theorised based on observation that nickel migration is dominated by segregation of a suspected silica phase homogeneously nucleating in the subsurface of the deposited layer.

Advancing Membrane Protein Expression in Cell-Free Systems for Bottom-Up Synthetic Biology
Elna Svegborn
Mentors: Richard M. Murray and D. Alex Johnson

Membrane proteins play vital roles in cellular processes, but extracting and purifying them is challenging. Liposome-encapsulated cell-free expression systems offer a promising solution. This research project aims to advance the development of a reliable membrane protein expression system for synthetic cells using a bottom-up approach. Gene circuits encoding three pore-forming membrane proteins have been synthesized for cell-free expression systems. Site-directed mutations that introduce cysteine residues into the membrane protein have also been done to enable cysteine labeling. The functionality of the membrane proteins, upon being inserted into vesicles, is examined using liposomes encapsulating calcein or a T4 phage assay. Future work will focus on generalizing the method and developing a comprehensive pipeline for unsupervised protein expression and effective fusion of proteins with the membrane in a predictable spatial orientation from encapsulated cell-free expression systems.

Light Yield Analysis of LYSO Scintillation Crystals for the Barrel Timing Layer at the Compact Muon Solenoid
Kai Svenson
Mentors: Maria Spiropulu, Adi Bornheim, and Jason Trevor

The Large Hadron Collider (LHC) is in the multi-year process of upgrading its particle beam luminosity, which will rename it the High Luminosity LHC (HL-LHC), expected to begin operation in 2028. The Compact Muon Solenoid (CMS) is one collision site located around the main LHC loop, and will require greater detection capabilities in order to account for the upgraded luminosity. In particular, a new minimum ionizing particle (MIP) Timing Detector (MTD) will be installed cylindrically around the collision chamber of the CMS in three parts: the Barrel Timing Layer (BTL) and two Endcap Timing Layers (ETL). The BTL will be comprised of cerium doped lutetium yttrium orthosilicate (LYSO) scintillation crystals paired with silicon photomultipliers (SiPMs), which will be packaged in modules sized approximately 5×5×0.5 cm. In the coming year, Caltech will become one of four assembly centers worldwide for constructing over ten thousand modules needed for the BTL. To this end, Caltech has constructed a device named the Quality Assurance/Quality Control (QA/QC) jig, which will be distributed to all the assembly centers. The jig measures the scintillation light yield of each read-out channel on a module to ensure that the quality of the construction has met passing criteria. We conduct a performance test of the QA/QC jig to commission its design. In particular, we examine the consistency and accuracy of the jig with different sources of radiation, SiPM over-voltages, and data analysis procedures. Our most notable result is a discrepancy on the order of 10% when comparing light yield measurements taken with different sources of radiation. We offer several potential reasons for this discrepancy, and discuss possible methods of correction. Further studies are required to officially commission the final design of the jig, but the results found in this project have provided evidence that the jig can deliver an accuracy within our desired tolerance.

Stability of Oil-Infused Submicron Parylene C SLIPS: An Anti-Biofouling Material for Implantable Devices
Elana Sverdlik
Mentors: Yu-Chong Tai and Suhash Aravindan

Implantable electrochemical sensors for health monitoring are prone to biofouling. Here we present a Slippery Liquid-Infused Porous Surface (SLIPS) material that improves sensing by mitigating biofouling and facilitating solubility- and size-based filtering of target molecules. To create SLIPS, a submicron thick layer of Parylene C was deposited by CVD and then wetted by 20 cSt Silicone Oil. The oil infusion process into the pores in the PAC membrane left a layer of excess oil on the surface. To prevent this surface oil from leaching out, and potential downstream systemic inflammation and infection, diverse techniques were studied for surface oil removal: RIE (O_2, CF_4, O_2 & CF_4 Plasma), cleanroom & filter paper absorption, and diluted acetone:deionized water (1:10, 1:20) washing, and other spinning techniques. Analysis of contact angle, mass, and reflectometer measurements regarding surface oil removal demonstrate the need for a synergistic approach, combining multiple procedures to completely remove the surface oil layer without damaging the underlying SLIPS material.

Stability Analysis of Traveling Wave Fronts in a Model for Tumor Growth
Brea Swartwood
Mentors: Jared Bronski and El Hovik

Many biomedical systems can be modeled and studied with applied and computational mathematics. One such model, the Gatenby-Gawlinski (GG) model, was developed in 1996 to represent the invasion of cancerous cells into healthy tissue. We aim to work with the Gallay and Mascia (GM) reduced model and study the stability of the traveling wave solutions. Informally, this process consists of finding the intersection of two 2-d manifolds in 3-d space. This intersection is the traveling wave solution; we then studied the orbital stability of the traveling wave solution.

Orbital stability is crucial to studying models as it determines which solutions are likely to be observed in practice. Through constructing the unstable manifold to connect fixed states of the GM model and applying a shooting argument, we constructed front solutions to the model. We then studied stability by constructing the spectrum for various parameters of the GM model. We found that the spectrum for the cancerous to healthy state is stable, while the spectrum for the mixed state to the healthy state is both stable and unstable depending on the parameters chosen. These findings provide critical information about the stability of tws for the GM model.

Understanding Mechanical and Acoustical Factors in Sonogenetics
Aaban Syed
Mentors: Mikhail Shapiro and Hao Shen

Controlling cellular activity is at the foundation of biological and clinical research. Light-based methods have been able to demonstrate high levels of control but suffer from low tissue penetration and high invasiveness. On the other hand, ultrasound (US) is capable of deep tissue penetration while maintaining high spatial resolution. Sonogenetics is a method in which US is used to control the activity of genetically defined cell populations. Mechanosenstitive membrane proteins (MSMPs) such as ecMscL-G22S, mmPiezo1, and hsTRPA1 have been reported to sensitize cells to US stimulation, but the performance of those MSMPs in vivo has been inconsistent. We reasoned this is potentially because various mechanical effects, only specific to the traditional in vitro sonogenetic setups, were often neglected upon in vivo translation. These include acoustic streaming, substrate vibration, and the formation of standing waves. This project aimed to determine how each of these effects might impact the responses of MSMPs upon US stimulation by testing previously reported MSMPs in our newly designed in vitro setup capable of decoupling those confounding effects from each other. To date, we have cloned and functionally validated those MSMPs in our setup and established the analysis pipeline for evaluating their sonogenetic performance through calcium imaging.

Early Brain Organoids From the Brain Region of Stem Cell-derived Mouse Embryo Models
Hanna Szafranska
Mentors: Magdalena Zernicka-Goetz and Pallavi Panda

Brain organoids are 3D stem-cell-derived models of the brain development and function. However, complex structures of the brain is difficult to mimic. The cytoarchitecture and connectivity of available brain organoids is far different from natural structures lacking appropriate 3D orientation and connections.

To address this problem my project aims at developing brain organoid from a stem-cell-derived mouse embryos called ETiX, which undergo develop a beating heart and a neural tube. ETiX structures are thus more complex starting point for brain organoids and simple stem cell culture. The approach would be to dissect the heads and optimise media conditions for maturation of these structures.

I used light sheet microscopy and cryosectioning to create a benchmark of natural embryo head development between E8.5 and E10.5. I found that light sheet is appropriate for general morphology and brain region visualisation, while cryosectioning serves better for cell type assessment. In my work E10/E10.5 was the time of initial progenitor differentiation, suggesting day 10 ETiX for brain organoid culture start. Further work includes improving the ETiX to ensure appropriate development until day 10, and optimisation of culturing media for the dissected heads with aim of observing maturation of the structures.

Development of Magneto-Optical Instrument and SHG Intensity Calculations for Different SHG-Processes
Terri Yu Chen Tai
Mentors: David Hsieh and Mingyao Guo

This project investigates the modification of the rotational anisotropy-second harmonic generation (RA-SHG) setup, specifically SHG measurements on magnetic materials, in which the time-reversal symmetry is broken below the critical temperature. By comparing patterns in different RA-SHG channels under magnetic fields, the symmetry of the magnetic order can be revealed, providing an accurate all-optical way to probe materials' intrinsic magnetic properties. The first part of this report will detail the design of a magneto-optical instrument that assists in collecting data for experiments regarding how the direction of the magnetic field affects the pattern when a laser beam is shone onto the magnetic material at a low temperature. The second part will walk through the calculations of the intensity of SHG from different dipole and quadrupole sources, which represent distinct polarization geometries, obtained using Mathematica.

Inferring Crustal Thickness for Enceladus From Tidal Strain Fields Through Multi-Scale Inversion
Riley Tam
Mentors: Mark Simons and Alexander Berne

Existing studies of Enceladus' crustal structure infer mean ice shell thickness and its variations from gravity, topography, and libration data. However, these studies yield discrepant inferences of crustal thickness. Additionally, variations in ice thickness around Enceladus are large, likely as big as the average thickness of the ice. Significant 3D structural variations will result in deformational behavior of Enceladus that differs considerably from predictions assuming spherically symmetric geometry. We present a self-consistent framework to recover spatially variable crustal thickness from tidally driven strain. We demonstrate proof of concept using a 2D model and discuss steps for extrapolation to a full 3D model of ice shell. Our methodology allows for decomposition of thickness variations into effects in different wavelength regimes and accounts for nonlinear effects. In our test models, we recover crustal thickness with mean residuals as low as 0.12% of the local crustal thickness. We also examine the impact of additional structural heterogeneities such as partially faulted crust and spatially variable rheological properties. This work motivates future missions to Enceladus to retrieve true strain measurements to implement this framework on real data. The derived crustal thickness profile will provide insight to Enceladus' thermodynamics and potential habitability.

Understanding Effects of Incorporating Stochastic Loading Noise Into Droplet-Based Digital PCR Model
Ritvik Teegavarapu
Mentors: Rustem Ismagilov and Matt Cooper

Abstract withheld from publication at mentor's request.

Ultrasound-Based Imaging of Kinase Activity Using Engineered Gas Vesicles: Specificity Testing for Protein Kinase A (PKA) and Enhanced Kinetic Properties
Tigist Terefe
Mentors: Mikhail Shapiro and Jee Wong Yang

In this study, we investigate the utilization of engineered gas vesicles (GVs) as an innovative ultrasound-based imaging tool, enabling real-time monitoring of kinase activity in living tissues. Kinases, pivotal regulators of cellular processes, play a crucial role in cancer progression, emphasizing the significance of accurate activity monitoring. Traditional fluorescent biosensors for in situ kinase activity visualization encounter limitations due to light scattering in deep tissues, compromising imaging precision. Through strategic modifications to the ribbed surface structure, engineered GVs are designed to enhance the acoustic differential signal. The research focuses on two primary aspects: firstly, evaluating the newly engineered GvpC (GV-associated protein C) for its specificity towards Protein Kinase A (PKA) and other cancer-related kinases while ensuring non-reactivity with other common kinases; secondly, exploring various GV constructs to optimize kinetics by accelerating ribbed structure shedding, thereby promoting faster buckling of GVs. The successful targeting of PKA and other cancer-related kinases with engineered GVs demonstrates the potential of this noninvasive, high-resolution ultrasound approach for real-time imaging of kinase activity in living tissues, opening new avenues for studying kinase dynamics and their implications in cancer research, providing valuable insights into the dynamic behavior of kinase signaling pathways in vivo.

Improving the Representation of Precipitation Particles in CliMA's Earth System Model
Apoorva Thanvantri
Mentors: Tapio Schneider and Anna Jaruga

Accurate climate models are vital to predicting the impacts of climate change and guiding mitigation strategies. The representation of clouds in climate models is critical due to their ability to cool Earth's atmosphere. Many cloud related processes act on scales that are too small to be resolved by climate models and therefore need to be parameterized. Rudimentary parameterizations of microphysical processes, such as the terminal velocity of precipitation particles (i.e. water droplets, ice crystals), lead to model biases. Terminal velocity in particular affects the particle's residence times, as well as their collision and diffusion growth rates - this, in turn, affects the simulated cloud cover, precipitation formation rate, and below cloud humidity.

Chen et. al. 2022 derived a new terminal velocity parameterization based on particle size, shape, and air density by using multiple gamma function terms and accounting for the asphericity of snow particles. My work integrates the new parameterization with the 1 and 2 moment cloud microphysics schemes at CliMA. I then analyzed the resulting differences for individual particles, their group fall speeds, and cloud simulations using a 1-dimensional kinematic model.

Signatures of Nonviolent Nonlocality From Scattered Waves on a Schwarzschild Black Hole
Agla Þórarinsdóttir
Mentors: Yanbei Chen and Brian Seymour

In the semi-classical approximation Hawking showed that by applying quantum field theory black holes must evaporate. Since Hawking radiation is thermal, such evaporation can lead to a violation of unitarity, since the black hole goes from a pure initial state to a mixed state. This loss of unitarity is known as the Information Paradox. Many ideas that attempt to resolve this paradox predict violent deviations from general relativity at distances $\sim l_p$ away from the event horizon. Nonviolent nonlocality (NVNL) is a proposal by Steve Giddings where quantum information is more softy transferred from the black hole interior to the exterior, via nonlocal mechanisms that manifest as random metric fluctuations at distances $\sim R_s$ outside the horizon. If NVNL exists, it will have observational implications in gravitational wave detectors such as LIGO and LISA. In this work, we study how the NVNL perturbations modify how gravitational waves scatter off a Schwarzschild black hole. Specifically, we compute the perturbation to the Zerilli equation caused by NVNL. In our preliminary study, we send in a Gaussian wave packet and examine how the random metric fluctuations caused by NVNL would affect the outgoing wave. Eventually, we would like to use more realistic waveform models that better approximate gravitational waves emitted by binary black hole mergers, and more accurately study how well detectors can search for NVNL.

Refining the Gamification Aspects of ZARTH
Dhyey Thummar
Mentors: Ashish Mahabal and Ivona Kostadinova

The Zwicky Transient Facility (ZTF) has revolutionized astronomy with its comprehensive sky survey, capturing cosmic transients. To engage the public, the ZTF research group developed the ZTF Augmented Reality Transient Hunter (ZARTH) app. ZARTH overlays transient objects on top of an existing layer of other objects like stars, planets, galaxies from SkyMap, offering an interactive experience akin to popular game Pokémon Go. The primary objective is to bridge the gap between large-scale sky surveys and the general public, educating and engaging users in astronomy. The project involved modification of the existing filtering algorithm, enhancement of the type assignment algorithm, implementation of a sparsification step for a more accurate representation of the transient distribution, and the inclusion of W1 and W2 transients in the pipeline was introduced, addressing the presence of two wild types of transients or ambiguous transients with high confidence scores in more than one class. Security vulnerabilities surrounding the android app were identified and rectified. Ongoing work includes integration with the Fritz science data platform, iterative improvements based on user feedback, and further analysis of the displayed transients to ensure the relevance and quality of the app's content. Further, the public release for the ZARTH app is imminent, as the project nears completion with ongoing improvements.

Extending Fourier Neural Operators to Partial Differential Equations With Discontinuities
Vansh Tibrewal
Mentors: Anima Anandkumar and Zongyi Li

Fourier Neural Operators (FNO) are state-of-the-art machine learning models capable of learning solutions to partial differential equations in various problem settings across science and engineering. However, the theoretical underpinnings of the FNO rely on smoothness in the Fourier domain, and thus they are not designed to deal with partial differential equations with discontinuities in their solutions. In this work, we propose the Shock Detecting Neural Operator (SDNO), a machine learning framework which extends the FNO to better capture partial differential equations with discontinuities or shocks. The SDNO utilizes a naive FNO model trained on the pre-shock regime to initially learn the partial differential equation, and then utilizes a spatial conformal prediction method to detect the location of shocks in the solutions in the whole dataset by means of calculating the partial differential equation loss at each point in each sample. This information is then used to augment the dataset and another head of the SDNO is trained on this dataset, including post-shock data. We demonstrate the effectiveness of the SDNO on a time-independent dataset with the steady state solution to the Euler's equation for a channel problem with deformed boundaries as well as a time-dependent dataset with a moving shock.

Rheoscopic Fluids Systems for Nonlinear Controls and Machine Learning
Marissa Till
Mentors: John Dabiri and Steve Brunton

With the rapid advancement of fluid mechanics and machine learning, the objective of this project is to design and construct inexpensive benchmark tabletop fluids systems capable of generating large amounts of high quality quantitative data through experimental measures for nonlinear controls and machine learning. Comparing the collected benchmark high quality data with existing data and using PINN (Physics-Informed Neural Network) architecture, we will back out the most likely velocity fields that explain our data and the Navier-Stokes equations. We will explore the capacity of quantitative information that can be extracted from qualitative measurements and how we can use machine learning to infer information about flow fields. This project will provide and democratize access to high quality fluid data for advancing research in machine learning and nonlinear controls of fluid dynamics.

The Fractal Hand: A Novel Synergistic Nonanthropomorphic Gripper for Minimally Planned Grasps
Malcolm Tisdale
Mentor: Joel Burdick

Robust, yet fast, grasp planning for adversarial objects remains an unresolved challenge in robotics. Synergistic grippers tackle this problem by trading computational with mechanical complexity, thus leveraging environmental features to achieve successful grasps. The expired patent US1059545A describes a highly conformable universal vise, also known as a fractal vise, whose design principles inspire our approach. We have developed a synergistic, nonanthropomorphic, Fractal Hand that is agnostic to an objects' shape and pose. The Fractal Hand enables grasping of adversarial objects with minimal grasp planning. This paper presents the design methodology and experimentation of a Fractal Hand embodiment, as applied to robotic manipulation. We first develop a type and dimensional synthesis method that quantifies the scale variant complexity — the range and variation of detail at different scales — of objects in a data set to generate a customized Fractal Hand embodiment. We then show the hand grasping adversarial objects using a fast, simple, grasp planning pipeline. This work aims to explore and highlight the potential of the extensive, yet largely unexplored, design space of fractal hands.

Understanding the Role of the Dorsal Motor Nucleus of the Vagus Nerve in Gastric Emptying in a Mouse Model of α-Synuclein Aggregation
Matthew Torres
Mentors: Sarkis Mazmanian and Matheus de Castro Fonseca

Parkinson's disease is characterized by neuronal loss in specific areas of the substantia nigra in the brain and accumulation of the protein α-Synuclein in both the substantia nigra and in neurons of other tissues in the body, such as enteric neurons of the gastrointestinal tract. This not only impacts motor function, but also results in gastrointestinal symptoms, like constipation, which can manifest before motor symptoms do. Previous research on the Thy1-hSNCA mouse model, which presents αSyn overexpression, has shown that 5 month old mice from this model display α-Synuclein aggregation in the stomach and reduced gastric emptying compared to wild-type mice. To attempt to explain how Parkinson's disease can cause impaired gastric emptying, we evaluated the dorsal motor nucleus of the vagus nerve, a region of the brain from which efferent neurons originate to initiate autonomic regulation of the stomach, via confocal fluorescence microscopy to compare the activation of neurons between wild-type and αSyn-overexpressing mice under fasted and fed conditions.

Simulating the Creation and Maintenance of Lunar Bases
Thang Tran
Mentors: Yuk Yung and Jonathan Jiang

Through Artemis III and other proposed Lunar missions, NASA and other space agencies plan to land humans on the surface of the moon and begin the construction of Lunar bases. Since the transport of materials and humans to the moon requires a large time and monetary investment, options for testing proposed base designs are limited. We are designing a realistic simulation environment as a cost-effective alternative to the testing of base designs on the Lunar surface or in an artificial environment. Users will be able to adjust a set of initial input parameters, experiment with several methods of base construction and resource generation, and monitor their base over time.

Investigating the Negative Effects of Environmental and Cosmic Radiation on Superconducting Qubits
Kayton Truong
Mentors: Joseph A. Formaggio and Xie Chen

Quantum computers, so named because their basic units of information are quantum bits (qubits), are the future of intricate computations. Whereas classical computers excel at simple tasks, quantum computers excel at quickly finding the solutions to complex problems. Due to the qubits' ability to store data as a superposition of 0 and 1 states, a system of n qubits can span 2^n vector dimensions. This makes qubits superior to classical bits in the scene of certain complex calculations.

The strength of quantum computers seems promising, but its realizability is severely limited by the tendency of qubits to become decoherent when not sufficiently isolated from the environment. Cosmic rays such as muons are notoriously difficult to block and can irradiate a square centimeter of area as frequently as once every few minutes. Until development of methods by which qubits can be protected from cosmic rays or by which computations can be educated of possible qubit decoherence, noise-free quantum computing is seriously hindered.

Our group wishes to research the superconducting qubit, just one of many kinds of qubits. We are equipped with a five-stage fridge named Despereaux, which is capable of reaching temperatures as low as 10 millikelvin in its deepest stage. These low temperatures are sufficient for superconductivity to manifest, and within this cryogenic environment we study superconducting nanowires for their ability to detect incident cosmic rays. Using both simulations and experiments, we hope to create a veto: a method by which an incoming cosmic ray can be detected and either the superconducting qubit turned off or the incidence be recorded so users of the computer know that something may have gone awry in the calculation at that time.

The Vertical Evolution of Marine Particulate Organic Matter
Eunice Tsang
Mentors: Alex Sessions and Shaelyn Silverman

The marine carbon cycle plays a key role in regulating Earth's global temperature and climate, as the largest reservoir of bioavailable carbon is stored in the ocean. In particular, marine particulate organic matter (POM) plays a crucial role in sequestering CO_2 away from the atmosphere through its vertical transport of carbon from the surface ocean to the seafloor. While sinking, POM can be remineralized back to CO_2 via microbial or animal heterotrophic processes, or it can disaggregate into smaller particles. Mechanistic understanding of the degradative processes acting on POM, and their controls, is crucial to be able to predict how these processes will change in the future. While these processes are difficult to probe *in situ* due to their dynamic nature, characterizing how the molecular composition and stable hydrogen isotope values of POM vary with depth in different marine ecosystems and size fractions may provide insight into the degradative mechanisms acting on these particles. We hope to apply a novel analytical tool – compound-specific hydrogen isotope analysis of amino acids (i.e., δ^2H_{AA} analysis) – to elucidate how δ^2H_{AA} values in POM shift diagnostically in response to different degradative processes. Here, we will present quantitative abundances of amino acids in sinking and size-fractionated particles collected by the Close lab (U. Miami) from ecologically distinct sites during NASA EXPORTS and BIOS-SCOPE expeditions. Additionally, we will incorporate δ^2H_{AA} values obtained from these POM samples into our future analyses. These measurements can provide insight into determining which environmental factors most significantly control POM degradation in different marine ecosystems. Results of this study may ultimately contribute to δ^2H_{AA} as a useful and highly important proxy for *in situ* degradative mechanisms acting on marine POM.

Composite Subsystem Symmetries and Decoration of Sub-Dimensional Excitations
Avi Vadali
Mentor: Xie Chen

Flux binding is a mechanism well understood for global symmetries. Given two systems each with a global symmetry, gauging the composite symmetry vs. each of the individual symmetry corresponds to the condensation of the charge pair and the binding of the two fluxes. In this paper, we study what happens when combining subsystem symmetries, especially when the component charges and fluxes have different sub-dimensional mobilities. We investigate 3+1D systems with planar symmetries where, for example, the planar symmetry of a planon charge is combined with one of the planar symmetries of a fracton charge. We propose the principle of *Remote Detectability* to determine how the fluxes bind and potentially change their mobility. This understanding can then be used to design fracton models whose sub-dimensional excitations are decorated with nontrivial statistics or non-abelian structures. In particular, one construction provides the "ungauged" subsystem symmetry-protected topological state corresponding to the Cage-net models.

Calcium Isotopes as a Biomarker: Are They Effective for Diagnosing Bone Disease?
Phillip A. Vakoula
Mentors: Francois Tissot and Rosa Grigoryan

Osteoporosis is a bone disease characterized by the loss of bone mineral density. The progression of osteoporosis is typically assessed using dual-energy x-ray absorptiometry (DXA or DEXA), which, while effective at quantifying bone loss, is poorly subscribed as a screening technique due to access barriers (travel to clinic, radiation exposure, etc.). Multiple studies have shown a promising future in the use of natural calcium isotope variability as a bone turnover marker and more specifically as a diagnostic tool for osteoporosis and other similar bone diseases, with the hope that it would provide a more readily accessible screening method. However, it has been shown that healthy individuals with no net bone loss still have considerable urinary isotopic variability, which confounds the sensitivity and specificity of this diagnostic tool. To better understand this variability, we created a model of bodily calcium isotope mass balance to simulate different scenarios involving both healthy individuals and those experiencing bone loss. We find that a healthy person's calcium isotope mass balance is not constant, due to variable dietary compositions and kidney reabsorption, and this is reflected by the isotopic composition of urinary calcium. While this complicates diagnosis of changes in bone mineral balance using urinary calcium isotopes alone, strong correlations between urinary calcium isotope ratios and calcium excretion rates allow a means of normalizing urine calcium data to improve the sensitivity and specificity with respect to diagnosing bone loss. We find that such normalizations could substantially improve the performance of this diagnostic tool, but would need to be calibrated against data from healthy individuals across various populations.

Controlled 2.5D Laboratory Experiments to Investigate Preferential Flow of Meltwater in Snow Analog
Priscilla Vazquez
Mentors: Xiaojing (Ruby) Fu and Nathan Jones

Snow is an important part of the hydrological cycle as 70% of the total freshwater that is circulating on Earth continuously is stored within snow or icy environments. Tracking meltwater infiltration in snow is a challenging process because of the emergence of preferential flow pathways or "fingers" due to the gravity fingering instability. The meltwater interaction between discrete snow layers is particularly (important) as it can refreeze into ice lenses or contribute to lateral runoff within the snowpack, yet the dynamics of this process are not yet understood. In order to study the interaction between preferential meltwater flow and layered snow systems, a quasi-2D flow cell filled with two distinct layers of glass bead packs is used as a snow analog. Experiments are performed considering multiple scenarios to investigate both hydraulic barriers and capillary barriers. Additionally, we have observed ponding in between layers as it occurs because of the 2D-flow cell. These observations will provide important insights into the dynamics of snow meltwater/layer interface interactions and will provide experimental data to validate the numerical model developed by the Fu group.

Accelerating Convergence of Climate Parameter Estimation With a Momentum Approach
Sydney Vernon
Mentors: Tapio Schneider, Oliver Dunbar, and Eviatar Bach

The Climate Modeling Alliance (CliMA) looks to accurately represent small-scale, climate-invariant processes, such as cloud physics, in order to reduce model uncertainty. Such representations often introduce unknown parameters. These parameters are estimated using Ensemble Kalman Inversion (EKI), an iterative gradient-free method which minimizes the distance between model output and observed data while balancing contributions from prior knowledge. EKI updates an ensemble of particles, converging on the optimal parameter value using statistical information about the ensemble to replace the role of a gradient in traditional approaches. EKI requires climate model evaluations, which are often expensive; it is therefore of interest to accelerate EKI convergence. We modify a known acceleration method for gradient descent, Nesterov's momentum, taking advantage of the fact that EKI approximates gradient descent. Intuitively, the method mimics a ball gaining speed while rolling down a constantly-sloped hill. We study multiple variants on the algorithm, including an approximated higher-order scheme, and compare their convergence on example inverse problems. We conclude that these methods do indeed accelerate convergence in practice, reducing the necessary model evaluations. The resulting EKI methods with momentum were incorporated into CliMA's publicly available codebase for use by the wider scientific community.

Establishing the Chronology and Story of the Old Engelmann Oak
Sarah Vierling
Mentor: Alex Sessions

An old Engelmann oak tree near the center of the Caltech campus succumbed to an incurable soil fungus in 2017. Estimated to be up to 400 years old, the tree potentially records a detailed history of local climate variability in Pasadena, California and was initially considered a witness to the creation of the United States, Spanish colonization, and the predecessor Tongva community. We will present results of radiocarbon dating, stable carbon isotope measurements, and high-resolution image analysis of tree ring widths from a radial slice of the oak tree trunk. Whole wood samples were purified to yield alpha-cellulose through a series of $NaClO_2$ and NaOH extractions; alpha-cellulose is a preferred archive for physiological and environmental data because it avoids post-synthetic oxygen or carbon exchange. Radiocarbon dating was performed on 14 alpha-cellulose samples at the W. M. Keck Carbon Cycle Accelerator Mass Spectrometer (Keck-CCAMS) Facility, University of California Irvine; results are still pending. Stable carbon isotope ratios ($\delta^{13}C$ values) of over 100 whole wood samples and ten alpha-cellulose samples were measured by elemental analyzer isotope-ratio mass spectrometry (EA-IRMS) at Caltech. Results indicate relatively constant $\delta^{13}C$ values (-25.54 ± 0.67‰) over the interior ~48.8cm of the tree, with a marked decline to -29.25‰ in the outer 6.1cm of the section. In the outermost 1cm, $\delta^{13}C$ values increase to -27‰. We tentatively interpret the decline as representing an increase in water availability via Caltech irrigation, while the return to higher $\delta^{13}C$ levels shows the tree weakening with age. Our data provide insights into the oak's age and how climate has changed the local biotic environment. Further research will replicate methodologies on different tree sections, enhancing our accuracy and understanding of historic climate behavior.

Leveraging Structural and Biophysical Information for Machine Learning-Assisted Protein Engineering
Annika Viswesh
Mentors: Frances Arnold and Jason Yang

Enzymes can be engineered to perform reactions to access specific and selective transformations that are challenging for traditional chemists. Directed evolution has emerged as a powerful technique to engineer such enzymes, but it only works efficiently when mutation effects in protein variants are mostly additive. Machine learning-assisted directed evolution (MLDE) addresses this limitation by training sequence-fitness models from experimental data collected from combinatorial libraries of protein variants, enabling more efficient exploration of sequence space. Previous MLDE methods have used sequence-only encodings of proteins as inputs to ML models. To address this shortcoming, in this study, we aim to use multimodal, physically informed representations encompassing both structural and biophysical information, to enhance the prediction accuracy of ML models. In particular, we leverage features such as residue-related distances, entropies, and potential energies extracted from molecular dynamics simulations and train various ML models ranging from linear regression to neural networks. Model performance is compared against models using sequence-only data, and we focus on a dataset involving an immunoglobulin binding protein called GB1.

Testing the Capabilities of SAM
Kieran Vlahakis
Mentors: Ashish Mahabal and Asitang Mishra

In January 2019, the CDC reported that from 2015 to 2019 nearly half of all lung cancers were diagnosed at a distant stage when survival is lowest [1]. Early-stage cancer is often curable, but detecting it is challenging. Low-dose helical computed tomography (LDCT) has become a popular early detection strategy, however, with high false-positive rates it is not without limitations [2]. The purpose of this study is to see if we can alleviate some of these issues with the inclusion of artificial intelligence (AI) models in cancer diagnosis. This is hoped to be achieved through the use of computer vision tools that are capable of identifying and highlighting the features present in lung nodule scans. So far, we have been able to successfully use Meta's recently released image segmentation tool, "Segment Anything Model" (SAM), to annotate singular slices of medical CT scans. This is done using the model's automatic mask generation feature to overlay masks on top of each given slice. With a little finetuning, it is hoped that these annotations can be used at a later time to generate annotated 3D images of lung nodules.

References:
[1] "Lung Cancer Statistics." Centers for Disease Control and Prevention, Centers for Disease Control and prevention, 6 June 2022, https://www.cdc.gov/cancer/lung/statistics/index.htm.

[2] Schabath, Matthew B. "Risk Models to Select High Risk Candidates for Lung Cancer Screening." Annals of Translational Medicine. AME Publishing Company, January 30, 2018. https://atm.amegroups.com/article/view/18248.

Design, Modeling, and Manufacturing of a Flexible Flying Vehicle
Keyu Wan
Mentors: Morteza Gharib and Ioannis Mandralis

Unmanned Aerial Vehicles (UAVs) have revolutionized numerous industries with their remarkable versatility and autonomy. The integration of deformable wing structures presents a transformative approach, enabling UAV wings to dynamically morph and adapt in real-time. This innovation takes inspiration from bird wings, and a novel bio-inspired flying carpet prototype has been meticulously designed and manufactured. The flying carpet's flexible movements, facilitated by multiple tiny motors, Electronic Stability Controls (ESCs), and Inertial Measurement Units (IMUs) integrated with a flexible thin sheet, allow for rotation and shape formation akin to natural avian flight. To optimize the flying carpet's performance, simulations and analysis have been conducted to identify optimal shape trajectories and potential nonlinear relationships between various deformation angles and air thrust.

Testing demonstrates its ability to achieve preliminary flight capabilities by hovering and suspending itself in mid-air from a tabletop. Ongoing research aims to enhance the carpet's efficiency by incorporating advanced controls, such as neural networks. The integration of deformable wing technology and the bio-inspired flying carpet prototype holds promise for advancing UAV capabilities, ushering in more adaptive, efficient, and maneuverable aerial platforms.

An MCMC and Diffusion Based Algorithm for Inverse Problem Solving
Austin Wang
Mentors: Anima Anandkumar, Hongkai Zheng, Nikola Kovachki, and Bahareh Tolooshams

In recent years, diffusion models have become more commonly used as unsupervised inverse problem solvers, given sufficient modification to the sampling process. Similarly, Markov chain Monte Carlo (MCMC) methods have seen widespread usage in scientific computing and inverse problem solving. We propose a MCMC-based algorithm that explores the latent sampling space of a diffusion model, incorporating the diffusion model's deterministic sampling process and the inverse problem's forward operator as feedback when computing acceptance probabilities. This pushes the chain towards higher probability regions in the latent space that, when used as starting points for the deterministic sampler, map to the observed data. We evaluate our method on smaller-scale synthetic data experiments and an image inpainting problem on the LSUN Bedroom dataset.

Bismuth Nanoparticles/Nanorod Niobium Oxide as Catalyst on Negative Electrode in a Vanadium Electrolyser for Decoupled H_2 Fuel Production
Haiyi Wang
Mentors: Chengxiang Xiang and Monica Hwang

Recently, there has been much interest on decoupling hydrogen and oxygen production in water splitting cell, and a $V^{3+/2+}(H_2SO_4)|KOH$ cell, which allows decoupled hydrogen production on demand from charged V^{2+} catholyte, was developed. However, the cell suffers from loss of coulombic efficiency due to hydrogen evolution reaction (HER) in the negative electrode during charging. Graphite felts coated with bismuth nanoparticles via electrodeposition and niobium oxide via hydrothermal method were investigated respectively. Cyclic voltammetry and linear sweep voltammetry were performed to evaluate their electrochemical performance in vanadium (III) reduction and ability of suppressing HER. Full cell tests were done to evaluate the adhesion of electrocatalysts, stability of the electrodes and amount of hydrogen gas evolved to calculate the coulombic efficiency. Co-deposition of niobium nanorods and bismuth nanoparticles will be investigated to maximise their ability as electrocatalyst for vanadium (III) reduction.

Early Visual Processing During Hunting in Mice
Jasmine Wang
Mentors: Markus Meister and Daniel Pollak

The superior colliculus (SC) is a region in the midbrain that affects head and eye movement in response to visual and somatosensory stimuli. While mice are known for their predator evasion, they also have innate hunting behaviors. Like escape, hunting in mice is strongly driven by vision. However, it is not fully understood how mice use natural visual inputs in real time to execute hunting bouts. Here, we use a machine learning tool, DeepLabCut, to perform pose estimation of mouse behavior from videos to investigate behavioral strategies for pursuing a visually salient target, specifically a cockroach. Previous mouse hunting behavior studies relied on accidental interactions between mouse and prey. Our behavioral assay produces such interactions multiple times by moving a magnetically coupled dummy in the hunting arena along a repeatable trajectory. We identified two trajectories from a large stimulus space that elicited high engagement. Mice without whiskers had less steady trajectories when hunting but were nonetheless highly engaged. The hunting assay here engages somatosensation and vision as mice with and without whiskers performed hunting bouts. Future studies will integrate this assay's insights with neural recordings in the SC to understand how sequences of images impinging on the retina initiate hunting.

Towards an Enantioselective Total Synthesis of Pedrolide
Jessica Wang
Mentors: Sarah E. Reisman and Cedric Lozano

Complex natural product synthesis is of great interest to organic chemists from both applied and intellectual standpoints. The Reisman Group has had a long standing interest in total synthesis, with particular attention to synthesizing natural products via convergent coupling approaches. Pedrolide, a novel tigliane-type diterpenoid that is heptacyclic and features an embedded bicycle[2.2.1]heptane system, is a compelling synthetic target based on its complex structure alone. Pedrolide also has interesting biological activity and medicinal potential. Our convergent synthetic strategy towards pedrolide relies on a radical-based cyclopropane fragmentation to construct the bicycle[2.2.1]heptane, and an enantioselective homo-Diels—Alder—developed in collaboration with the Sigman Group at the University of Utah—to construct the cyclopropane. Herein we report efforts regarding two enantioselective synthetic routes towards pedrolide, focused on answering synthetic questions regarding functionalization and our key synthetic steps. These efforts will ultimately contribute towards an enantioselective total synthesis of pedrolide.

Cu-catalyzed Photoinduced Enantioconvergent Alkylation of Anilines by Unactivated Secondary Alkyl Halides
Rina Wang
Mentors: Gregory C. Fu and Arup Mondal

Amines are of great significance in various disciplines, e.g., biology, organic chemistry, pharmaceutical chemistry, and material sciences. Anilines (the primary aromatic amines and their derivatives) are starting materials for synthesizing numerous pharmaceutical and industrial products. To synthesize higher-order amines, though chemists have developed transition metal-catalyzed cross-coupling reactions to replace the traditional S_N2 pathways, those reactions with unactivated secondary alkyl halides remained challenging owing to the low reactivity of the substrates. Furthermore, the situation becomes complicated when one considers the need to control the stereochemical outcome of the reaction. In this project, we aim to develop an enantioconvergent alkylation of anilines by unactivated secondary alkyl halides. To achieve this goal, the consideration of background reactivities and the search for ligands that would produce the most suitable catalyst is required. Also, potential electrophiles, including γ-bromophosphonates, β- bromosulphones, γ-bromoesters, and γ-bromoamides will be synthesized and tested for the substrate scope. The yield and enantiopurity of the test reactions will be determined using nuclear magnetic spectroscopy and supercritical fluid gas chromatography respectively.

Patchy Clouds and Other 3D Effects in the Infrared Spectra of Young Hot Gas Giant Exoplanets
Ruizhe Wang
Mentors: Heather Knutson and Julie Inglis

General Circulation Model (GCM) can be used to simulate exoplanet atmospheres based on governing physical principles. We use an existing GCM model to simulate emission spectra for the planetary mass companion VHS 1256 b. Existing studies primarily model exoplanet atmospheres as one-dimensional objects, neglecting their three-dimensional structures. For the first time, we can study the extent to which three-dimensional structures bias the retrieved properties by fitting the spectra with known three-dimensional properties using one-dimensional models. We experiment with physically motivated and empirical parametrizations that could better capture the three-dimensional nuance, especially in the atmospheres of young, self-luminous directly imaged planets and brown dwarfs, in which inhomogeneous condensate clouds form and pose a challenging task to model. This study demonstrates the bias with existing approaches and will inspire more realistic modeling of cloudy atmospheres.

Investigating Potential Finite-Time Blowup in Models for 3D Euler Singularity Using Fixed-Point Method
Xiuyuan Wang
Mentor: Thomas Y. Hou

The fundamental question on the global regularity of the 3D Euler and Navier-Stokes equations with smooth initial data remains one of the most challenging open problems in fluid dynamics. Huang et.al. have developed a fixed-point method to prove the existence of self-similar finite time blowup in 1D generalized Constantin-Lax-Majda model, which is a simplified model for vorticity formulation of the 3D incompressible Euler equations. Our current work aims to further advance this line of research by extending this method to multi-dimensional cases and applying it to investigate possible finite-time singularities in several simplified models proposed to study 3D Euler singularities, both numerically and theoretically.

Contract-based Design of Autonomous Electric Automobiles Using Pacti
Kenadi Waymire
Mentors: Richard Murray and Inigo Incer

Issues arise within the design of specifications of complex engineering systems, largely due to human error. Utilizing contract-based design (namely assume-guarantee contracts) allows engineers to mitigate many of said issues. In this project, we use contract theory and a Python package Pacti to model an autonomous electric vehicle capable of being used to answer various questions that may emerge during such a design process. Examples of such questions include cost to efficiency comparisons, battery lifespan, and vehicle driving range.

Investigating Stripped-Envelope Supernovae Progenitor Environment With Hubble Space Telescope Ultraviolet Observations
Anastasia (Ziyi) Wei
Mentors: Mansi M. Kasliwal and Christoffer Fremling

Stripped-envelope supernovae (SE SNe) are explosions massive stars whose progenitors lost their outer hydrogen (Ib/IIb) and helium (Ic) layers through either metallicity-driven stellar winds or mass-transfer with companion stars. To investigate the precise nature of SE SNe progenitors, we utilize ultraviolet (UV) observations from the Hubble Space Telescope (HST) covering 116 SE SNe to closely examine of radial SN distribution and their proximity to star-forming regions. If a specific subtype of SN shows a tendency to be located near star-forming regions or closer to the galactic center, which are associated with higher metallicity, it would indicate a preference for a mass-loss mechanism driven by metallicity-driven winds. We measure physical offsets normalized by the host galaxies' half-light radii and characterize surface brightness at SNe locations. So far, no statistically significant distinctions have been observed among different SE SNe subtypes in our sample, hinting at predominantly binary progenitors. This preliminary finding is yet to be confirmed with surface brightness measurement using HST UV images, which provides more accurate tracing of star-forming activities.

Synthetic Cells as Viral Testbeds
Phillipe Wiederkehr
Mentors: Richard Murray and Zachary Martinez

The minimalistic and programmable nature of synthetic cells make them a promising candidate for studying the viral infection mechanisms of understudied pathogens, yet synthetic cells currently lack the capacity to host viral infection. To create a synthetic host, the T4 receptor protein Omp C was imbedded within the liposome membrane. Viral DNA and its replication were detected in the cell-free system with RNA toehold switches and hoescht 33258 dye, both triggering fluorescence when in contact with the T4 genome. We have thus far found that TXTL, a crude cell-free expression system, is capable of expressing virions directly from the T4 genome. Furthermore, a toehold switch designed to detect the T4 P37 gene has shown high fidelity for the trigger sequence. The final steps of the project include integrating the Phi29Pol DNA polymerase gene into our cell-free extract to facilitate replication of the viral genome. This extract could then be contained in a lipsome with Omp C imbedded within the membrane, and T4 plaque-forming-unit concentration could be measured before and after introduction to the lipsomes to determine if the phages underwent the viral life cycle within the synthetic cells.

A Recurrent Neural Network Model for Sequence Learning Built Upon Endotaxis
Meg Wilkinson
Mentors: Markus Meister and Zeyu Jing

Sequence learning holds a pivotal role in animal navigation. From previous experiments, after repeated trial-and-errors in the maze, the animal becomes able to execute smooth, optimal paths towards a chosen goal without hesitation. These observations lead to our conjecture that the learning process transitions from a trial-and-error approach to sequencing actions together. This project aims to construct a sequence learning model that is downstream to the pre-existing Endotaxis model. The Endotaxis model is a three-layer neural network that offers explanation for the trial-and-error phase of learning. We constructed a recurrent neural network (RNN) that learns sequences of actions by the supervising signal from Endotaxis. This network demonstrates how the agent is able to learn the correct action at each node in the maze and furthermore, is able to sequence these correct actions together to form the shortest path to the chosen goal. This project paired with the Endotaxis model offers a more complete explanation of the behaviour of an agent in a new environment: from the earliest stages of exploration, trial-and-error and goal learning to the latter stage of sequence learning and planning.

Utilizing STABILON and Exin21 Sequence Motifs to Optimize Anti-GnRH Antibody Production
Grace Wilson
Mentor: Bruce Hay

Feral horses are an exotic invasive species in North America that present a threat to native ecosystems. Adeno-associated virus (AAV) has the potential to be used to develop a low-cost gene therapy contraceptive to induce long-term infertility in this invasive species. AAV is a viral vector that has the ability to deliver and incorporate engineered DNA into target cells. It is possible to induce long-term infertility in mice by using AAV to deliver a gene that encodes for an antibody that binds to GnRH, a peptide hormone required for gamete and sex steroid production in males and females of all vertebrates. In order to develop an effective gene therapy for horses, the anti-GnRH construct of interest must produce a sufficient antibody titer for a mammal as large as a fully developed horse. STABILON and Exin21 are two novel sequence motifs that have been shown to increase protein production and protein stability. We cloned the STABILON and Exin21 sequence motifs into the open reading frame of the anti-GnRH construct, transfected HeLa cells with the constructs, and used an ELISA to evaluate the ability of the sequences to increase anti-GnRH antibody production.

An Analysis of Hydrogen Dissociation and Ionization Rate Constants for Applications in Gas Giant Atmospheric Entry Probe Heating Simulations
Jacob Wolmer
Mentors: Guillaume Blanquart and Alex Carroll

The software used to calculate the heat flux experienced a probe entering an atmosphere at hypersonic velocities, velocities greater than five times the speed of sound in the gas, needs to accurately predict the rate of the reactions that will occur in the atmosphere directly in front of said probe. At these velocities, the gas can be heated to tens of thousands of degrees kelvin causing it to undergo thermochemical and ionization reactions, the rate of which affects the heating experienced by a probe. This study focused on the rate of Hydrogen dissociation and ionization rates as the atmospheres of the gas giants mostly consist of hydrogen. This analysis involved a review of the literature of both experimental and theoretical calculations as well as a recalculation of some of the rates. In this analysis, dissociation and recombination rates were considered as they allow for room temperature observations, while dissociation rates are measured between 2500K and 20,000K. A similar analysis was conducted for the ionization rate of dissociated hydrogen. However, this could only include high temperature rates as hydrogen ionization requires collisions of over 10.2 eV (11600K), which only occur at high temperatures. We have proposed fitted rates for each of these reactions.

Design and Physical Prototyping of a Reconfigurable Surface Structure
Audrey Wong
Mentors: Sergio Pellegrino and Alexander Wen

The shape of a structure is often closely tied to its function, and can optimize performance when tailored to a specific application. As a result, structures capable of changing shape to achieve different results are highly desirable. Kirigami-inspired structures permit large deformations without permanent damage and are advantageous in design versatility. While folding cannot intrinsically change the curvature of a structure, it can approximate multiple target surfaces of varying curvatures. The objective is to design and prototype a structure which achieves a set of desired target configurations, implement the necessary torsion spring stiffness values, and restrict the hinge rotations to the required ranges. This structure is designed to achieve rigidity in multiple target configurations through the placement of unilateral constraints and springs.

Experimental Demonstrations of Robust Safety Critical Control on a Quadrotor
Jana Woo
Mentors: Aaron Ames and Ryan Cosner

Safety in robotics, especially in fields like autonomous vehicles and medical devices, relies on control theory and mathematical concepts of control invariance to ensure system safety by maintaining it within a predefined safe region. However, these theoretical ideas often assume ideal conditions such as perfect sensing, exact dynamics knowledge, infinite resources, and no delays, which are too idealistic for practical scenarios. For the robot to account for these stochastic uncertainties and disturbances, significant theoretical work has gone into developing Control Barrier Functions (CBFs) with probabilistic safety guarantees to create safety-focused controllers capable of handling stochastic uncertainties and disturbances in the real world. To the best of our knowledge, these methods have only ever been demonstrated in simulation. We seek to conduct hardware experiments using a quadrotor to demonstrate the efficacy of these robustified CBF-based methods. Using the laboratory's motion capture system and other sensing tools, we aim to quantify the effects of disturbances and unmodeled dynamics.

Verifying Web Browser Security With Cachet, a JIT Compiler DSL for Expressive Static Assertions
June Woodward
Mentors: Deian Stefan and Richard M. Murray

Implementations of dynamically-typed programming languages often perform *inline caching*, which takes advantage of observed regularities in an executing program and speeds up the "fast path" by replacing a function call with the type-specific method that it delegates to. However, since a dynamically-typed program is not required to maintain these regularities, implementations must also preface each inline cache with a *guard*, ensuring that a method is not called on the wrong type. SpiderMonkey's just-in-time (JIT) compiler has experienced multiple bugs and vulnerabilities from subtle mismatches between these assumptions and checks. The PLSysSec team at UCSD has made Cachet, a domain-specific language (DSL) where these invariants can be expressed and statically verified, and partially rewritten SpiderMonkey's CacheIR-to-MASM compilation step in Cachet. In my SURF project I continued to apply Cachet to SpiderMonkey, and improved the build system and documentation.

Hardware Design and Software Integration for the Autonomous Flying Ambulance
Brittany Wright
Mentors: Soon-Jo Chung, Joshua Cho, and Matthew Anderson

The autonomous flying ambulance (AFA) is an eight-motored vertical take-off and landing vehicle that is intended to transport a patient and paramedic to a medical facility faster than land-based emergency transportation. The AFA is on its 4^{th} iteration with a testbed (a 4x2 grid of motors with electronics attached) that runs Neural-Fly, a deep-learning model for unmanned aircrafts. This testbed functions as a research platform for fault-tolerant control where in the event of a motor failure, the aircraft re-allocates motor efficiencies to maintain steady flight. Apart from this testbed, a $1/5^{th}$ model of the AFA's fuselage has been built. On this model, we install the testbed electronics which include a flight controller that uses adaptive control and an onboard computer that runs Neural-Fly. This installation involves designing mounts to secure the electronics while accounting for constraints like space, wire management, power management, and mass distribution. This also includes integrating the flight software, Ardupilot, onto the electronics and using open-source applications such as Mission Planner to set flight parameters. After completing this hardware and software integration, we intend to have this $1/5^{th}$ model fly with the same capabilities as the testbed.

Understanding the Role of Microglia in Neurodegenerative Diseases

Sophia Wu
Mentors: Thomas Südhof, Viviana Gradinaru, and Connie Wong

Neurodegenerative diseases, characterized by protein aggregation and synaptic dysfunction, pose significant challenges to the global health sector. My study explores two interlinked facets of these disorders: protein aggregation and synaptic content. With recent studies highlighting microglia activation in neurodegenerative diseases, the first objective of my study is to investigate the potential impact of microglia removal on protein aggregation. Therefore, I eliminated microglia in culture to assess the histological and biochemical aggregation properties of proteins (Aβ, α-Synuclein, TMEM106B), which aggregate in neurodegenerative diseases. Our preliminary findings from these explorations suggest that removing microglial cells in primary culture does not significantly alter protein aggregates or protein expression. Beyond protein aggregation, synaptic alterations is another common feature in neurodegeneration. Therefore, we pioneer a new method for visualizing and tracking synapses in real-time by adding fluorescently labeled nanobodies to an ALFA tag inserted to the presynaptic marker Neurexin3β in primary culture. This novel technique offers valuable capabilities for studying synaptic dynamics in neurodegenerative diseases. Overall, our integrated approach seeks to unravel the intricate interplay among protein aggregation, microglial function, and synaptic activity, potentially revealing novel therapeutic avenues for these debilitating diseases.

Domain Walls and Conductivity: Relating Domain States and Transport Properties in a Magnetic Weyl Semimetal

Yuxiang Wu
Mentors: David Hsieh and Dan Van Beveren

Different patterns of different magnetic domains on a Magnetic Weyl Semimetal emerge when the CO_2 lasers which are shone upon them are manipulated in different ways. Magneto Optic Kerr Effect (MOKE) imaging is used to extract these domain patterns, and image analysis would be carried on each of the images, trying to quantify the domain wall orientations. After image processing and refining, domain walls are traced using the “Sobel” Technique, the straight lines which appear on the domain walls are extracted using the Hough Transform, and values such as entropy, mean domain wall direction, and number of domain walls across the image are calculated using these straight lines. These different ways of quantifying domain edges were then being compared to the resistance of each lased material to examine whether the domain walls have an effect on the transport properties of a material.

Uncovering the Mechanisms of *Drosophila* Odor Formation: A Study of Early Life Olfactory Sense Modification Process With a Chronic Natural Odor

Zihang Xiao
Mentor: Elizabeth J. Hong

Just like humans, olfactory experience in early life can alter how *Drosophila melanogaster* behave towards odors in later life. Understanding how early life experience affects olfactory function provides insights into understanding the development of the nervous system and the role of the sensory environment in shaping this process. Prior work showed that chronic exposure to natural odors increases the attraction of flies to familiar odors when measured in a free-flight trap assay. However, both the neural and behavioral mechanisms that mediate this increase in attraction are not known. Here, we optimized an odor-dependent upwind running assay, in which the intensity and timing of the odor stimulus relative to the fly can be precisely controlled, to investigate if and how odor experience affects odor intensity thresholds for upwind attraction in flies. Additionally, we used transgenic flies that enable genetic silencing of defined neural populations to investigate the contribution of dopaminergic function to odor-experience dependent plasticity.

Development of Secondary Channel Networks Correction on Wetlands Hydrodynamics System Modeling

Olivia Xu
Mentors: Michael Lamb and DongChen Wang

The coastal wetland ecosystem is highly sensitive to local hydraulic conditions and is impacted by the presence of numerous secondary channels that alter water flows. However, these narrow channels sometimes are not well resolved in the bathymetry data due to resolution limitations and/or survey errors, giving rise to issues in channel network connectivity. The accurate representation of the channel network is crucial for the wetland hydrodynamic model to predict the future behavior of the system. We develop a geospatial data analysis tool in Python to extract channel widths from remotely sensed images, employing convolution and segmentation techniques for edge detection as well as feature and cross-sectional data extraction to automatically perform secondary channel network corrections. We also leverage MATLAB software OceanMesh2D for the development and utilization of a mesh generation tool that adopts an automated approach for mesh refinement based on the corrected bathymetric data. The framework's application on land build processes at the Atchafalaya River Delta region and AVIRIS datasets enables a more comprehensive analysis of secondary channel networks' influence on wetland ecology, morphology, and materials transport efficiency.

Asymptotic Formulas of Scattering Diagrams in the Tropical Vertex Group
Brian Yang
Mentors: Tony Yue Yu and Thorgal Hinault

Scattering diagram factorizations of commutators in the Tropical Vertex Group are related to Gromov-Witten invariants of genus 0 relative stable maps and the Euler characteristics of moduli spaces of quiver representations. However, the numerical asymptotics of the coefficients of power series associated with such factorizations are not yet well-understood. In this project, we improve existing and develop new algorithms to compute the power series of these factorizations (truncated) to large ($N > 100$) degrees. Two algorithms are mainly considered: a "brute force" algorithm in which the truncated power series are computed iteratively, and an recursive algorithm, inducting on truncation degree, modeled after the standard proof of the existence of scattering diagram factorizations. We present a complexity analysis of both of these algorithms. We implement both algorithms using a multithreaded program written using C and the FLINT computational algebra system. Using our findings, we are able to state several conjectures on the asymptotics of the scattering diagram factorizations.

Estimation of Computational Models of the Impact of Attention on Simple Choice Using Julia
Lynn Yang
Mentors: Antonio Rangel and A. Zeynep Enkavi

Neuroeconomics studies the neurocomputational bases of decision-making. Experiments within this field often include simplified choice scenarios, such as picking one of two snack options where experimenters record choice and response time data. Literature has shown that behavior in such tasks are well-described by a noisy evidence accumulation process that compares values associated with each item, and attention can especially bias this process. Inspired by evidence accumulation models in cognitive psychology, the attentional drift diffusion model (aDDM) formalizes how overt attention, measured by fixation patterns, biases choice and response times. Current methods for estimating parameters of the aDDM are computationally inefficient and can take hours to days. To address this issue, we developed a new toolbox in Julia. By taking advantage of the compiled language and multithreading packages we significantly sped up parameter estimation. Wider adoption of our toolbox can enable researchers to test more complex models of decision-making by significantly reducing the time between building and fitting models.

Expressing Quantum Ground States Efficiently With Classical Neural Networks
Tai-Hsuan Yang
Mentors: John Preskill and Mehdi Soleimanifar

Finding quantum ground state is crucial problem in quantum mechanics. However, the complexity of finding ground state is QMA-complete, which means that the problem is difficult even for a quantum computer. In this project, we prove that certain gapped ground states with the physical property called approximate conditional independence can be described with only polynomial many parameters with the construction of artificial neural network. We also prove that for 1D shallow quantum circuit equips with this property and show that various spin models would satisfy this property by numerical experiments.

Towards a Two-Dimensional Array of Ultracold NaCs Molecules
Zitian Ye
Mentors: Kang-Kuen Ni, Nicholas Hutzler, Conner Williams, and Christian H. Nunez

The approach in the Ni Lab to obtain ultracold molecules is through the magneto-association of individual atoms trapped in optical tweezers. The Ni lab has previously demonstrated the assembly of a single NaCs molecule in its rovibronic ground state, so the next-generation apparatus aims to scale up to a two-dimensional array with high loading rate and individual control over constituent molecules, which will serve as a powerful platform for quantum computing and quantum simulation. In this project, we work on multiple aspects of the construction of the next-generation apparatus. We design and build the shim coils for the magneto-optical trap (MOT) and the coil mount in CAD to assist with the trapping of Na and Cs atoms. We also benchmark a spatial light modulator (SLM) to produce a tweezer array, and we explore a new technique to paint time-averaged Gaussian traps by dithering the trap array with a 2D acoustic-optic deflector (AOD).

Role of Serotonin in Sleep Behaviors of Zebrafish and Generation of UAS/GAL4 Transgenic Zebrafish Lines
Alanna Yelland
Mentors: David Prober and Grigorios Oikonomou

Although sleep is a common phenomenon among animals, the genetic mechanisms of sleep are still relatively unknown. Serotonin (5-HT) has been shown to play a part in sleep, but its true role is a bit unclear. Thus, part of this project seeks to gain understanding of the role of 5-HT in sleep. *tph2*-incross zebrafish were video-tracked with programmed day and night conditions and analyzed for their sleep behaviors, then were genotyped using polymerase chain reaction and electrophoresis to understand the relationship between the *tph2* gene, which codes for a protein that is responsible for catalyzing 5-HT synthesis, and sleep behaviors. Additionally, different combinations of *tph2; nf1a; nf1b* fish were crossed to test how the *nf1* gene interacts with *tph2*. A secondary part of the project involves using the UAS/GAL4 system to generate transgenic lines that allow us to manipulate neuronal activity. To do this, transgenic fish with either the *5xUAS:rsChRmine; huc:gal4; casper+/-* or *5xUAS:zfTRFV; huc:gal4+/-; casper+/-* genotype were outcrossed with TLAB fish to produce progeny that were later screened for the desired UAS transgenes through fluorescent microscopy. By identifying founders with the UAS transgenes, these fish can later be studied and further understood.

Trail Following and Olfaction in the Myrmecophile *Sceptobius lativentris*

Jessica Yin
Mentors: Joseph Parker and Hayley Smihula

The myrmecophilous rove beetle *Sceptobius lativentris* facilitates its social parasitism of host ant *Liometopum occidentale* through behaviors like trail-following. We propose that *Sceptobius'* trail-following behavior is mediated by detecting volatile iridoids in *Liometopum's* foraging trails through olfaction. To confirm this mechanism, the odorant receptor co-receptor (Orco) was knocked down in adult *Sceptobius* via RNAi, rendering all olfactory receptors nonfunctional, and the beetles' ability to trail-follow was then evaluated. An additional rove beetle, the free-living species *Dalotia coriaria,* was also tested in order to establish the effectiveness of Orco RNAi knockdowns in adult rove beetles. 1-octen-3-ol, a mushroom alcohol, induces avoidant behavior in wild-type *Dalotia*, but CRISPR-mutant Orco-knockout beetles are unable to discriminate the odor and do not show such avoidance. Comparing the 1-octen-3-ol responses of Orco-knockdown beetles to those of wild-type and Orco-knockout beetles will help determine the effectiveness of RNAi in producing a behavioral phenotype. Confirmation of the RNAi method in *Dalotia* and any resulting changes in *Sceptobius'* behavior when Orco is knocked down will lay the groundwork for establishing which specific odorant receptors are recruited during trail following, further increasing our understanding of how *Sceptibius'* symbiotic relationship with *Liometopum* is maintained and facilitated.

On R-repetitions of Colorings in Euclidean Spaces

Jonah Yoshida
Mentor: David Conlon

For the alphabet Σ, a r-repetition is a sequence of words X repeated r times. Denoted $\mathrm{E}^d \nrightarrow X^r$, the question of whether a coloring of a Euclidean space E^d, often either $\mathbb{Z}^d$ or $\mathbb{R}^d$, avoids r-repetitions is a well-explored one in Euclidean Ramsey theory. We investigate a few problems in relation to this central question. First, if $E^d \nrightarrow X^r$ and the minimal number of colors necessary to avoid r-repetitions is $\pi_r(E^d)$, then $\exists\, r = r(d)\; s.t.\; \pi_r(\mathbb{Z}^2) = 2$? Considering such a question, we investigate the repeated-word-avoidance properties of the Thue-Morse sequence and random colorings on the finite field F_q^d. We also consider the same problem for the finiteness of π in the $\mathbb{R}^d$ regime alongside a spherical coloring. While introducing the spherical coloring for this problem, we present some trivial generalizations of a spherical coloring that permits $\mathbb{R}^d \nrightarrow C_{2t+1}$, where C is a set of three collinear points of twin gaps $2t + 1,\ t \in \mathbb{N}$.

Contrastive Language-Image Pre-training Meets Masked Video Distillation: A New Paradigm for Zero-shot Video Representation Learning

Andrew Zabelo
Mentors: Pietro Perona, Markus Marks, and Neehar Kondapaneni

Knowledge Distillation and Representation Learning via Masked Autoencoders are powerful tools for Computer Vision, enabling state of the art performance on video tasks through pre-training frameworks such as Masked Video Distillation (MVD). Likewise, Contrastive Language-Image Pre-training (CLIP) sets the standard for zero-shot performance on image classification tasks by contrastively learning a joint embedding space via image and text encoders. However, the synergy between these two paradigms has not been fully captured, as previous efforts to finetune CLIP features have struggled to preserve the joint space and current extensions of CLIP to video introduce inductive biases that make it difficult for the model to generalize to new data, hurting performance. We propose to distill features from a frozen CLIP teacher model to a student encoder using the MVD architecture. We show that the student learns to extract rich spatio-temporal features while preserving the zero-shot capabilities provided by the CLIP joint embedding space. [Results, Applications, and Ablation Study TBD]. We release our code and pre-trained model weights at [github link TBD].

Behavior Flexibility and Neural Representations of Humans, Mice, and RL Models in Navigation

Alina Zhang
Mentors: Pietro Perona and Rogério Guimarães

In the realm of behavioral adaptations, understanding how different species exhibit behavior flexibility is a captivating avenue of exploration. Our research delves into this fascinating domain, focusing on humans, mice, and reinforcement learning (RL) models within navigation tasks. Behavior flexibility, defined as the capacity to adapt to varying circumstances, plays a pivotal role in survival and decision-making across species. Through a comparative

approach, we analyze navigation behaviors of humans and mice using the versatile Manhattan Maze framework. By studying their strategies, we aim to uncover shared patterns and distinctive adaptations, potentially revealing conserved neural mechanisms underlying these behaviors. Moreover, we investigate whether RL models can replicate the observed behaviors in both humans and mice. Our exploration delves into different RL architectures, both model-based and model-free, aiming to discern the extent to which these computational models capture the intricate cognitive processes involved in navigation tasks. Furthermore, we delve into the neural basis of behavior flexibility, analyzing neuronal representations in both mice and RL agents navigating the Manhattan Maze. This analysis offers insights into the convergence between biological organisms and computational models. Overall, we aim to unravel fundamental principles governing adaptive behaviors, fostering broader implications for decision-making and survival strategies.

Slow Intercellular Calcium Wave Dynamics in Shoot Apical Meristems
Claire Zhang
Mentors: Elliot Meyerowitz and Ting Li

Roughly 90% of the world's plants are flowering plants, and moreover, at least 80% of human nutrition is derived from flowering plants—gaining a comprehensive understanding of the mechanisms behind plant development has paramount implications for climate change and human welfare. At the tip of each shoot in every flowering plant are shoot apical meristems (SAMs), a collection of self-maintaining stem cells for shoot, leaf, and flower development. This project observes and analyzes the different calcium dynamic responses induced in *Arabidopsis thaliana* SAMs by treating the dissected SAM with various neurotransmitters, particularly L-glutamate, glycine, and D-serine. Testing of these reagents on glutamate receptor-like (Glr) mutant lines is performed to determine channel specificity. Results show that both L-glutamate and glycine target Glr channels in the SAM. Characterization of the calcium dynamic responses are made visually with the use of a transgenic line with calcium ion fluor indicators (GCaMP3) and quantified using ImageJ, a post-processing image software, to produce fold-change plots. Additionally, the effect of lidocaine on these reagents will be tested to determine if lidocaine has any blocking effects on the neurotransmitters like it does in a normal neural environment. Synergistic effects between various combinations of neurotransmitter reagents will also be explored.

Dusty Galaxies as Seen by SPHEREx
Edward Zhang
Mentor: Andreas Faisst

Dust plays a critical role in the study of galaxies as it is strongly related to the formation of stars and the evolution of galaxies. Dust grains have been observed to scatter and absorb blue light and emit it at infrared wavelengths. The new SPHEREx infrared space telescope will provide all-sky, low-resolution, spectroscopic observations of stars and galaxies at wavelengths of 0.75 - 5 μm, allowing for the study of the dust properties of many galaxies. However its sensitivity, wavelength coverage, and the strategy of the survey will only allow SPHEREx to get useful data for a subsample of galaxies. Additionally, it is unknown how well the SPHEREx observations can constrain different models of galaxy spectra, hence their respective dust properties. Thus this project prepares for the SPHEREx observations by first creating spectral templates using data from the 2006 AKARI infrared satellite combined with theoretical models of dust emission. These templates are then run through the SPHEREx Sky Simulator to obtain realistic observed spectra. By varying the dust emission model and the brightness of the sources, we can study the parameter space in which useful measurements with SPHEREx can be obtained.

Development of a Chemically Recyclable, 3D Printable Silicone Material
Hongyi Zhang
Mentors: Julia R. Greer, Seneca Velling, Sammy Shaker, Seola Lee, and Akash Dhawan

Silicone is a versatile polymer material with many desirable characteristics, such as corrosion resistance, thermal stability, low toxicity, and electrical insulation properties, and has widespread application in commercial, medical, and research scenarios. However, its 3D crosslinked structure has impeded its recycling and manufacturing through extrusion-based 3D printing techniques, and its high gas permeability and crosslink chemistry prevented its application in UV-curing-based 3D printing techniques. Previously, it was reported that the photoinitiated thiol-ene click chemistry, where a thiol and an alkene connect to form a thioester, allowed the UV-crosslinking of mercaptan-functionalized polysiloxane and vinyl- terminated polysiloxane and enabled the digital light processing 3D printing of silicone elastomers. Separately, introduction of disulfide moieties in polymer chains was shown to facilitate the chemical degradation of the cured material through base-catalyzed thiol-disulfide exchange reaction. This work aims to develop a chemically recyclable, 3D-printable silicone materials by integrating the thiol- disulfide exchange reaction with the photoinitiated thiol-ene silicone system. We show that disulfide moieties can be introduced into mercaptan-functionalized polysiloxanes through a clean and facile iodide-catalyzed oxidative coupling reaction, and the resulting partially oxidized mercaptan-functionalized polysiloxanes, when mixed with vinyl-functionalized polysiloxane and photoinitiators, can be UV-cured to form disulfide-containing silicone networks. Ongoing work focuses on performing chemical degradation on the cured disulfide-containing silicone and characterizing the thermomechanical properties of silicones prepared from the recrosslinking of recycled polysiloxane oligomer.

Provide a GUI and Web Platform for Calculations of SNR and Exposure Time With PSIsim and Specsim for TMT-MODHIS and Keck-HISPEC
Huihao Zhang
Mentors: Dimitri Mawet and Ashley Baker

PSIsim and Specsim are two Python packages utilized for simulating the signal-to-noise ratio (SNR) for the spectroscopic characterization of exoplanets with TMT-MODHIS and Keck-HISPEC. PSIsim and Specsim employ Phoenix and Sonora models to simulate stars and planets and the Mauna Kea Sky Emission model to account for the noise from the sky background. Both simulators implement instrument throughput budgets and AO-driven coupling efficiencies, as well as thermal emission budgets from TMT-MODHIS and Keck-HISPEC. The simulators compute the total number of photons arriving at the detector per second and the associated noise level.
We have refined and updated the functionalities of both PSIsim and Specsim. Based on these advancements, we are developing a comprehensive graphical user interface (GUI) that will serve the broader community, accompanied by a dedicated web portal. These platforms aim to calculate the SNR and determine exposure times specific to TMT-MODHIS and Keck-HISPEC across varied observing scenarios and science cases.

Biochemical Reconstitution of Nuclear Pore Complex Cytoplasmic Filaments Using Thermophilic Eukaryotic Model Organisms
Wentao Zhang
Mentors: André Hoelz and George Mobbs

Within eukaryotic cells, massive ~110-MDa transport complexes called nuclear pore complexes (NPCs) facilitate the selective transport of macromolecules across the nuclear envelope. Protein constituents of the NPC, called nucleoporins (nups), are essential to biology's central dogma, facilitating directional transport of RNA from nucleus to cytoplasm. We utilize *Alvinella pompejana*, a thermophilic extremophile worm living near deep-sea vents, as a model organism to investigate the structure and biochemical interfaces of the cytoplasmic filament nup205. Using cryo-EM, X-ray crystallography, and affinity assays, we will elucidate the structure and interaction interfaces of nup205 to near-atomic resolution. Our findings will facilitate a more complete understanding of NPC structure and assembly mechanics and will lead to development of targeted therapies targeting erroneous NPC homologies.

Sample Complexity of Learning Physical Processes
Haimeng Zhao
Mentors: John Preskill and Matthias C. Caro

Learning what happens during a physical experiment is a fundamental task in many fields of science. The intrinsic complexity of this task can be characterized by the sample complexity: the number of samples scientists need to collect to accurately and confidently infer the underlying quantum process. In this work, we analyze the sample complexity of learning physically implementable processes that are local and have bounded circuit complexity. We find that the sample complexity of learning these processes to average case accuracy scales linearly with the circuit complexity up to logarithmic factors. In contrast, we prove that learning to worst case accuracy requires exponentially more samples. We also investigate the sample complexity of learning from classically described data and the curse of dimensionality in learning to approximate certain multi-variable functions. Our results provide statistical foundations of the fundamental question: how can we possibly learn about nature efficiently, and offer theoretical guidance to the practical implementation of quantum machine learning.

Accessing the Temperature-Dependent Vibrational Dynamics of Pb Using Inelastic Neutron Scanning
Zhiyi Zheng
Mentors: Brent Fultz and Camille Marie Bernal-Choban

Inelastic neutron scattering serves as a powerful experimental technique to investigate the temperature-dependent phonon anharmonicity of materials. Such analysis offers insights into anharmonicity's effect on the sample's thermal properties, such as vibrational entropy and thermal expansion. This study applies this method to face-centered cubic (fcc) solid lead (Pb), investigating its behavior within the temperature range of 298 K to 573 K. By employing MCViNE simulations, the vibrational densities of states (DOS) were determined, allowing for a comprehensive examination of the vibrational dynamics response. Preliminary results indicate that the crystal's vibrational entropy constitutes the primary component of its total entropy, with a contribution exceeding 85 percent. The material's overall thermal behavior will also be discussed.

Autonomous Flying Ambulance: Hardware Integration and Testing
Zhonghe Catherine Zheng
Mentors: Soon-Jo Chung, Matthew Anderson, and Joshua Cho

The overarching goal of the project is to build a scaled-down version of an Autonomous Flying Ambulance (AFA), an emergency vehicle capable of carrying patients and medics to hospitals. In the current 4th iteration of the AFA, researchers are developing a new fault-control algorithm that stabilizes the aircraft when one or multiple motors fail. Testing the algorithm is dangerous and costly if done on the actual AFA model; hence, the algorithm is currently being developed on a skeletal prototype. While the fuselage of the model was already manufactured, the model still lacked the electronics required to fly. This project focuses on integrating those electronics into the model, which involves designing and fabricating the electronic casing, wiring the components, and calibrating the hardware for the new system.

Both the prototype and the AFA model use a Pixhawk flight controller with ArduPilot and an onboard computer to run the algorithm. While the prototype is an eVTOL octocopter, the model has both eVTOL and fixed-wing modes, meaning it can take off vertically while also using its wings to produce lift when flying. This more sophisticated flight model allows algorithms to be demonstrated on a higher fidelity aircraft, producing more accurate data and results.

Experimental Feasibility of Photon Blockade With Weakly Nonlinear Kinetic Inductance Resonator
Daniil Zhitov
Mentors: Mohammad Mirhosseini and Chaitali Joshi

A theoretically proposed protocol for producing photon blockade in weakly nonlinear systems is studied. Feasibility of its experimental implementation using a kinetic inductance resonator with fourth-order nonlinearity is analyzed in relation to limitations of nonlinearity, one- and two-photon drive strengths. Parameter optimization is discussed. The analysis was conducted using numerical simulations and theoretical tools. The protocol is found to be possible, but challenging, to implement. There is potential for producing highly non-classical non-Gaussian and Wigner negative states, that could be a valuable resource for quantum technology. Further work includes attempting to implement the protocol 'on-chip' and verifying its performance with quantum state tomography.

Accessing Lewis Acid-activated N_2 Complexes for Potential Fe-catalyzed Photo-driven N_2 Reduction
Luke Zhou
Mentors: Jonas C. Peters and Emily Boyd

Activation of the N_2 bond is a crucial step in the formation of fixed-N products, including NH_3 and N_2H_4. Recent work from Boyd and Peters has shown that the binding of a sterically bulky $\mathbf{[Sm^{III}]^+}$ reagent stabilizes an anionic $\mathbf{Fe}N_2^-$ complex to generate the neutral species $\mathbf{Fe}N_2$––$\mathbf{Sm^{III}}$, enabling reduction of $\mathbf{Fe}N_2$ by weaker reductants. While photo-driven N_2 reduction has been achieved with Mo-based catalysts, extension to Fe has been limited by the low reduction potential of $\mathbf{Fe}N_2$. Herein, we investigate whether incorporation of $\mathbf{[Sm^{III}]^+}$ can facilitate photoreduction of $\mathbf{Fe}N_2$ with an $\mathbf{Ir^{II}}$ species that is incapable of reducing $\mathbf{Fe}N_2$ to the free anion $\mathbf{Fe}N_2^-$. We further evaluate the potential for this reduction event to occur in a broader photocatalytic N_2 reduction system, where the reduced $\mathbf{Ir^{II}}$ photoreductant is generated *in situ* via the reduction of an $\mathbf{[Ir^{III}]^+}$ excited state by the Hantzsch ester, a sacrificial reductant. We present the results of the attempted generation of the $\mathbf{Fe}N_2^-$ anion via EPR spectroscopy as well as the attempted photo-driven N_2 reduction experiments, demonstrating in the process the competition between N_2 reduction and the hydrogen evolution reaction (HER).

Sensory Deception: Unveiling Audio-Visual Illusions Within Blind Spots
Chelsea Zou
Mentors: Shinsuke Shimojo and Ailene Chan

Human perception is inherently multisensory. The brain seamlessly integrates incoming sensory inputs to create a unified understanding of the environment. While cross-modal information is usually complimentary, researchers have reported multiple scenarios where the senses appear to “deceive” one another. These multisensory illusions are especially robust when one of the senses is unreliable. In this study, we are interested in analyzing the effects of audio-visual illusions in blind spots. Blind spots, characterized by the absence of photoreceptors due to the optic nerve exiting the retina, are intriguing areas in the visual field. Our investigation focuses on the possibility that auditory stimuli can evoke visual experiences within these blind spots. To probe this phenomenon, we employed two multisensory illusions developed by the lab: the Double Flash and Rabbit Illusions. We mapped each participant’s blind spots and presented the experiments using custom code scripts written in PsychoPy. Surprisingly, our findings suggest that blind spots may not be as "blind" as conventionally thought. Other senses appear to play a role in influencing the perception of these areas. This discovery challenges traditional notions of sensory isolation and highlights the complex interplay between our sensory modalities, even within areas of apparent sensory deficiency.

The Search for Lunar Trojans Using Non-Symplectic Integration Techniques
Hanna Adamski
Mentor: Mike Brown

The two-body problem within planetary dynamics describes the well-defined interaction between two isolated point masses affected by mutual gravitational attraction. However, once a third mass is added to the system (such as that of the Moon or of a co-orbital Lunar Trojan), the equations of motion of the N-body problem become analytically unsolvable. Fortunately, approximations using numerical integration schemes introduce an opportunity to map the trajectory of the masses at each defined time interval. Whether a symplectic, non-symplectic, or hybrid integration architecture is used depends on the dynamical structure of the system. We are particularly interested in the equilibrium solutions of the Earth-Moon-Sun System at Lagrangian points L4 and L5, as these regions, which lie co-orbital with the Moon, could be potential hosts to Lunar Trojans. In this work, we investigate the capture probabilities of Near-Earth Objects (NEOs) using a source population of 802,376 NEOs from realistic orbit and source-specific absolute magnitude distributions derived by Granvik et al 2018. Using IAS15, a non-symplectic high-order algorithm within the N-body integration package REBOUND, we perform various collections of integrations on the orbits of the synthetic population and extract both the probabilities of transformation from NEO to Trojan, as well as gain insight on the mean lifetime of NEOs as a function of their escape route. Previous studies show that objects that move in tadpole orbits about the triangular equilibrium points tend to remain in these stable orbital configurations for millions of years. Therefore, since NEOs act as invaluable dynamical and compositional tracers of both various places and time periods within the planetary system, we hope to better comprehend the origins of the system's dynamical history by quantifying the rate of NEO capture within Earth's sphere of influence.

Characterization of Thin-Film $BaTiO_3$ Using Surface Acoustic Waves
Nuha Akhtar
Mentors: Mohammad Mirhosseini and Hao Tian

With the ability to be confined close to the surface, coherently excited and detected with microwave electronics, stored in compact high-quality resonators, and have their properties engineered by choice of material, Surface Acoustic Waves (SAWs) have become the ideal candidate for studying quantum behavior of macroscopic objects. Using piezoelectric materials, which have a unique property of electromechanical coupling, acoustic devices can be used in the quantum regime. Since functionality of a piezoelectric crystal is based on its physical parameters, this property-dependent performance acts as motivation in the search to find materials that will accomplish the task of sensing and actuating SAWs. Having many excellent physical properties, Barium Titanate (BTO) has become the piezoelectric crystal of interest in this lab. With a limited amount of thin-film nanofabrication and analysis of material properties reported, we aim to establish a parameter space that maximizes the effect of BTO's piezoelectric response through finite element analysis and material characterization. In the future, this information will allow for the fabrication of a successful SAW device that can be used to characterize BTO for a variety of quantum applications at the cryogenic level.

Propagation and Polarization Effects of FRB20201124A
Nadja Aldarondo Quiñones
Mentors: Sterl Phinney and Dongzi Li

Fast Radio Bursts (FRBs) are millisecond duration bursts of radio emission that originate from far outside our Milky Way galaxy. While the origin of FRB's is still uncertain, the most widely considered models involve magnetars. Repeating FRBs tend to have unique phenomena not seen in non-repeating FRBs, such as high amounts of circular polarization, oscillating fractional polarization, and oscillating polarization angle. This can give us an indication into what the surrounding magneto-ionic environment around the FRB looks like. This project aims to identify bursts with significant circular polarization and analyze the distinct phenomena that occur due to this. To help identify the origins of FRB we look at their properties such as their burst polarization, spectrum, dispersion measure, and rotation measure. For this, we graphed 1,062 bursts from FRB20201124A highlighting their Linear and Circular Polarization, their Polarization Angle, and their Fractional Polarization. Bursts with similar occurring events were separated into different subgroups to discuss the required magneto-environment for those events to occur. Finally, we looked into correlations between the various phenomena to better understand what is the nature of the FRB's immediate environment.

LINC Project, Autonomous Path Following: Real-Time Centerline Mapping Using Image Processing for GVR-Bot
Grace Archibeck
Mentors: Soon-Jo Chung and Matthew Anderson

The current state of practice for robotic systems is to assume a constant model, which poses an issue when that model is altered. The motivation behind the LINC project is to design a software stack that is able to recognize when the underlying plant model has changed and accurately reconstitute control. The LINC project is being conducted through the use of a GVR-Bot. In one research exercise, the GVR-Bot is directed through a closed loop path, known as the Chicane track. One of the challenges of this project is to have the GVR-Bot be able to quickly and accurately navigate the Chicane track, even with degraded drive tracks. This can be achieved by segmenting the track into images that the GVR-Bot takes while moving along the path. By finding the centerline of these segmentation images, the software can apply corrective actions to the driver's inputs, helping overcome the system degradation.

Factors Regulating DRP1 Independent Mitophagy
Valeria Arroyo
Mentors: David Chan and Yogaditya Chakrabarty

Mitochondria can change their morphology through the processes of fission and fusion. These processes are known as mitochondrial dynamics. The regulation of mitochondrial fission depends on the recruitment of dynamin-related protein 1 (DRP1). Another essential process of mitochondrial dynamics is mitophagy which is the selective degradation of damaged mitochondria through lysosomes. DRP1 is also involved in mitochondrial fission during mitophagy. This protein divides mitochondria which allow autophagosomes to engulf and degrade them. However, recent experimental results suggest that mitophagy can still occur in the absence of DRP1. Yet, the other factors involved in mitochondrial fission during DRP1-independent mitophagy are not known. Therefore, the focus of our study is to identify DRP1-independent mitochondrial fission factors involved in mitophagy. In order to approach our question, we are conducting a dual sgRNA-based whole-genome CRISPRi screen where the library consists of constructs containing two sgRNA cloning slots. One slot contains a sgRNA targeting DRP1 and the other slot is used to input an sgRNA library targeting the whole human genome. It is important to understand mitochondrial dynamics since disruption in these processes has been linked with human diseases.

Developing FISH Microscopy Techniques in *Methanosarcina* to Visualize Methanotrophic Archaeal Diversity
Stella Baldwin
Mentors: Victoria Orphan and Daniel Utter

The factors controlling microbial diversification remain relatively unknown, particularly in harsh deep sea environments. Anaerobic methanotrophic archaea (ANME) pair symbiotically with sulfate-reducing bacteria (SRB) to fuel the anaerobic oxidation of methane (AOM) and other biologically productive processes. ANME-2b dominate methane seep sediments off Southern Californian coasts. The Orphan Lab identified three ANME-2b groups (gI, gII, and gIII) and hypothesized that only gII and gIII contain nifH, a gene that encodes an essential nitrogen fixation protein. However, experimental validation of this hypothesis has proven difficult. Here, we developed fluorescence in-situ hybridization (FISH) techniques to help resolve ANME-2b lineages. Genome-directed FISH offers extreme specificity but low signal, so we chose signal amplification methods like hybridization chain reaction FISH (HCR-FISH). We improved HCR-FISH probe contrast by testing complex samples under different experimental conditions (i.e., temperature). HCR-FISH probe validation requires known positive/negative targets, so we also conducted microscopy in the model archaeon *Methanosarcina*. Once refined, genomic HCR-FISH could illuminate the intraspecific ecology and evolution of many microbial systems.

Improving the Symmetric Group Construction in the Group-Theoretic Approach to Fast Matrix Multiplication
Thomas Baxley
Mentor: Christopher Umans

The Cohn and Umans paper "A Group-theoretic Approach to Fast Matrix Multiplication" describes an algebraic and representation-theoretic approach to the matrix multiplication problem. The method reduces the matrix multiplication problem to a problem involving a group G and 3 subsets X,Y,Z which satisfy the *triple product property*. The paper also introduces a construction in the symmetric group, the improvement of which is the focus of this investigation. This project explores the required properties of $g \in G$ that are not in subgroups X, Y, or Z, such that adding g to one of the subgroups results in a collection of sets that still satisfy the triple product property. We go on to investigate the properties of a set S of elements not in X,Y,Z satisfying those same requirements. We identify a family of elements in the symmetric group that satisfies this property, thus showing that the construction can be improved.

Using Gene Drive Systems to Modify and Suppress *Drosophila* Populations
Jacob Bonadio
Mentor: Bruce Hay

Gene drive is a process in which genes, multi-gene cassettes, or large chromosomal regions spread through populations even if their presence (including any cargo genes they carry) results in a fitness cost to those who carry them. Gene drive systems offer an opportunity to alter wild populations to benefit humanity, the economy, and the environment. Invasive species such as the drosophila suzukii wreak havoc on our environment. In 2008 it was reported that there was a total yield loss of $393 million in value of production of all crops, in California alone due to drosophila suzukii population. Eliminating such pests can benefit our agriculture and economy. The gene drive system that we are working on is called X-Shredding and is meant to bring about population suppression. The

X-Shredder consists of the Cas-9 nuclease, which is guided by a small RNA (the gRNA) to its target sites, where upon it creates a double strand DNA break. In our case Cas-9 and a gRNA will be located on the Y chromosome. Cas9 is expressed under the control of a spermatogenesis-specific promoter, from the beta tubulin gene. The gRNAs target Cas9 to cleave the ribosomal DNA repeats, which are located on the X chromosome. The hope is that this will cause the loss of X-bearing sperm. This will result in the male flies not being able to pass on the X chromosome, leading to only male progeny after mating. Our hypothesis is that the female population will decrease over time while the transgenic male population increases, which will result in population suppression.

Incorporating Relative Time Delay and Magnification Distributions Predicted by Lens Models Into Ranking Possible Subthreshold, Strongly Lensed Candidates
Haley Boswell
Mentors: Alan Weinstein and Alvin Li

We consider the possibility of gravitationally lensed pairs of gravitational waves, a phenomenon that has predominantly been studied in regard to electromagnetic waves. Under the strong lensing hypothesis, lensed gravitational waves from the same source are identical in waveform apart from a relative arrival time delay and an overall scaling factor in amplitude. It is possible that strong lensing produces magnified, super-threshold events that are registered as a trigger and demagnified, subthreshold events that get buried in the noise background. To remedy this, we search for subthreshold triggers using the gstLAL-based TargetEd Subthreshold Lensing SeArch (TESLA) pipeline, which considers the catalog of registered gravitational waves as potential lensed, super-threshold events. In this research, we modify the search pipeline's ranking statistic calculation to include the time delay and magnification probability distributions for a given lens model. This allows us to rank the trigger as a potential subthreshold counterpart to a specified super-threshold event. We determine the overall performance of this change in a final simulation campaign, gauging its effectiveness by its ability to uprank a lensed signal injected into the data.

Neural ODE-based Modeling and Control of Dynamical Systems for Robotic Planning
Jessica Brown
Mentors: Yisong Yue and Ivan Jimenez

For effective motion control in robotic platforms, accurately modeling and predicting dynamics is essential. In this project, we employ Neural Ordinary Differential Equations (Neural ODEs) using the JAX library in Python to establish a pipeline for modeling the parameters, dynamics, and control of dynamical systems. This setup is generalizable to various dynamical systems due to its modular design. In utilizing JAX, our pipeline facilitates the efficient execution of parallelized experiments on GPUs. Central to our investigation is the development and comparison of control strategies, specifically Model Predictive Control (MPC) and Proportional-Integral-Derivative (PID) controllers. This endeavor is part of a larger initiative aimed at advancing long-term robotic planning. A significant challenge in this field lies in the balance between rapid responsiveness and precision in control. Through our dynamical systems modeling approach, we aim to provide techniques to achieve robotic planners adept in both speed and precision.

Chemoenzymatic Functionalization of Quinolines With *Carbene Transferases*
Luis G. Burgos Hernández
Mentors: Edwin Alfonzo, Ziqi Li, and Deirdre Hanley

Quinoline, a sp^2-rich heteroaromatic, has gained significant recognition in the medicinal chemistry community because of its presence in numerous pharmacologically active substances, presenting a broad range of biological activities. Notably, the molecule's lack of unsaturated, chiral centers indicate potentially unexplored chemical space within its scaffold. Given precedent in the Arnold group, we posited that reduction and carbene transfer could significantly increase quinoline's sp^3 centers. Here we present a heme-enzyme, *Aeropyrum pernix* protoglobin (*Ap*Pgb), that can perform olefin cyclopropanation on products derived from quinoline reduction. This cyclopropanation occurs with significant chemo- and diastereoselectivity. Additionally, it is expected that the enzyme's chemo-, diastereo-, and enantioselectivity can be refined with directed evolution. These findings further elucidate the new-to-nature chemistry for heme enzymes and could lead to the discovery of new molecules with promising biological activity.

Epitaxial Growth of Rare-earth Antimonide Thin Films on Atomically Flat Oxide Substrates
Amari Butler
Mentors: Joseph Falson and Adrian Llanos

Lanthanum diantimonide ($LaSb_2$) is a square net metallic compound that possesses fascinating electronic transport properties in bulk. It has been observed to exhibit superconductivity at temperatures below 2K and linear magnetoresistance in magnetic fields as high as 45 T. Using Molecular Beam Epitaxy (MBE), a technique for growing single crystal thin films by evaporating elemental source materials onto a crystalline substrate, we can synthesize and probe for these phenomena in thin film $LaSb_2$. We prepared and grew on different substrates with different crystal structures and surface reconstructions to study how the epitaxial relationship between the film and the substrate affects the crystallinity and electronic properties of thin film $LaSb_2$. This investigation sought to tune the electronic properties by modifying the crystal structure using the substrate. We have successfully prepared atomically flat Sapphire (0001) in the $\sqrt{31} \times \sqrt{31}$ surface reconstruction, Sapphire (11-20), and Magnesium Oxide (001) and have grown films on each of these substrates. By growing on MgO, we have suppressed a previously observed structural transition and stabilized the superconducting ground state.

Organic Films Alter Cation Effects in Heterogeneous Electrochemical CO_2 Reduction
Sebastian Castro
Mentors: Jonas C. Peters and Madeline Hicks

Copper is a unique catalyst for CO_2 reduction (CO_2R) because of its ability to produce valuable C_{2+} products, albeit with poor selectivity. One strategy is to use certain organic additive films electrochemically deposited on the electrode, which can dramatically improve the performance towards carbon-coupled products. Additionally, the electrolyte cations have a significant role in the performance of CO_2R, and mixing these cations yields a range of results. We investigate how N-tolyl pyridinium additive impacts the cation effects in Cu-catalyzed CO_2R. Electrochemical techniques including chronoamperometry (CA), modified pulsed voltammetry (mPV) and electrochemical impedance spectroscopy (EIS), can provide insight into how cation size affects the electrochemical environment. By doping Cs^+ into Li^+ electrolyte, we find that selectivity and activity plateau at different Cs%'s for bare Cu and additive-modified Cu, emphasizing how the additive creates a unique electrochemical environment close to the electrode surface. Analysis of mPV and EIS data suggests that the local electric field at the Cu cathode does not change with the presence of the additive, which narrows down the difference in performance between bare and additive-modified Cu to physical, or nonelectric field, effects.

Suppressors and Enhancers of Mitofusin and ATPIF1
Priscilla Ceja
Mentors: Bruce Hay and Ella Wood

When mitochondria within a cell accumulates a high frequency of mutant mitochondrial DNA (mtDNA*), the energy requirements of the cell are not met. This leads to cell and tissue dysfunction and death, and serves a possible explanation for neurodegenerative diseases. It has been proposed by (Kandul et.al 2016) that decreased levels of the protein mitofusin (Mfn) and increased levels of ATPIF1 reduce heteroplasmy (the frequency of mtDNA*) in the cell. This project aims to analyze known interacting proteins of Mfn and ATPIF1 to identify any potential inhibitors and enhancers of heteroplasmy. Using the Gal4/UAS system in Drosophila flies, crosses were created from which to extract quantifiable concentrations of mtDNA*. Fly lines expressing IFM GAL4, IFM AfIII, and IFM T4 ligase – which creates a 5 kb mitochondrial deletion – were crossed with UAS overexpression and RNAi knockdown lines of the following interacting proteins: MIB, MIRO1, and Smad4. My goal in my remaining time in the lab is to determine if GAL-4 dependent expression of any of these UAS transgenes results in an increase or decrease in the levels of deletion bearing mtDNA. This will involve the extraction of DNA from several different fly lines, and the use of quantitative PCR to determine the levels of total mtDNA and deletion-bearing mtDNA.

Probing Thin-Shell Structure Stability: Efficacy of the 3-D Printing Approach to Optimize Design Parameters
Sage Cooley
Mentors: Sergio Pellegrino and Meital Carmi

Longerons are thin-shell structures found in the Caltech Space Solar Power Project deployable architecture. They derive the majority of their stiffness from geometry rather than mass; however, thin shells buckle unpredictably. Thin-shell stability analysis has recently advanced to include an energy landscape approach which can be used to identify resilient longeron geometric configurations under pure bending. Finding a more stable geometry is important for longerons because the composite material configuration has been shown to have highly unstable behavior. Efforts to uniformly 3-D print thermoplastic (PLA, PET-G, RGD 525) longerons reveal the potential for additive manufacturing to produce uniform, strong, and flexible thin shells appropriate for probing experiments. Initial bending and probing tests show the ability for 3-D printing samples to accelerate geometry optimization through iterative changes in the cross-section and comparison between energetic quantities.

Exploring a Range of Sound Frequencies to Create Mucus Flow in the Eustachian Tube
Juhi Dalal
Mentors: Mory Gharib and Alexandros Rosakis

Eustachian tube dysfunction arises from persistent obstruction within the tube due to the accumulation of fluid, mucus, and inflammation, leading to chronic discomfort. This study aims to investigate the potential for dislodging mucus from the eustachian tube by subjecting it to various frequencies of sound. To replicate the eustachian tube conditions, an air chamber-based model was devised to simulate pressure gradient, accompanied by a tube emulating the tube's inherent characteristics. Mucus was introduced into this model and subjected to a diverse spectrum of sound frequencies to observe its responses. The findings from this endeavor will yield insights into the simulation of eustachian tube dysfunction and how different sound frequencies impact mucus behavior within the tube. Moving forward, the project's progression should encompass a continued exploration of diverse sound frequencies to discern alterations in mucus flow dynamics within the eustachian tube.

Quantifying the Ultrafast Dynamics of Monolayer Graphene Coupled to Plasmonic and Dielectric Resonators via Ultrafast Differential Reflectivity
Gloria Davidova
Mentors: Harry Atwater and Arun Nagpal

It has recently been shown that plasmon emission in graphene occurs, in the mid-infrared, but the ultrafast decay mechanisms are still not understood completely. This has laid groundwork for the ultrafast photoluminescence properties of monolayer graphene to be studied as a function of Fermi energy in a GFET configuration. Now the graphene plasmon is also studied when coupled to an array of resonator devices. Here, the graphene plasmons couple to gap plasmons in planar devices as well as the modes of plasmonic and dielectric microdisk resonators. In the planar devices, the thickness of the gap between the monolayer graphene and gold back-reflector was modified such that the effect of detuning- between the gap plasmon and graphene plasmon- on emission may be understood. Transfer matrix modelling was done to select the necessary thicknesses for the gap plasmons to be resonant with or slightly detuned from the graphene plasmons. Optical excitation of the devices was done at 800 nm with a pulse width ~40 fs to capture the emission of "hot" electrons in graphene coupled to electromagnetic modes supported by newly fabricated resonators. Device characterization involved Raman spectroscopy, ellipsometry, profilometry, and electrical transport measurements. The finite-difference-time-domain electromagnetic field solving algorithm was used to obtain mode profiles and time dynamics of the structures. This paves the way for stimulated emission from surface plasmons to be performed and even utilized for high efficiency light-to-electricity energy conversion later on.

Modulation of the *Drosophila* Microbiome With *Lactobacillus brevis* to Promote Tissue Regeneration
Christian Dimayuga
Mentors: Lea Goentoro and Judah Bates

Only some taxa have evolved the ability to regenerate whole limbs after amputation, and yet continued research by the Goentoro lab suggests that the ability of limb regeneration may be present across wider metazoan species. Regenerative response to injury is influenced by the immune, endocrine, and metabolic state of an organism. Preliminary findings in the lab suggests that the microbiome can influence limb regeneration in the fruit fly *Drosophila*, a genetic lab model used for its simplicity, scalability, and conserved molecular processes. In this project, I investigated how leveraging microbiota within the *Drosophila* gut might prevent typical muscle wasting upon limb amputation and promote a regenerative response. To do this, I exposed young adult flies to *Lactobacillus brevis*, a known gut symbiont in *Drosophila*. After 24 hours, I amputated each fly at the mid-tibia. Brightfield and confocal images taken at 21 days after amputation showed that flies fed *L. brevis* had higher instances of muscle tissue survival and recovery than untreated flies. Therefore, administering probiotics before injury helps muscle tissue survive injury better. My next goal is to characterize how *L. brevis* promotes muscle survival and regeneration using transcriptomic and metabolic modeling analysis. Findings from this research may eventually contribute to identifying new therapeutic avenues for trauma-induced muscle atrophy.

Immune Response to the Mosaic-8b-mi3 Immunogen in mRNA Pre-immunized Mice
Ana Duarte Montano
Mentors: Pamela Bjorkman and Jennifer Keeffe

A large part of the world has received an mRNA vaccine licensed by Pfizer or Moderna with the goal of combatting SARS-CoV-2. However, as the virus continues to evolve, the virus evades the existing immunity provided by mRNA vaccines. In our study, we investigate the ability of the Mosaic-8b-RBD-mi3 vaccine to elicit a broad response in the immune system of mice that had been pre-immunized with a Pfizer-like vaccine. The nanoparticle contains 8 different receptor binding domains from 8 different sarbecoviruses, including the SARS-CoV-2 Beta variant[2,] and was designed to target conserved epitopes on SARS-CoV-2 and zoonotic viruses that are currently unknown[1]. The mouse model was used to mimic humans that received an mRNA vaccine. A qualitative analysis of single B cells was done using the Berkeley Lights Beacon instrument and monoclonal antibodies from individual B cells from the mice were cloned using Golden Gate Assembly. We characterized the polyclonal and monoclonal antibody response via ELISA. The data collected will provide evidence for how the human immune system might respond to the Mosaic-8b-RBD-mi3 vaccine and support the move to clinical trials.

References.

1. Cohen, A. A., van Doremalen, N., Greaney, A. J., Andersen, H., Sharma, A., Starr, T. N., Keeffe, J. R., Fan, C., Schulz, J. E., Gnanapragasam, P. N., Kakutani, L. M., West, A. P., Saturday, G., Lee, Y. E., Gao, H., Jette, C. A., Lewis, M. G., Tan, T. K., Townsend, A. R., Bjorkman, P. J. (2022). Mosaic RBD nanoparticles protect against challenge by diverse sarbecoviruses in animal models. *Science*, *377*(6606). https://doi.org/10.1126/science.abq0839
2. Fan, C., Cohen, A. A., Park, M., Hung, A. F.-H., Keeffe, J. R., Gnanapragasam, P. N. P., Lee, Y. E., Kakutani, L. M., Wu, Z., Malecek, K. E., Williams, J. C., & Bjorkman, P. J. (2022). *Neutralizing Monoclonal Antibodies*

Elicited by Mosaic Rbd Nanoparticles Bind Conserved Sarbecovirus Epitopes. https://doi.org/10.1101/2022.06.28.497989

Analysis of Intervenors of Potential Fast Radio Burst Host Galaxies Through Spectral Energy Distribution Fitting With Photometry
Matilda Eriksson
Mentors: Vikram Ravi and Jean Somalwar

The gas around galaxies in the circum- and intergalactic medium (CGM and IGM respectively) is not well understood. In the close universe (z~0), most of the gas is ionized making it difficult to observe directly. Fast radio bursts (FRBs) are short duration (~millisecond), highly energetic radio pulse transients of which their host sightlines can be studied by the propagation effects that the ionized gas has on the radio pulses. Since detection of FRBs has been an active area of research for the last 15+ years, we now have large samples of well-localized FRBs that we can use to study the CGM and IGM in the sightline. To achieve this, we need to measure redshifts and stellar masses of the intervening galaxies. This project focuses on measuring these properties using spectroscopy and photometry.

Unlocking the Cyclization of *Z*-oriented Exocyclic Azetines
Rei Fejzulla
Mentors: Sarah Reisman and Stanna Dorn

Z-oriented exocyclic azetine structures are a common motif across the field of organic chemistry. In current literature, strategies to access this motif involve multistep procedures that often necessitate the presence of stabilizing functional groups to ensure 4-membered ring formation. For this work, we disclose attempts towards the development transition metal-mediated strategies to cyclize linear fragments into exocyclic azetine scaffolds. Although the formation of the desired structure has not yet been achieved, side products generated in this reaction demonstrate the feasibility of initial proposed mechanistic steps. Overall, the findings from this work could lead to the optimization of methods to access a variety of azetidine-containing motifs.

Formal Languages and Constructing the Noncommutative Geometry of Icosahedral Quasicrystals
Francesca Fernandes
Mentor: Matilde Marcolli

Quasicrystals are crystal-like structures without translational symmetry and with rotational symmetries of orders five or greater than six. In two dimensions, these structures can be mathematically represented using Penrose tilings, which have been studied extensively. A powerful construction for these tilings exists using formal languages, which can compactly encode the necessary substitutions, decorations, inflation and deflation rules, and local matching rules. However, besides the case of the icosahedral Danzer tiling—which uses four tetrahedra as prototiles—little progress has been made in using formal languages to model quasicrystals. In this project, we work towards constructing a D0L formal language for the icosahedral tiling using a rhombic triacontahedron, rhombic dodecahedron, rhombic icosahedron, and prolate rhombohedra as prototiles. We also aim to examine the properties of this language and the corresponding noncommutative geometry of this quasicrystal.

Towards Robotic Exoskeleton Multi-Contact Walking via a Gait Library
Sara Frunzi
Mentors: Aaron Ames, Maegan Tucker, and Amy Li

Using robotic mechanisms to restore autonomy through walking in paraplegic individuals is an active field of robotics research. Current work in the AMBER Lab has improved dynamic walking with ATALANTE, a crutch-less exoskeleton developed by Wandercraft, but only with a flat-footed model, wherein the dynamics of the foot are simplified so it can be assumed that the entire surface of the foot is coming into contact with the ground at once. This model has been useful for walking in many robots, but it makes an unnatural comparison to human-like walking and is infeasible for rough terrains. This work presents the utilization of a gait library as a step towards implementing multi-contact walking, a model which takes into account regions of the foot striking the ground in succession, as opposed to the entire foot at once. In this approach, we generate multiple gaits of several velocities using optimization functions and constraints based on physical limitations of the exoskeleton and desired traits of a gait. These gaits are stored in a library that can be accessed by the robot controller. By tracking the robot's velocity, the controller can switch to a different gait upon interference to prevent the robot from falling. Because multi-contact walking is more complex than flat-footed walking, singular gaits may be less stable for prolonged use; using a gait library addresses this stability concern. Future work on this project will incorporate user feedback to change the desired velocity and take user preferences into account.

Cold Radioactive Molecules for Precision Measurements
Mumtaz Gababa
Mentors: Nick Hutzler and Chandler Conn

Polyatomic molecules have gained recognition as a sensitive probe in the search for new physics beyond the Standard Model (BSM), specifically the search for the combined violation of charge and parity (CP) symmetries. Specifically, linear triatomic molecules possess many attributes that aid BSM searches: laser-coolability and large polarization that is induced by a doubly degenerate bending motion in a vibrationally-excited state, leading to powerful rejection of systematic errors through internal co-magnetometry. Radioactive molecules retain all the benefits of polyatomic molecules, including their laser-coolability and easy polarizability, while adding additional benefits due to the exotic properties of the deformed, radioactive nucleus. However, the complexity of their production and study has, until just recently, prevented us from realizing their exciting applications not only in fundamental precision measurements, but also in astrophysics and relativistic quantum chemistry. Before we can control and manipulate these molecules to perform symmetry violation measurements, the internal quantum structure must be studied in detail. In this work, we are exploring and mapping the near-infrared transitions in radium monohydroxide (RaOH), a molecule of particular interest for fundamental physics experiments, in hopes of determining branching ratios for laser cooling. This will be second radium-containing molecule to be studied spectroscopically and the first direct probe of the internal structure of a radium-containing polyatomic molecule. Enhanced molecular production and signal optimization are discussed, utilizing cryogenic buffer gas cooling with unique absorption and fluorescence techniques for better characterization of the internal structure of RaOH.

Creating an Oxygen Sensor With Parylene Laser Induced Graphene

Alondra Galindo
Mentors: Yu-Chong Tai and Suhash Aravindan

Pancreatic islet cell transplantation is a developing treatment that recovers lost cellular functions and can be used for type 1 diabetes. Without a sufficient supply of oxygen however, these cells can undergo decreased insulin secretion or even cell death. Our lab is developing an oxygen sensor to detect the oxygen tension surrounding these cells using parylene laser induced graphene (LIG). We create LIG by using a CO_2 laser and pulsed irradiation on parylene that causes an accumulation of thermal energy and induces a chemical reaction to create graphene. The current theory is that oxygen alters the resistance of the LIG and can be used as an indicator to show how much oxygen is present around the cells. To test this, we optimized laser parameters and created LIG samples with the lowest sheet resistance. Then, to replicate the sensor being in the body, our experiments were performed with LIG underwater and the resistance of the LIG was monitored as oxygen dissolved back into the water. Our initial data using parylene C suggests that LIG is not significantly sensitive to oxygen adsorption. Future work will include pulsed irradiation and water tests on different types of parylene such as N and HT.

Constraining the Capacity of Sediments to Carry Organic Carbon in Arctic Rivers

Asiah Giuntoni
Mentors: Michael P. Lamb and Yutian Ke

Rivers contribute substantially to the production, transport, and deposition of both sediments and organic carbon (OC). Eroded solids that are transported in the form of suspended particulate matter (SPM) and consist of particulate organic carbon (POC) are redistributed to varying geomorphic units. Various properties of sediments such as their grain size, mineralogy, and specific surface area (SSA) directly constrain OC loading as a result of aggregate formation, layering and burial processes, and mineral surface coverage. By investigating the controls of OC loading and interpreting the possible fates of eroded permafrost OC, we can therefore address how accelerated bank erosion in permafrost regions will influence the global carbon cycle. For this project, we explored the relationship between the grain size and total OC (TOC) content of SPM collected from three discontinuous permafrost sites on the Yukon River. Aliquots of sediment were analyzed for grain size using the Mastersizer 3000 and for TOC content with the Costech Elemental Analyzer. Initial results show that OC loading is dependent on the dominant grain size and thus changes in different geomorphic domains; The Alakanuk Delta has higher OC loading because it is dominated by fine-grained silts and is located downstream.

Mapping and Interpreting the Formation of Martian Depositional Rivers

Emiliano Gonzalez
Mentors: Michael Lamb and Abdallah Zaki

The Martian surface was once dramatically different from today, featuring extensive lakes, rivers, and even clues of an ancient ocean. Although erosional valley networks have been identified since the early history of Mars exploration, a planet-wide discovery of Martian depositional rivers has recently been mapped, supporting the presence of ancient sedimentary basins. These depositional rivers appear as sinuous ridges standing as topographic highs due to long-lived aeolian erosion. However, the similarity in the morphology of Martian ridges to glacially formed eskers on Earth and volcanically formed wrinkle ridges may suggest that they were also formed by glacial and volcanic activity. Although previous studies have determined the major forces responsible for the formation of Martian depositional rivers, no studies have systematically interpreted or distinguished the various processes involved in their formation. We have developed a method to interpret these depositional rivers' origin as fluvial, glacial, or volcanic by comparing their morphological characteristics. Features such as sediment color, sedimentary structures, texture, and pattern were used to form a hypothesis behind a system's formation, which helps to specify the erosional and depositional processes involved in their formation, contributing to our understanding of the ancient Martian hydrological cycle, and processes that shaped the planet's surface.

Towards Structural Characterization of DPAGT1/Alg13/Alg14 Complex in Mammalian Cells
John Guardado
Mentors: William M. Clemons, Jr., and Jessica Ochoa

Asparagine-linked glycosylation (NLG) is a frequent posttranslational modification in all domains of life. NLG relies on the expression and function of a number of membrane-bound phosphotransferases. In mammalian cells, the first membrane-committed step is DPAGT1 which is hypothesized to form a complex with the secondary enzymes Alg13 and Alg14. These membrane-proteins have bacterial homologs, MraY and MurG, respectively, which form a complex. In order to understand their mechanism, our lab is interested in pursuing structural studies of the DPAGT1/Alg13/Alg14 complex. Understanding this complex will give further insight on the mechanism of NLG and provide a framework for the future development of targeted inhibitor development. We have begun work to structurally characterize a recombinant GFP-tagged DPAGT1 (DPAGT1_GFP) from mammalian cells. At the moment we are optimizing the purification using different detergents with a GFP immuno-precipitation (GFP-IP). We have also begun optimizing freezing conditions and collecting data of purified DPAGT1_GFP for single particle cryo-electron microscopy. In addition to our DPAGT1 work, we have also begun to co-express recombinant GFP-tagged DPAGT1 and a recombinant Alg14/Alg13 chimera using transient transfection. Next, we will optimize expression and purification conditions to overexpress and isolate the DPAGT1/Alg13/Alg14 complex.

Characterizing a Thruster Array Water Tunnel
Shana Hartwick
Mentors: Morteza Gharib and Sean Devey

Traditional water tunnels used for fluid dynamics experiments push fluid through a large circuit, which include complicated features like turning vanes, diffusers, pumps, and more. Most of the body of a traditional water tunnel consists of these flow conditioning and straightening features; the test section is only a small percentage in comparison. An alternative water tunnel design and its characterization will be presented that takes up less space and resources than large circuit water tunnels but still has a comparable test section size. The design's flow velocity range and spatial and temporal characteristics were determined using particle image velocimetry (PIV). This facility will support a variety of research experiments, from fundamental fluid mechanics to the hydrodynamics of boxfish.

Instrumentation of an Ultrafast EELS Instrument
Samuel A. Holloway
Mentors: Scott Cushing and Nick Heller

Electron Energy Loss Spectroscopy (EELS) is an analytical technique that uses excitation of electrons to discern changes in the electrical structure of a sample. This is done through the inelastic interaction of pump and probe electrons and electrons in a sample material. When the interaction occurs, the sample electrons create a "hole" in the atomic orbital due to excitation that can then be measured. What makes this EELS instrument different from other EELS instruments is its Electron-pump Electron-probe set up. The pump and probe electrons interact with and excite the valence band and conduction band of the sample through collision interactions. These interactions allow for an observer to view the electronic changes in a sample down to femtoseconds. The instrument itself combines ultrafast x-ray and ultrafast Transmission Electron Microscopy inherently, as most EELS set-ups can perform these tasks. The value in this form of spectroscopy is the capability to obtain a more detailed view of bond structures, chemistry, and electronic structure of thin samples compared to set-ups only using electrons in either the pump or the probe. The characterization of the element can be determined by the elements "fingerprint" as each element interacts with these excitations in different yet discernible ways.

Comparative Neuroanatomical Analysis of Peripheral and Defense Circuitry in Rove Beetles
Maria Jaimes
Mentors: Joe Parker, Jess Kanwal, and Jaison Omoto

Selective ecological pressures often lead to the evolution of novel anatomical structures which require concurrent changes in the central and peripheral nervous system. Despite the importance of evolutionary changes to the nervous system, how neural circuits are rewired to control novel structures remains largely understudied. Here, we aimed to identify how peripheral circuits have been evolutionarily modified to alter motor behavior and enable the control of an anatomically novel exocrine defense system in free-living versus socially symbiotic rove beetles. Rove beetles are a hyperdiverse clade that have convergently evolved multiple times toward symbiotic interactions with ants from an ancestral free-living state. We first mapped and compared the central nervous system neuroarchitecture of the free-living, *Dalotia coriaria*, and the socially symbiotic, *Platyusa sonomae,* beetles. Using immunostaining and dye injection protocols, we identify the major segments of the ventral nerve cord (VNC) as well as expression pattern of motor neurons responsible for leg movements. Furthermore, we attempted mapping the efferent and afferent nerve connections between the abdominal defense gland and the VNC. Our neuroanatomical mappings provides the first comparative analysis of the motor system between rove beetle species and bring us closer to uncovering neurobiological mechanisms underlying the evolution of species interactions.

Magnetic Field Effects on the Electrocatalytic Oxygen Evolution Reactivity of CoPi/CoBi Catalysts for Applications in Sustainable Hydrogen Production and Artificial Photosynthetic Devices
Hermann F. Klein-Hessling Barrientos
Mentors: Ryan G. Hadt and Ruben Mirzoyan

In an effort to transition away from fossil fuels, photoelectrochemical water-splitting presents a promising avenue to generate sustainable molecular hydrogen as a fuel source and molecular oxygen as a biproduct on the commercial scale. The kinetic and thermodynamic barrier behind this process is the oxygen evolution reaction (OER), which involves the transfer of 4 protons and 4 electrons to form the oxygen-oxygen bond. This study investigates the effects of a directional, uniform, and tunable externally applied magnetic field on the oxygen evolution reaction (OER) activity of the phosphate-based and borate-based amorphous cobalt oxide thin films, which serve as oxygen evolution catalysts (OEC's). These films are of particular interest since they consist of abundant earth materials, are low-cost, operate at neutral pH, and have self-healing properties. A magneto-electrochemical setup was designed and 3D printed to investigate how varying strengths of a magnetic field influence the OER performance in these catalysts. Increases in OER catalytic activity of up to an order of magnitude, as defined by Tafel Slope analysis, was observed at highest attainable field strength of 1.4 T. The observed magnetic field effect was found to be dependent on film thickness, pH, and film composition (i.e., electrodeposited from either phosphate vs. borate buffers). The results offer unique insights into the capabilities of magnetic field enhancing OER catalysis in amorphous cobalt oxide films, and further supports the yet-inconclusive intramolecular oxygen radical (O*) coupling mechanism for the oxygen evolution rate determining step between adjacent Co oxo units.

Position-Specific Carbon Isotope Analysis of Tree Ring Cellulose via Orbitrap Mass Spectrometry
Celia Kong-Johnson
Mentors: Alex Sessions and Hannah Dion-Kirschner

Tree rings are a critical archive for paleoclimate research, and the carbon isotope composition ($\delta^{13}C$) of their cellulose records information about past climate, including water availability. However, existing methods for isotopic measurements of tree rings combine signals from environmental changes and tree physiology. We are developing a new method of position-specific carbon isotope analysis (^{13}C-PSIA) to differentiate between these two signals using Orbitrap mass spectrometry. This method requires the conversion of whole wood to gluconate without altering $\delta^{13}C$ values of cellulose in preparation for PSIA via Orbitrap. We tested protocols to purify cellulose from wood, hydrolyze glucose from cellulose, and oxidize glucose to gluconate, with the best methods to date achieving 50-70%, 40-55%, and 70-75% yields, respectively. After further optimization, we have confirmed that our cellulose purification process yields pure cellulose with no side products and does not fractionate carbon isotopes. Additional analyses are required to ensure no fractionation is occurring throughout the other conversion processes. The preparatory chemistry we have developed enables Orbitrap PSIA of cellulose, which will help distinguish environmental and physiological signals in tree rings and allow paleoclimatologists to reconstruct climate variations more accurately.

Accessing Medium-sized Rings via Vinyl Carbocation Intermediates
Naiara Lebrón Acosta
Mentors: Hosea Nelson and Zhenqi Zhao

Cyclic structural motifs are commonly found in natural products, pharmaceuticals, and advanced materials. Among cyclic compounds, 5- to 6-membered rings are the most prevalent due to their stability and ease of preparation. Synthetic methods for small-ring cyclic structures (5–7 membered rings) have been well-established and developed. However, these methods encounter challenges when attempting to achieve the synthesis of medium-sized rings (8–11 membered cycles). Medium-sized rings possess torsional and transannular strains, rendering them less stable and consequently more difficult to synthesize. The Nelson Lab has recently laid the foundation for generating vinyl carbocation intermediates through Lewis acid-weakly coordinating anion catalysis. In this study, we present a catalytic method for synthesizing medium-sized ring systems via intramolecular Friedel-Crafts reactions of vinyl carbocations.

Targeted Recombination in Active Populations of Photo-stimulated Neurons: Developing a Functional Label of Subcircuits Within an Aggression Locus
Mark J. Lewis
Mentors: David Anderson and Amit Vinograd

Targeted recombination in Active Populations (TRAP) is a genetic labelling technique used to fluorescently mark cells expressing activity-dependent $CreER^{T2}$ within a limited timeframe. Anderson et al. have identified and correlated a small population of neurons in the ventrolateral sublocus of the ventromedial hypothalamus (VMHvl) with aggressive behaviors in mice. Inducing aggression states in the presence of injectable tamoxifen results in distinct labelling of VMHvl neurons, as well as its upstream/downstream projections. Photo-stimulation uses optogenetic sensors and actuators to render a cell “active” for a highly controllable period of time. We present a novel combination of these methods to allow for the robust labelling of an aggression subcircuit in the VMHvl with minimal noise.

Optimize Burst Wave Lithotripsy: MFC and Strain Energy
Xuezhen Li
Mentors: Tim Colonius, Jean Sebastien Spratt, and Haeyoung (Chloe) Choi

Kidney stones affect a significant proportion of the American population and pose a heavy burden to the healthcare system, necessitating effective and safe treatment methods. Shock wave lithotripsy (SWL) is a commonly used non-invasive method, which lowers the risk of wound infection but is plagued by a high retreatment rate. The single-cycle high-amplitude shock wave also generates cavitation bubbles which collapse violently and may injure the nearby tissues. Therefore, researchers are investigating burst wave lithotripsy, which uses low-amplitude, multi-cycle, sinusoidal ultrasound waves. BWL limits the growth of cavitation bubbles and provides more flexibility for urologists to control the parameters. Although there have been clinical trials, the optimization of BWL is still not clear. While it is difficult to conduct experiments, Multi-component Flow Code (MFC), a high-performance software, can numerically analyze BWL. This research aims to use strain energy to predict the fragmentation of stones and find the optimized case with MFC.

Understanding the Neural Circuits for Aggression: *Drosophila* Wing Threat Behavior
Mina Mandic
Mentors: David Anderson and Shuo Cao

Innate social behaviors involve complex and functionally relevant movements. However, it remains unclear how these actions are coordinated by the brain. Drosophila display “wing threat” behavior - a complex, multi-motor aggressive behavior, composed of four different actions: wing elevation, pump, turn, and charge. The Anderson lab has identified genetically labeled “AIP neurons” that specifically control wing threat display. To understand the aggression circuitry in the Drosophila brain, it is crucial to identify other connectome-derived neurons that are involved in wing threat and elucidate their connection to AIP neurons. Our methodology entails identifying split-gal4 drivers to label each downstream neuron of interest, followed by gain-of-function and epistasis behavior experiments. Gain-of-function results tell us which behaviors are caused by activation of the neuron of interest. Epistasis results determine whether the effects of AIP neurons are mediated by the inhibited neuron. Our preliminary findings indicate that the neuron CL139 plays a role in wing elevation, and DNp45 induces an augmented velocity response to optogenetic stimulation. Future investigations involve epistasis tests to discern which wing threat behavior DNp45 is responsible for. Additionally, we aim to classify other downstream neurons (DNg39, CL335, CL176) of AIP to gain further insights into the circuitry governing wing threat behavior.

Advancing Autonomous Underwater Vehicles Through the Innovation of a Robotic Fish Fin Propulsor
Hambik Margoosian
Mentors: Morteza Gharib and Meredith Hooper

Autonomous Underwater Vehicles (AUVs) have the potential to revolutionize exploration methods by offering convenience and cost-effectiveness. However, conventional AUVs utilizing screw propellers for propulsion face limitations such as inefficient power consumption, reduced maneuverability, and a large acoustic footprint, impacting their practicality in certain applications. In contrast, bio-inspired AUV designs, mimicking fish locomotion, have the potential to improve power efficiency, maneuverability, and operate quietly. The power efficiency optimization of AUVs is of high priority to maximize its potential use in longer missions. This project focuses on developing a mechanism that utilizes a fish-like caudal fin capable of three-axis rotation controlled by a fin trajectory optimization algorithm which aims to achieve efficient propulsion.

Designing an Efficient Decoder for a Novel Quantum Error Correction Scheme
Nadine Meister
Mentors: John Preskill and Chris Pattison

One of the largest obstacles in developing quantum computers is its sensitivity to unwanted interactions with the environment that lead to errors in the computation. Hence, reliable error detection and correction is necessary to build large scale fault tolerant quantum computers. To correct errors in the physical qubits, quantum error correction schemes encode a single logical qubit into multiple physical qubits. Unlike classical bits in classical computers, qubits are typically not easily transportable. Consequently, quantum gates can only be applied between nearby qubits. Given this geometrically local restriction, a newly proposed quantum error correction scheme, the hierarchical code, asymptotically outperforms previously known state of the art quantum error correction codes. In any of these schemes, when trying to detect errors, simply measuring each qubit will collapse the state and destroy some of the encoded information. Thus, recovery operations must decode the information by performing measurements to identify which errors have occurred without fully collapsing the state. We developed a decoder for the hierarchical code to determine how many physical qubits are needed to protect a certain number of logical qubits at a target logical success rate, and ultimately, estimate the overhead of quantum error correction.

Development of a Deep Sea Thermophilic Model Organism for the Study of Large Scale Protein Assemblies
Filipe Andreas Melo
Mentors: Andre Hoelz and George Mobbs

Alvinella pompejana is a polychaete worm identified at hydrothermal vents near the sea floor, a habitat exhibiting temperatures as high as 80°C. This extreme environment has led to an unusually high degree of thermostability within the *A. pompejana proteome*, making the expression of recombinant proteins an attractive option for structural biologists aiming to determine structures that have proven intractable from alternative higher eukaryotic model systems, such as humans due to their relative lack of stability. We aim to demonstrate *A. pompejana* as a useful model organism by showing the structural homology of proteins within its nuclear pore complex (NPC), compared to their human and fungal counterparts, which have recently been characterized. The NPC is an ~110MDa protein complex that makes up the only pathway through the nuclear envelope and is central to the export of mRNA from the nucleus to cytoplasm. I aimed to recapitulate crystal structures of the NPC protein Nup214, the proteins Nup214 and Ddx19 in complex, and Ddx19 in complex to Gle1 to compare them to their human homologs. I did this by expressing these proteins in *E. coli*, purifying them to a high degree of homogeneity by affinity, ion exchange, and gel filtration chromatography, then screening for crystallization conditions. This study demonstrates the suitability of this structural model organism with ample yields and promising crystallization hits obtained.

Characterization of *ins-6* Expression Within the *C. elegans* Chemosensory System in Response to Ascaroside Input
Soraya Mercado
Mentors: Paul Sternberg and Mark Zhang

C. elegans is one of the most influential biological models for developmental biology and neurological research because of its fully sequenced genome and its compact nervous system. The most compelling aspect of their nervous system is that their neurons can perform a myriad of different responses after exposure to a singular input. These responses can either be short-term chemical responses, or they can be long-term phenotypic changes. The long-term phenotypic change in this study would be the dauer diapause state, which worms enter under exposure to ascarosides. This project focuses on how *C. elegans*' chemosensory neurons regulate gene expression for dauer diapause and studies their neuron's omnidirectional potential in terms of creating a myriad of responses after receiving a singular input. To do this, we measure the expression of *ins-6* after exposing the *C. elegans* to different combinations and concentrations of ascarosides; the expression of *ins-6* should decrease after treatment. From this research, we found that ascarosides only influence *ins-6* expression when in conjunction with each other, but ascaroside #8 reduces *ins-6* expression the most within ASJ neurons. Further research into this subject will create a more accurate model of gene regulation within a nervous system.

Deformation and Misorientation Barometer of Experimentally Shocked Olivine: A Micro- to Meso-Scale EBSD Study
Jenna Meyers
Mentors: Paul Asimow and Jinping Hu

Precise constraints on the shock conditions experienced by meteorites during their impact histories offer insights into the evolution of their parent bodies and, more broadly, the dynamics of our solar system. Shock pressure is the key information provided by shock metamorphic features in meteorites. However, the challenge lies in the fact that many features, like fractures and mosaicism, occur across a wide pressure range, making it difficult to obtain narrow pressure brackets.

Ruzicka and Hugo (2018) used Electron BackScatter Diffraction (EBSD) to quantify the crystallographic misorientation of olivine from seven chondrites of shock stages S1-S5 and developed correlations between shock stage, temperature, and olivine misorientation. To tie this method to well-defined peak shock pressures, we conducted two shock recovery experiments, S1258 and S1259, on Transvaal dunite (Hu and Asimow 2020). S1258 used an Mg-Cu graded density impactor to achieve a quasi-isentropic loading path to 30 GPa with well-defined shock temperature. In contrast, S1259 was shocked by a regular steel flyer to 26 GPa but the sample was saturated with pore water to enhance local melting. Both starting samples were cut into cylindrical wedges and assembled with a matching steel wedge to create frictional sliding along the sample-wedge interface.

We performed detailed SEM analysis to study the shock deformation in the recovered samples. In both samples, in addition to pervasive fracturing, sub-grain development, and local melting, planar deformation features were observed in several grains in heavily deformed areas. We observed misorientations ~4° in olivine grains; the misorientation angles are correlated with distance to the ramp and the edges. These numbers are generally consistent with shock stage S4-S5 meteorites. With their well-defined pressure and temperature, our experiments serve as a solid tie-point in the shock classification scheme.

References
Hu J, Asimow PD (2020) 51st Annual Lunar and Planetary Science Conference, abstr. 2326.
Ruzicka AM, Hugo RC (2018) Geochimica et Cosmochimica Acta 234:115-47.

Elucidating the Molecular Mechanism of Membrane Protein Insertion by MTCH2
Cassandra Morin-Gaona
Mentors: Rebecca M. Voorhees and Masami Hazu

Approximately 20% of the human proteome are membrane proteins, and it is crucial that they are correctly sorted to each organelle in order to maintain proteostasis and organelle specialization. Some membrane proteins can be sorted based on their signal sequence, but most are sorted based on their transmembrane domains and the surrounding residues. Defined as tail-anchored (TA) proteins, these proteins are diverse in their biophysical properties and thus require diverse biogenesis machinery. The lab recently identified MTCH2 as a mitochondrial outer membrane protein insertase. We aimed to investigate if MTCH2 has a selectivity filter that selects for mitochondrial TA proteins and against TA proteins destined for other cellular locations. We introduced point mutations to MTCH2 surfaces that may be involved in membrane protein insertion. To study the insertion of substrates via MTCH2, we used a split green fluorescent protein (GFP) reporter system. We used constructs containing GFP, red fluorescent protein (RFP)-tagged substrate, and a viral 2A skipping sequence between them, which allowed for comparison of stoichiometric amounts of RFP-tagged protein and cytosolic GFP. Through flow cytometry analysis of the RFP/GFP ratio, we will better understand which surfaces of MTCH2 are involved in the insertion of mitochondrial TA proteins.

Galanin+ Enteric Neurons as the First Link in the Progression of Parkinson's Disease
Marceline Mostafa
Mentors: Viviana Gradinaru and Jonathan Hoang

Parkinson's disease is a multifaceted disease with clinical data implicating the gastrointestinal tract in its progression. Braak's hypothesis claims that pathogenic ɑ-synuclein moves from the gut to the brain via the vagus nerve accelerating the disease, composed of neurons with high ɑ-synuclein that have projections to another affected cell. An unpublished meta-analysis of publicly available single-cell sequencing data pointed to a possible marker, galanin, of neurons expressing ɑ-synuclein that could be the first step in Parkinson's pathology . Gut tissue was cleared and immunostained to validate the effectiveness of galanin as a relevant protein in ɑ-synuclein progression. Most galanin-positive neurons expressed ɑ-synuclein at high levels, possibly marking a class of neurons responsible for transferring ɑ-synuclein to the vagus nerve. In parallel, brainstem tissue processed in a similar manner demonstrated ɑ-synuclein expression localized to the most ventral rostral part of the dorsal motor nucleus of the vagus. Future research will focus on bridging the gap between both populations of neurons via retrograde labeling of galanin projections as well as perturbing the galanin-positive enteric neurons in an attempt to halt the progression of ɑ-synuclein from the gut to the brain.

Building a Spectral Library of Serpentinization With a Focus on Fe-rich Brucite
Kenzie Mounir
Mentors: Bethany Ehlmann and Rebecca Greenberger

Serpentinization, where water interacts with ultramafic rocks, yields minerals like serpentine and brucite, fostering potential habitability in celestial bodies like Mars, volatile-rich asteroids, and outer planets' icy moons. Hydrogen gas production during this process varies due to the involvement of various Fe-bearing minerals. Our objective is to characterize the products of serpentinization with planetary mission-relevant spectroscopies in order to provide a database for interpreting mission data as well as terrestrial datasets, e.g., micro imaging spectroscopy of the Oman Drilling Project's serpentinized ophiolite sequence. We focus first on Fe-bearing brucites because of their role in enhancing H_2 production as Fe(II) in brucite oxidizes through fluid-rock reactions.

We synthesized $Mg_xFe_{(1-x)}OH_2$ samples via coprecipitation, dried them at the University of Colorado, and analyzed them under argon in a Caltech anoxic glove box. Spectral measurements on four samples (Mg#'s 90, 66, 50, 33) show wavelength shifts consistent with trends in other minerals like Fe(II)-bearing smectites. We also studied natural samples of Fe-bearing serpentines and will present analyses using FTIR, UV/Vis, Mössbauer, and Raman spectra. Our new spectral library will aid in distinguishing Fe(II)-bearing brucites, key to understanding H_2 production during serpentinization.

Determining the Composition of Earth-Sized Planets in the TOI-406 System
Kendra Nguyen
Mentors: Heather Knutson and Michael Greklek-McKeon

M dwarfs are stars smaller and cooler than the Sun but are more active with more frequent flares. As such, planets orbiting M dwarfs may have properties different from planets in our solar system. By obtaining the masses and radii for M dwarf planets, we can determine their bulk composition and gain insight into the impact of M dwarf stellar activity on planetary formation, evolution, and habitability. We have obtained such measurements for two Earth-sized planet candidates, TOI-406.01 and TOI-406.02. Observations of the TOI-406 system were conducted through the Las Cumbres Observatory global telescope network, and we used the ExoWIRC photometric reduction pipeline to produce transit light curves and determine the transit times. Finding the transit time is needed for calculating masses based on transit timing variations (TTVs). TTVs are deviations from expected transit times due to gravitational interactions between planets in a multi-planet system. With inputs of planet masses and orbital parameters, the code TTVFast efficiently models transit times. Thus, by generating models that match the transit times we found, we have determined the masses. With the masses and radii, we calculated the bulk densities and placed the first direct constraints on the composition of both TOI-406.01 and TOI-406.02.

Searching for EM Counterparts to Binary Black Hole Mergers in AGN Using LIGO O4
Cece Ochoa
Mentor: Matthew Graham

Active galactic nuclei (AGN) have been found to be promising locations for binary black hole (BBH) mergers. Utilizing LIGO and the Zwicky Transient Facility (ZTF) we are able to continue the search for EM counterparts to BBH mergers. LIGO provides us with alerts when gravitational waves are detected, along with possible sources including BBHs. ZTF is a wide field imager located on the Palomar 48-inch Oschin telescope which surveys the sky each night searching for EM flares that could be the result of BBH mergers. Here we present our preliminary results from the current LIGO observing run (O4) and from LIGO O2, which ran from November 2016 to August 2017. By creating a more extensive data set of EM counterparts to BBH mergers, we hope to fill gaps in our current knowledge of BBHs and AGN, and expand upon pre-existing science.

Alkynalated Carbondots as a New Vial for Gene Delivery of Cy3-DNA Into *Nicotiana benthamiana* Mediated via CuAAC Click Chemistry
Alexander Ortíz-Rivera
Mentors: Gözde Demirer and Jesus Galeana

Food security concerns are at a constant rise due to the reduction in crop yields associated with climate change and pathogenic organisms. Novel methods for biomolecule delivery to plants present a promising avenue to achieve effective plant genetic engineering and equip crops with enhanced resistance to a diverse range of abiotic and biotic stressors. However, one major limitation still needs to be addressed, the 5-20 nm size exclusion limit of the plant cell wall, which hinders the delivery of biomolecules. Recently, carbon nanomaterials, such as carbon nanotubes (CNTs), have been studied as an effective option for nanoparticle-mediated biomolecule delivery method. Similarly, an interest in using other carbon allotropes like carbon nanodots (CNDs), which are typically smaller than 10 nm in diameter, have gained traction for their ability to serve as biomolecule vectors and fluorophores. Specifically, when functionalized with positively charged polymers like polyethyleneimine (PEI), CNDs and CNTs can electrostatically absorb DNA on their surface, creating a CNT-DNA or CND-DNA complex suitable for biomolecule delivery *in planta*. Unfortunately, the loading limit dictated by electrostatic interactions hinders the use of surface passivated CNTs and CNDs for the delivery of biomolecules. Motivated by this, our work proposes a novel method for the covalent attachment of DNA via a simple copper(I)-catalyzed azide-alkyne cycloaddition (CuAAC) click chemistry to carbon nanodots covalently modified with alkyne functional groups. This research will present the synthetic route to the surface passivation of carbon dots with alkynes necessary for CuAAC mediated biomolecule attachment.

Drag Reduction and Stability Analysis of Biohybrid Robotic Jellyfish Mounts
Giannka Picache
Mentors: John Dabiri and Kelsi Rutledge

Biologging—which is the practice of using animals equipped with sensor tags—is a promising new avenue for ocean monitoring. However, a limitation of biologging is that it only provides data on where the animal swims. Biohybrid robotic control—which is the ability to navigate an animal along a desired path of motion—addresses that limitation. By implanting a microprocessor and electrodes into the bell (the umbrella-like body) of a jellyfish, previous research has shown enhanced swimming speeds up to 3 times its normal gaits. Moreover, it was found that the implanted cap, which is the plastic housing for the jellyfish's microelectronics system, further increases swimming speeds when affixed to the apical surface of the bell. In this study, we aim to further explore the hydrodynamic influence of implanted caps. We tested different shapes and surfaces to determine an optimal design for decreasing drag and increasing stability. We measured the terminal velocity and corresponding drag coefficient of both traditional and bioinspired drag-reducing designs. We identify an optimal shape and surface texture for maximum performance in biohybrid robot jellyfish. This study provides important design considerations for the jellyfish platform while giving insights into drag-reducing shapes and surface textures in low velocity, laminar flows.

Stabilization of High Oxidation State Complexes for Nickel-Catalyzed Aryl Fluoride Cross-Coupling
Eric Ramos
Mentors: Theodor Agapie, Meaghan Bruening, and Matthew Espinosa

In catalysis, high oxidation state compounds can significantly lower the activation energy to perform difficult transformations. One such process is the formation of aryl-fluoride bonds, which are a common motif in pharmaceuticals, agrochemicals, and materials. Nickel has been shown to facilitate this coupling through some high-valent nickel species, and that these states can be supported by pyridine-containing ligands. The isolation of these species is necessary to enable reactivity studies. Fluorinated silicates developed in the Agapie Group could be a solution to this problem. By appending these silicates to a pyridine-based ligand core, we hypothesize that high oxidation state metal complexes can be isolated. To synthesize the target ligand, a Negishi Coupling approach was taken. We report spectral data that indicates the product is formed, but it remains a challenge to isolate and purify the material before metalation.

Mapping Local Reaction Dynamics in CO_2 Reduction Gas Diffusion Electrodes via Laser Scanning Confocal Microscopy

Cristian Reynaga Gonzalez
Mentors: Harry Atwater and Annette Boehme

Electrochemical reduction of carbon dioxide (CO_2) with gas diffusion electrodes (GDEs) has emerged as a promising approach towards generating sustainable value-added chemicals and fuels. Carbon monoxide (CO) is one prominent CO_2 reduction product and is particularly important because it is used as a feedstock for many key chemical processes. Understanding local reaction dynamics inside operating GDEs is crucial for optimizing the CO_2 conversion process. Our research goal is to map the local CO concentration around operating CO_2 reduction GDEs. To this end, we measure the fluorescent signal emitted by a CO-detecting dye, NCCA, via laser scanning confocal microscopy (LSCM). Initial dye calibration procedures utilized a CO-releasing molecule, CORM-3, but the inconsistent release of CO prompted a shift to gaseous CO. Utlizing LSCM we examined NCCA's behavior under operating CO_2 reduction conditions with different catalysts such as gold, silver, and copper. These experiments revealed a persistent dye reduction and hence, change in fluorescent signal, at the catalyst surface. To overcome this challenge and enable the imaging of the local CO concentration, we deposited a semi-permeable Nafion layer on the catalyst to prevent premature dye reduction. Despite these efforts, initial results suggest that dye reduction persists, indicating the need to investigate different additive materials, layer thicknesses or appropriate potential windows. Our findings mark significant progress in understanding the dye's behavior around operating CO_2 reduction cathodes and underscore the need for further investigations. The ultimate goal is to establish a consistent and reliable way to measure the local CO concentration around operating gold and copper CO_2 reduction GDEs.

Studying Low-Energy Symmetry Properties of 1D Cuprates With Time-Resolved Time-Domain Terahertz Spectroscopy

Eleanor Richard
Mentors: David Hsieh and Yuchen Han

Cuprates are a class of materials that have generated a lot of interest for their strongly correlated degrees of freedom, including spin and charge. This strong correlation has given way to high-temperature superconductivity and other interesting quantum phenomena. A subset of these materials, called 1D cuprates, have the characteristic Cu-O chain in one direction and provide an important avenue in better understanding cuprates and the quantum phenomena that arise. We are interested in investigating the properties and dynamics of the 1D cuprate Sr_2CuO_3 in the low energy regime to search for nonequilibrium phases. To access this energy scale, we employ a technique known as time-resolved time-domain terahertz spectroscopy. We have observed polarization dependence in the material's equilibrium state in the form of four-fold symmetry with increased absorption diagonal to the chain direction. We plan to excite the material with various energies and polarizations to possibly uncover novel quantum phenomena.

PdPtOx Thin Film Catalyst Synthesis for Olefin Epoxidation

Yamilet M. Rivera Cintrón
Mentors: Karthish Manthiram and Chenyu Jiang

Production of propylene oxide with hydrogen peroxide requires the direct burning of fossil fuels to reach elevated reaction temperatures. Electricity can serve as a greener alternative to fossil fuels, sustainably functionalizing olefins with the aid of efficient and selective electrocatalysts. However, understanding mechanisms of electrochemical reactions remains untrivial due to dynamic changes of the catalysts under applied potential. Olefin epoxidation using water as the oxygen atom source has been previously demonstrated in ambient conditions with PdPtOx/C nanoparticles as the catalyst drop-cast onto carbon paper (CP) electrodes (Chung et. al. 2023, *Science, manuscript under review*), achieving a Faradaic efficiency (FE) higher than 90% for cyclooctene oxide. Due to its porous nature, CP is regarded as an unsuitable substrate for *in situ* spectroscopies that require an ultra-high vacuum environment, such as soft X-ray absorption spectroscopy. By changing the substrate to a nonporous material and depositing the catalyst without sacrificing its high catalytic performance, the mechanism of this oxidation reaction can be investigated to reveal the reason why PdPtOx excels as a novel catalyst for olefin epoxidation. This study provides insight on how deposition methods of PdPtOx affect its structure and catalytic properties by analyzing the FE obtained from the use of CP, indium tin oxide, and glassy carbon as substrates.

PdPtOx thin films were prepared by drop-casting, sputtering, and spin coating, and chronopotentiometry was carried out at 40 mA/cm^2 until a total charge of 20C was passed. A series of characterization methods were performed to obtain information on the oxidation states, morphology, and thickness of PdPtOx thin films.

Evolutionary Comparison of Neuromodulatory Systems in Rove Beetle Species
Camila Romero
Mentors: Joseph Parker, Jess Kanwal, and Jaison Omoto

Animals have evolved their nervous system to interact adaptively with members of other species. In particular, neuromodulatory systems can play a critical role in modulating the function of circuits over evolution without anatomical re-structuring. However, the evolutionary changes to neuromodulatory systems that enable novel interspecies behavioral interactions are largely unknown. Here, we characterize and compare how the expression patterns of key neuromodulatory systems are evolutionarily modified to enable symbiotic specialization. To investigate this phenomenon, we used two rove beetle species: the free-living beetle *Dalotia coriaira* that chemically defends itself against predatory ants and the social symbiont *Platyusa sonomae* that deploys an appeasement chemical to reduce ant aggression and lives alongside ants. Using immunostaining and confocal microscopy, we compared neuromodulator expression patterns within and between the central nervous systems of *Dalotia* and *Platyusa*. Specifically, we looked at tachykinin, serotonin, and dopamine expression, as these neuromodulators have previously been associated with aggressive and defensive behaviors. We hypothesize that the neuromodulator expression patterns for these neuropeptides may differ to reflect the behavioral differences between rove beetle species. Our comparisons lay the groundwork to uncover neural changes underlying the evolutionary shift in behavioral interspecies interactions in these two beetle species.

Time-domain Observations at Millimeter Wavelengths Using SPRITE
Olivia Rourke
Mentors: Vikram Ravi and Nitika Yadlapalli

SPRITE consists of two 10.4-m radio dishes operating at 90 GHz and is designed to perform time-domain observations at millimeter (mm) wavelengths. Millimeter observations allow us to peer into the inner regions of extreme astronomical environments. The primary focus of our project is to improve SPRITE's system calibration and data quality. Beyond this, we also utilize SPRITE to observe various sources that are known radio emitters such as young eccentric stellar binaries, flaring blazars, and certain stars such as UV Ceti. There are numerous goals that can be accomplished using SPRITE including learning about the mechanisms behind outbursts from the magnetospheres of nearby stars, collisions between supernova explosions and dense surrounding matter, and the physics of active galactic nuclei powered by supermassive black holes.

Assembly and Characterization of Neural Probe Systems for Dense Electrophysiological Recordings
Omar Salas
Mentors: Michael Roukes and Laurent Moreaux

Our perception of the world is based on the circuit-like interaction between our neurons. While we have made a lot of progress understanding the mechanics behind individual neurons, we have little knowledge on how neurons interact with each other inside the brain. We assembled a 32-channel electrophysiological (ephys) probe to measure the electrical signals from the interneurons in the cortex *in vivo*. The dense array of channels allows better resolution to isolate distinct waveforms and triangulate the location of emitting neurons compared to previous ephys systems. The recorded ephys data was then analyzed using SpyKING Circus. Allowing us to look at spikes at a determined threshold, identify overlapping spikes, and sort them based on their features. In addition, we look at possible designs for higher channel probe assemblies based around a 256 dense electrode array probe. These include the design of a custom PCB to accommodate 64 channels as well as the use of an interposer to spread out all 256 channels, thus facilitating the assembly of a 256-channel probe.

Optimization of the SMI41 Antibody-Expressing rAAV Vector to Mediate Long-Term Contraception
Sydney Singal
Mentor: Bruce Hay

The lack of efficient, long-term contraceptive methods to control the overpopulation of various wild animal populations remains a widespread issue. One approach to inhibiting fertility is long-term vectored contraception (VC). In VC, a single injection of a non-replicating, recombinant adeno-associated viral (rAAV) vector delivers to muscle cells a gene encoding a protein that inhibits a key molecule required for fertility. Our work centers on the monoclonal SMI41 antibody, which binds to and blocks the gonadotropin-releasing hormone (GnRH), thereby inhibiting gamete development for several years. While this approach was shown to block fertility in mice, it may be ineffective in larger mammals because high levels of the SMI41 antibody are required to mediate contraception. Our goals are to enhance AAV targeting to muscle and overall SMI41 expression as ways to increase the levels of SMI41 produced per vector genome. We are working to identify a capsid that mediates vector entry into muscle and exploring the inclusion of two expression-enhancing sequences in the vector transgene. An enzyme-linked immunosorbent assay (ELISA) was performed to quantify the amount of SMI41 expressed in vitro by the optimized vector constructs. Future steps may include in vivo analysis of vector function and antibody expression in mice.

I. Impact of Novel H_2O Cross-Sections on the Present-Day Martian Atmosphere
II. Solving the Mystery of Life on Mars Using Sulfuric Isotopic Fractionation
Kayla Smith
Mentors: Yuk L. Yung and Danica Adams

In Mars's early history, it likely had a denser atmosphere with greenhouse gases, suggesting previous surface liquid water. Over time, water might have lost to space due to UV radiation-induced photo-dissociation, forming H and OH radicals. These radicals are central to the Martian atmospheric odd hydrogen cycle, leading to H_2 production and potential space escape. Ranjan et al. (2020) highlighted the potential significance of water photolysis at wavelengths ≥ 205 nm, often underexplored in past studies. Here, we examine the effects of this on the Martian atmosphere using an adapted KINETICS, Caltech/JPL's 1D Photochemical/Transport Model. Integrating longer wavelengths into previous water vapor absorption datasets, we assess their impact on Martian photochemistry and atmospheric escape. Findings indicate near-surface CO concentrations decrease by 25% and 12% based on the initial dataset. This slowdown in CO accumulation might promote CO_2 stability, potentially warming Mars. We also observed a rise in HNO_3 concentrations by about 50% and 18%. In a subsequent 2D model adaptation of KINETICS, considering latitude-dependent water concentrations from EMARS data, the latitude variation influenced atmospheric species behavior. Furthermore, understanding the history of potential life on Mars has been a major conversation in the science community for many decades. The formation of sulfates play an essential role in elucidating whether there was life/is life on Mars since it provides atmospheric, geologic and biologic history about planets. Geological evidence, including fluvial features and hydrated minerals, has suggested that there was once water that flowed on ancient Mars' surface. Along with fluvial structures, hydrated clays have also been discovered on the Martian surface. Finding sulfates and other sulfate mineral veins, as a result of a study done at Yellowknife Bay, within the clay supports the idea that it was hydrated at one point in time. These sulfates likely originated from atmospheric formation, deposited to the ground, and underwent aqueous and/or geologic alteration. I am utilizing the Caltech/JPL Photochemical Model, KINETICS, in order to investigate the atmospheric formation of Mars' sulfates. In order to do this, we adapted the photochemical model from Venus chemistry/parameters (Pinto et al., 2021) to Mars' chemistry/parameters. We are now analyzing the formation and deposition of sulfuric acid (H_2SO_4) aerosols as well as elemental sulfur (S_8) aerosols.

Orbit Design for Formation-Flying Missions
Andres Torres
Mentor: Soon-Jo Chung

Multi-satellite missions have been well-established for a long time, particularly constellation swarms. A frontier of multi-satellite missions is formation flying satellites, which enables much more complicated and expanded satellite capabilities. One major difficulty in formation flying is determining suitable orbits for each satellite. Our goal is to design orbits that: (1) best position satellites to achieve their mission objectives; and (2) minimize fuel costs needed to maintain the orbits. This problem can be transformed into an optimization problem. One approach that we have applied with success and are actively improving is a genetic algorithm, which iteratively improves a formation into a better one. However, despite the success of the genetic algorithm there are still two main challenges: (1) it can get stuck in local extrema, meaning that the formation generated might not be the best possible one; and (2) it takes a while to converge to an acceptable formation. An alternative is using deep reinforcement learning, which after training, can provide high quality formations significantly faster than the genetic algorithm. We apply and compare both methods to NASA's Distributed Aperture Radar Tomographic Sensors (DARTS) mission concept which has the goal of drastically improve radar imaging of the Earth.

Search for Nonresonant Pair Production of Highly Energetic Higgs Bosons Decaying to Bottom Quarks
Sherry Wang
Mentors: Maria Spiropulu, Si Xie, Christina Wang, Cristián Peña, and Artur Apresyan

We reconstruct the rare production of a pair of Lorentz-boosted Higgs bosons via gluon and vector boson fusion, as well as its subsequent decay into two bottom quark-antiquark pairs. This analysis focuses on drawing correspondence between proton-proton collision data collected by the CMS Collaboration during Run 2 of the Large Hadron Collider (LHC) and various simulated signal and background samples generated by POWHEG 2.0. Performing the analysis in the signal, top, and one-lepton control regions, each defined by the strictness of selections on jet properties, allows us to understand the features of both of the dominant background processes as well as the $X \rightarrow bb$ tagger modeling. By isolating and researching jet properties, we lay the groundwork for a future interaction network-based jet tagger. The ultimate goal of the analysis and tagger algorithm together is to further constrain the strength of the Higgs self-coupling constant, providing insights on how the Higgs mechanism structure gives rise to electroweak spontaneous symmetry breaking and potential phenomena beyond the Standard Model.

Determining Stress Adaptation in Methanogenic Archaea Through Ribosome Biogenesis

Ilsa Weeks
Mentors: Victoria Orphan and Rodney Tollerson II

Archaea are single celled prokaryotic organisms that have the ability to live in extreme environments. The archaea examined throughout this project are known as methanogens. Methanogens are anaerobic organisms that produce methane through the reduction of carbon dioxide and methylated compounds. The information known about archaea and how they adapt to stress is minimal. One way to examine how archaea adapt to stress is to look at the number of ribosomes transcribed. More rRNA operons present directly relates to a greater ability to adapt to environmental stressors. Using quantitative reverse transcription polymerase chain reaction to count the number of times DNA replicates can determine if the operons are transcribed differently. Cultures are grown in a variety of media ranging from rich media to minimal media. By comparing these results with results obtained from bacteria can increase the understanding of how archaea with fewer operons adapt and grow similarly to bacteria which possess higher numbers of operons.

Experimental Tests on the Controls of Flocculation Using Light Sensors
Kayde L. Williams
Mentors: Michael P. Lamb and Kimberly L. L. Miller

Current models for predicting river transport and deposition of mud in deltas lack a mechanistic understanding of the behavior of fine grain sediment. However, recent studies have examined the role of flocculation – the aggregation of clay and organic matter producing larger effective sediment size - in river systems and its effect on mud deposition. These models are calibrated using a limited set of field data. To further investigate the degree of flocculation in freshwater rivers, we perform well-controlled experiments with a flocculation mill to test the effects of shear stress, organic matter content, and the clay to silt ratio on flocculation including floc settling velocities and size distributions. Specifically, in my project, I analyzed data from an array of light sensors within the mill, which measure suspended sediment concentration profiles, to calculate floc settling velocity. Preliminary observations indicate the increased organic matter and clay fraction are related to larger flocs. More analysis is to be completed to determine the functional effect these parameters have on flocculation and ultimately mud deposition.

Modeling the Evolution of Long-lived Binary Neutron Star Merger Remnant
Tuojin Yin
Mentor: Elias R. Most

Important discoveries about binary neutron star (BNS) mergers have been enabled by the combination of the gravitational-wave (GW) and electromagnetic (EM) signals of GW170817, such as insights into properties of nuclear matter at extreme densities. Despite its success, current detectors can only probe the final orbits of the binary; direct information about the final end state, black hole or neutron star, remains current inaccessible. EM observations indicate that the remnant neutron star evolved from differential to uniform rotation before collapsing to black hole. Our project thus focuses on the period after uniform rotation is achieved. We aim to combine numerical relativity (NR) simulations evaluated on the parameters of the binary from GW170817 with our refined analytical toy model to provide a more accurate picture of how the uniformly rotating remnant core increases in mass and angular momentum due to accretion. This may have direct implications for some of the constraints on dense matter derived from this event. We also hope to discover a universal relationship for the angular momentum of the uniformly rotating remnant core so that future investigation into the fate of BNS remnants with new GW data can be performed faster without running computationally expensive NR simulations.

Using Multi-Wavelength Datasets as a Growth Rate Indicator for Supermassive Black Holes
Miranda Zak
Mentors: Fiona Harrison, Peter Boorman, and Murray Brightman

Active galactic nuclei are powered by accretion onto a supermassive black hole. Studying the Eddington ratio, or the ratio of the bolometric luminosity to the Eddington limit, can help us understand accretion and outflow processes as well as the evolution of the AGN and its interaction with the host galaxy. However, the Eddington ratio can be difficult to estimate—both the black hole mass and bolometric luminosity are necessary in calculating the Eddington ratio. Accurate measurements of these quantities are not easy to obtain, particularly for obscured sources, and they often require dedicated follow-up. In order to develop a way of predicting Eddington ratios in cases of incomplete data, we use data from sources with extensive multi-wavelength coverage from the BAT AGN Spectroscopic Survey and the BAT 70-month catalog. We train and test the random forest machine learning algorithm on different combinations of observed and intrinsic X-ray, optical, and infrared parameters for 385 obscured and 345 unobscured sources. We present several methods of predicting the Eddington ratio for a given sample of non-blazar AGN, compare their accuracy and the significance of individual parameters in the predictions, and predict the Eddington ratio for around 900 sources from the BAT 105-month catalog.

Characterizing the Fabrication Parameters of Holographic Lithography for Scalable Production of Architected Materials
Zhangqi (Jackie) Zheng

Mentors: Julia Greer and Kevin Nakahara

Nanoarchitected materials have recently emerged as a highly desirable class of materials capable of exhibiting combinations of properties, for example, ultra-low density, high energy absorption, stimulus responsivity, and enhanced damage tolerance, exceeding the limits of their constituent materials. Using a 3D laser interference lithography (LIL) process with a metasurface mask, we produce nano-architected sheets (35 μm thick and 2.5 × 2.5 cm^2 wide, 500 nm internal feature size) made of negative tone epoxy-based photosensitive resist (SU-8). During the LIL fabrication, a wide variety of defects and morphological variations arise due to chemical, thermal, and optical gradients inherent to photopolymer development. This work shows that by characterizing and decoupling the contributions of all the dosage steps and optimizing their energies relative to the resin formulation, we can reduce the processing time and increase the yield of the LIL process significantly. Using the optimized energy contributions, we also present how active adjustments may be made to the fabrication recipe to mitigate the likelihood that an imperfect dosage at one step will lead to an unwanted defect in the resulting structure. Furthermore, by tuning the resin composition and compensating with corresponding dosage steps, we can expand the range of sample thicknesses to better suit different experimental needs.

Characterization of *Sphingopyxis alaskensis*
Michael Zitser
Mentors: Jared Leadbetter and Lydia Varesio

Oxidation of manganese has been theorized to fuel the growth of chemolithoautotrophic microorganisms. Our lab isolated *Candidatus Manganitrophus noduliformans* (Species A) and *Ramlibacter lithotrophicus* (Species B) and found them to rely on Mn(II) oxidation for growth. Unpublished observations show that *Sphingopyxis alaskensis* can substitute for Species B. This study characterizes *S. alaskensis* and attempts to label it fluorescently for further research on manganese oxidation by Species A. Cell and colony morphology were characterized, and growth kinetics were measured in different media. Furthermore, the recovery of the bacteria from frozen stocks in different cryoprotectants was investigated, indicating a preference for 10% DMSO over 15% and 25% glycerol. While *S. alaskensis* was first isolated from Alaskan salt water, our strain was derived from tap water in Pasadena. We explored salt tolerance and found that our strain grew in salinity concentrations up to 28.13 ppt (highly saline). To establish parameters for building a genetic toolset in *S. alaskensis,* I tested the bacteria's resistance to ampicillin, kanamycin, and chloramphenicol. With these data, I am in the process of constructing fluorescently labeled transformants. This work has assisted in understanding and developi *S. alaskensis* as a model organism to probe into biotic Mn oxidation.

Connectomics Approach Predicts Muscle Activity in *Drosophila* Flight
Deven Ayambem
Mentors: Michael Dickinson and Ivo Ros

During locomotion, the brain transforms sensory and internally generated information into a cohesive set of commands that generate motor output. The architectural logic of connections between networks of neurons in the brain and motor neurons that drive behaviors is an important step in understanding fundamental principles that underlie the actions we humans perform on a day-to-day basis. Using an animal model system such as the fruit fly allows for rigorous study of stereotyped behaviors. For example, when searching their environment, flying flies execute a series of straight flight segments interspersed with rapid turns called flight saccades(Collet and Land, 1975). This work will expand on a Dickinson lab discovery of a sparse network consisting of four descending command neurons that generates these flight saccades. The network consists of two, mirror-symmetric couplets, one for right turns and one for left turns, each containing one excitatory neuron (DNa0X) and one inhibitory (DNb01) that project to the ventral nerve cord. My project maps the downstream connectivity of these descending neurons and predicts how these DNs engage the sparse set of the flies' 12 pairs of steering muscles to saccade. I am developing a principled and robust connectivity analysis to predict functional activation of steering muscles during flight saccades. The overall goal is to develop an analysis framework to characterize the functional organization of premotor circuits that transform descending control commands into concerted movement.

Development of Molecular Qubit Systems for Quantum Information Science
Miriam Aziz
Mentors: Theodor Agapie, Fernando Guerrero, and Matthew Espinosa

Two-level quantum systems (qubits) have emerged on the frontier of quantum information science (QIS) research. Relative to classical components, these qubits offer a substantial increase in information storage capacity and processing speed. Rare-earth metals hold promise as light-matter interfaces, facilitating coherence transfer to nearby nuclei. For example, optically addressable lanthanides with narrow optical linewidths have recently been reported. We aim to adjust the described ligand scaffold by known synthetic methods to investigate the impact of nuclear spin, distance, and chemical environment on coherence transfer. Here, we work toward conducting a synthesis of multimetallic macrocycles of graphene-fixed aromatic hydrocarbons doped with nitrogen. We develop methods to generate a high-solubility mesityl-based ligand by tuning existing phenyl-based syntheses. Additionally, we perform the modular synthesis of alternating oligomers, an essential step in generating a multi-nucleating ligand. Ongoing research to grow these systems involves deliberately and systematically harnessing control over the terminating ends of the compounds. This research sheds light on the interactions within these quantum systems and further advances the field of quantum information science.

Studying Intracellular Trafficking in Autism and Alzheimer's Using *C. elegans*
Ella Brissett
Mentors: Paul Sternberg and Alakanada Das

The intracellular pathways underlying neurodevelopmental disorders such as autism and Alzheimer's remain poorly understood. To gain insights into the intracellular mechanisms associated with these disorders, it is crucial to consider the interactions of protein mutations involved in cellular activities, such as the ubiquitin-proteasome degradation pathway. One mutation of interest in this context is in ufd-3, a protein in *Caenorhabditis elegans* that has been implicated in sensory function. The mating processes of *C. elegans* are a valuable model for studying the impact of the ufd-3 mutation on sensory function, as worms predominantly rely on olfactory and sensory signals during mating. Utilizing behavioral assays and fluorescent imaging analysis, this project aims to understand the implications of the ufd-3 mutation on mating-related behaviors and the protein trafficking and degradation processes. Results indicate impaired sensory function and impaired sperm function during mating in these ufd-3 mutants. These results contribute to our understanding of the protein degradation processes and intracellular mechanisms underlying these neurodevelopmental disorders in humans.

Spin-labeling Biological Membranes to Probe Interfacial Phenomena
John Cao
Mentors: Ryan Hadt and Christian Totoiu

Molecular quantum sensing seeks to leverage the unique phenomenon of quantum coherence to quantify biological properties that are difficult to access through optical methods. Paramagnetic molecules are particularly desirable as probes for this purpose, owing to their addressability by electron paramagnetic resonance (EPR)—a spectroscopic technique used to study unpaired-electron systems and capable of measuring quantum decoherence times. Understanding the behavior of coherence and decoherence in complex biological systems is essential for further developments in quantum information science, especially quantum sensing. Although lipid membranes have been subject to previous EPR studies, there exists an opportunity to investigate quantum coherences in such biologically relevant microenvironments. To address this, we incorporated a chemically-inert nitroxide-based paramagnetic spin label into simple self-assembling micellar structures to track changes in decoherence times in response to systematic chemical perturbations. We observed tunability of morphological properties for sodium dodecyl sulfate

(SDS), Tween 20, and Triton X-100 surfactant micelles using dynamic light scattering (DLS) and cryogenic electron microscopy (cryo-EM), and correlated these properties to quantum decoherence times using EPR. This investigation of the effects of aggregate micellar morphology on decoherence time offers an attractive application of quantum sensing.

The Mechanism of Skd3's Dual Disaggregase and Foldase Activity
Andrew Choe
Mentors: Shu-ou Shan and Wren Stiefel

Protein aggregation is a major challenge in maintaining proteostasis, and cells have evolved AAA+ chaperones that resolubilize aggregates to protect against this proteostatic stress. In humans, Skd3 is a medically relevant, hexameric AAA+ disaggregase that functions in the mitochondrial intermembrane space. Recent work has found that Skd3 also assembles into dodecameric cages that trap disaggregated proteins and promote their proper refolding. In this project, we investigate the substrate trapping mechanism of Skd3's foldase function by engineering a complex formed by the association of Skd3 with the protease ClpP. After designing plasmids and introducing desired mutations, we independently expressed and purified the Skd3 mutant and ClpP. The Skd3 mutant's activity was verified by assessing its ability to refold aggregated luciferase. We then confirmed ClpP function by measuring its digestion of casein in conjunction with an established mutant Hsp104 co-chaperone that we also cloned, expressed, and purified. Having prepared the component proteins, next steps for the project will be verifying Skd3-ClpP association before running protein digestion assays with the complex. Proteolysis fragments from these experiments will be analyzed using mass spectrometry, and the results will illuminate the mechanism and forces driving Skd3's foldase function.

Development of a CRISPR/Cas9 Based Knock-in and Knock-out Genome Editing Tool in a Species of Rove Beetles, *Dalotia coriaria*
Arianna de la Torre Roehl
Mentors: Joseph Parker and Hannah Ryon

The implementation of direct genetic editing tools has greatly advanced the study of gene functions by enabling the targeted mutations in endogenous genes and the introduction of exogenous genes in the genome. The application of this tool in functional genetic studies will allow for a deeper understanding of the ways in which genetics are implicated in the evolutionary mechanisms of rove beetles in the Aleocharinae subfamily, using the free-living beetle *Dalotia coriaria* as our model organism. We aim to use a recently developed CRISPR/Cas9 based technique in insects that uses non-homologous end joining (NHEJ) to introduce transgenes at a specified target location, enabling simultaneous gene knock-ins and knock-outs. We hypothesize that this genome editing tool will yield germline transmissible mutations, facilitating the establishment of the first ever stable transgenic line of rove beetles. With the capability to knock-in exogenous genes, we are able to screen for novel knock-outs, and can knock-in any gene desired going forward, opening up an entirely new area of rove beetle research.

Reverse Engineering AAV to Understand Its Gene Delivery Pathway in the Blood-Brain Barrier and Central Nervous System
Ayoola Fadonougbo
Mentors: Viviana Gradinaru and Tim Miles

Adeno-associated viruses (AAVs) are viral vector tools used for gene transfer. Limited by an incomplete understanding of their underlying mechanisms, the ability to forward-engineer AAVs for targeted gene delivery across the blood-brain barrier (BBB) is constrained. Reverse-engineering AAVs specialized in infecting only the BBB, neurons, or all brain cells (neurons and glial cells) could address this. AAVs selected for reverse-engineering are PHP.eB, PHP.V1, PHP.N, CAP.B10, AAV9, CAP.B1, CAP.B2, CAP.B8, CAP.B18, and CAP.B22.

Genome protection assays (GPAs), differential scanning fluorimetry (DSF), and surface plasmon resonance (SPR) will provide a foundation for exploring AAV mechanisms and drawing comparisons between their biology and documented capabilities. GPAs may inform how the AAV capsid protects and releases its DNA cargo. Analysis of DSF data could establish a relationship between capsid melting point, capsid stability, and how far it can travel through the BBB. SPR will examine a relation between surface binding strength and capsid BBB crossing. These experiments aim to develop an in-depth map of how AAVs non-invasively infect the brain; the map will start with AAV crossing the BBB and end with releasing a gene in the targeted cell.

Photoinduced, Copper-Catalyzed Enantioconvergent C-N Coupling of Nitrogen-Containing Heterocyclic Electrophiles With Nitrogen Nucleophiles
Grace Fleury
Mentors: Gregory Fu and Hyungdo Cho

Nucleophilic substitution reactions with alkyl halide electrophiles, such as S_N2 and S_N1 reactions, are often utilized in organic synthesis but are not without limitations in reactivity and stereoselectivity. Transition-metal catalysis can be employed to address these shortcomings with a variety of electrophiles and nucleophiles. Our work aims to further the progress in enantioselective cross-coupling of unactivated secondary alkyl electrophiles with nitrogen nucleophiles using a photoinduced, copper-catalyst in the reaction of 3-halo pyrrolidine derivatives and nitrogen nucleophiles. Resulting chiral 3-substituted pyrrolidines are frequently occurring motif in bioactive molecules. The reaction is catalyzed by copper-based complexes generated in situ with three ligands: a bisphosphine, a phenoxide, and a chiral diamine. The copper/bisphosphine/phenoxide complex serves as a photocatalyst to be activated with 440 nm blue LEDs for carbon-halogen bond activation. This complex works in conjunction with the copper/chiral diamine/phenoxide complex which catalyzes enantioselective carbon-nitrogen bond formation. Our optimization process of this reaction between pyrrolidine derivative alkyl halides and nitrogen nucleophiles is ongoing with a goal to obtain quantitative yields and greater than 90% enantiomeric excess.

Structural and Biochemical Characterization of *Alvinella pompejana* Nucleoporins
Nika Gladkov
Mentors: Andre Hoelz and George Mobbs

Challenges in expressing and purifying requisite amounts of relevant human proteins have significantly hindered contemporary investigations of post-synaptic biochemistry, limiting our understanding of the fundamental biochemical processes that underlie neural function. In order to overcome these challenges, the Hoelz lab has identified deep-sea worm *Alvinella pompejana* as a promising model organism candidate for sourcing proteins with superior biochemical stability, high amenability for large-scale expression, and significant structural homology to their human counterparts. With the broad goal of validating *A. pompejana* as a novel model organism for the study higher-order biochemical processes, we seek to structurally characterized several protein constituents—termed nucleoporins—of the *A. pompejana* nuclear pore complex (NPC), the structure of which is well-characterized and conserved across a wide range of phyla. We focus our efforts on several nucleoporin constituents of the cytoplasmic filament nucleoporin complex—a key-sub-complex of the NPC which plays several roles in not only nucleocytoplasmic transport but also the structural integrity of the NPC—the solenoid region of nucleoporin 93, the R2 region of nucleoporin 35, and nucleoporin Gle1. We seek to express, purify, and crystallize the nucleoporins in order to verify structural similarity to their human homologues, thus establishing *A. pompejana* as a suitable model organism for the study of neural biochemistry.

Optimizing Small Molecule Mitophagy Modulators
Ian Horsburgh
Mentors: Tsui-Fen Chou and William Rosencrans

Macroautophagy, also referred to simply as autophagy, is a cellular system to degrade organelles or protein aggregates via the lysosome. The PINK1/Parkin pathway, which selectively targets damaged mitochondria for autophagy, is often mutated in neurodegenerative disease such as Parkinson's, causing a buildup of damaged mitochondria in neurons. Certain proteins are also known to be capable of initiating autophagy and activating them could help clear damaged mitochondria and thus improve neuronal health in patients with dysfunctional PINK1/Parkin. In this project, I use both computational and in vitro approaches to optimize small molecule binding efficiently to these proteins capable of inducing autophagy, thus enabling targeted degradation of damaged mitochondria.

Development of Ca-Isotope Spectrometer for Monitoring of Bone Mineral Density In-Flight
Kyla Hudson
Mentors: Mitchio Okumura and Termeh Bashiri

In micro-gravity environments, individuals have experienced rapid bone loss and osteoporosis. Presently, there is no technology that will allow for in-flight monitoring. Furthermore, calcium isotope fractionation has preliminarily been related as a possible biomarker for bone loss. As such, the development of an analysis tool for the determination of calcium isotopes is being pursued. Optogalvanic spectroscopy (OGS) has been identified as having an ultrasensitive detection capability and is being utilized to obtain spectra of calcium isotopes. Further work includes obtaining spectra, analysis of calcium ratios, development of cell for samples, and enhancing spectral clarity.

Progress in the Electrochemical Carboxylation of Aryl Aldehydes
Nuren Lara
Mentors: Karthish Manthiram and Thu Ton

Electrochemical carboxylation has emerged as a promising method for converting CO_2 into value-added organic compounds. The electrochemical carboxylation of organic compounds has several advantages, such as using a non-toxic and abundant carbon source to perform C-C bond formation. Additionally, the electrochemical carboxylation of aldehydes results in the synthesis of alpha hydroxy acids (AHAs), a commercially significant compound. A sacrificial-anode free method for the electrochemical carboxylation of benzaldehyde to mandelic acid was studied. Efforts focused on increasing the faradaic efficiency and yield by attempting to reduce the hydrogenation side reaction. Preparing electrolytes in water-free environments suggest that reducing the water content of salts and solvents increases the faradaic efficiency of the reaction. Future work will focus on the development of a high performance liquid chromatography method for the simultaneous quantification of mandelic acid, benzaldehyde, and other side products in the reaction mixture.

Applying a DNA-Encoded Chemical Library to Screen for Selective Binders of HDAC Isoforms
Jessica Mann
Mentors: Mitchell Guttman and Mackenzie Strehle

DNA-encoded chemical libraries (DECLs) are powerful, high-throughput tools for small molecule screening. Generated by attaching chemical compounds to sequenceable oligonucleotide barcodes, millions of DECL molecules can be screened simultaneously for binding to a protein target. This process is faster and more affordable than other screening platforms, avoiding the need for specialized equipment. In this study, we apply a DECL to screen for selective binders of different HDAC isoforms using a pool-and-split, affinity selection-based screening process. HDACs, or histone deacetylases, are an enzyme family involved in regulating gene expression, implicated in several human diseases including cancer, neurodegenerative diseases, and cardiovascular disorders. HDACs are difficult to drug individually due to the similarities between their active sites, so these results can be used to develop highly specific drugs against each HDAC isoform. Additionally, we compare screening data using two different methods of protein isolation to inform subsequent screening experiments, either via endogenous purification or cloning with a V5 tag. In the future, my group will apply this DECL technology to develop a split-pool screening workflow against proteins and RNAs.

Probing Neural Correlates of Performance-Based Arbitration During Model-Based and Model-Free Control
Sarita Raghunath
Mentors: John P. O'Doherty and Vincent Man

Arbitration between multiple systems is the key to decision making. Previous studies in model-based (goal-driven) and model-free (habitual) reinforcement learning indicate that meta-level control mechanisms assess the reliability of each system to guide decision makers towards the strategy that predicts rewards more accurately. However, recent work from the lab suggests a novel performance-based arbitration mechanism - unlike reliability-based models, performance-based arbitration models weigh the system that yields the highest expected reward (performance). We hypothesize that medial prefrontal (mPFC) regions are involved in performance-based strategy-switching due to their role in top-down control. We also investigate the basal ganglia, particularly the globus pallidus, given its role in strategy switching for reliability-based arbitration. To explore this, we apply this new computational model to fMRI data from participants performing a two-step decision-making task, previously used to indicate model-based/model-free decision-making. By utilizing variables from performance-based arbitration in GLM analysis, we aim to better understand the neural correlates for performance-based arbitration over multiple decision-making systems. In the future, we will use these fMRI analysis results to guide electrophysiology work which will investigate the underlying physiological signal in the globus pallidus and basal ganglia.

Assessment of Electrochemical Sensors Sensitivity for Integration in Chronic Wound Management Device
Alex Seder
Mentor: Wei Gao

Increasing instances of chronic wounds have become a significant concern, particularly in cases of cancers, heart conditions, diabetes, and autoimmune disorders, necessitating specialized care and extended healing periods. In this study, we focus on enhancing wound monitoring through the application of previously established electrochemical sensors within the Gao lab's Smart Bandage device. Our objective is to enable noninvasive tracking of wound physiological conditions, including pH, hydrogen peroxide, oxygen, nitric oxide, and temperature. Testing of pH, hydrogen peroxide, and nitric oxide sensors was conducted following standard protocols, with sensitivity and stability consistently maintained within a range of 5-10% for all tested sensors.

Our findings revealed that hydrogen peroxide stability is compromised outside the pH range of 7 due to the instability of the Prussian Blue. Nitric oxide sensors demonstrated robustness across different pH levels, displaying enhanced sensitivity and voltage at lower pH values, and reduced sensitivity with lower voltage at higher pH values. Through systematic assessment of our sensors under varying pH and temperature conditions, we effectively determined the bandage's capabilities in assessing diverse pH and temperature scenarios. Looking ahead, the integration of electrophysiological therapeutic treatment into the bandage holds promise for stimulating tissue regeneration. Furthermore, the potential utilization of solar cells or magnetoelastic generators for powering such therapeutic measures introduces the possibility of a self-sufficient and comprehensive monitoring system tailored for chronic wounds.

Elucidating the Cranial Neural Crest Gene Regulatory Network in Craniofacial Development
Taylor L. Simonian
Mentors: Marianne Bronner and Sierra Marable

Neural crest cells are multipotent progenitor cells unique to vertebrates that play a crucial role in embryonic development. A complex gene regulatory network coordinates their specification, migration, and differentiation, imbuing neural crest cells with distinct cellular identity and differentiation potential. In amniotes, the cranial neural crest is the only subpopulation that has the ability to develop into craniofacial cartilage and bone. In this project, we have been investigating the gene regulatory network regulating cranial neural crest differentiation into cartilage of the developing mandible. We are characterizing chondrogenesis in the first branchial arch of chick embryos using hybridization chain reaction and immunofluorescence staining to examine markers of cartilage condensation. In addition, we are investigating the expression pattern and function of the transcription factors like Barx1 and Sox5 in the cranial neural crest using CRISPR-Cas9 technology to perturb these genes. These studies will provide insight into the neural crest gene regulatory network that controls craniofacial development.

Understanding the Roles of Intrinsically Disordered Regions in Chimeric Oncogenic Transcription Factor Pax3-FoxO1

Anish Somani
Mentors: Shasha Chong and Barun Maity

Intrinsically disordered regions (IDRs) of proteins can experience weak, multivalent interactions with other disordered regions, driving formation of locally enriched hubs. Transcription factors (TFs) often contain such IDRs for the recruitment of coactivators and transcriptional machinery. Human alveolar rhabdomyosarcoma is driven by the oncogenic Pax3-FoxO1 fusion protein, which consists of the Pax3 DNA-binding domain fused to the strongly activating FoxO1 IDR. In this project, we utilize live cell fluorescence imaging of full length IDRs as well as truncated variants, to identify whether FoxO1 IDRs promoted the formation of transcriptional hubs and any dominant interactions driving hub formation. We also employ luciferase assays to study the functional relevance of such interactions on transcription. We demonstrate that Foxo1 IDR, but not Pax3 IDR, was able to form local hubs of enrichment, underscoring the relevance of such interactions. From various truncation mutations, we identify that blocks of positive and negative charge were major drivers behind IDR colocalization. By characterizing dynamic features driving colocalization of IDRs relevant to cancer, we hope to open novel therapeutic avenues towards the treatment of alveolar rhabdomyosarcoma.

Structural Characterization of Human Nuclear Pore Membrane Protein GP210

Philip Spyrou
Mentors: Andre Hoelz and Sema Edjer

The human nuclear pore is an anchored macromolecular assembly forming the only bidirectional gateway regulating the exchange of macromolecules across the nuclear membranes. One of the 34 unique proteins which assemble the nuclear pore, GP210 is an integral membrane protein composed of a singular helical transmembrane domain and 17 repeated domains of an Ig like fold. GP210 is one component of the inner ring of the nuclear pore complex, and is theoretically responsible for anchoring the nuclear pore, providing flexibility, and stabilizing the nuclear envelope curvature. Due to its high flexibility, GP210 was subdivided into individual Ig-like domains. Seventeen Ig-like domain have been identified, which were each individually tested for expression and solubility. Soluble Ig-like domains were tagged with a histidine-SUMO tag for Nickel affinity purification by and then ion exchange chromatography based on the pI of the purified domain. Finally, a size exclusion chromatography allowed researchers to obtain highly pure protein sample suited for crystallization. Commercially available crystallization screens were used to increase the probability to obtain protein crystals. Crystals for Ig17 have been obtained and been optimized. Due to poor yields of other soluble Ig domains, new expression constructs are being generated to create longer chains of Ig domains with potentially better expression and solubility. Structural characterization at high resolution of these Ig domains will allow researchers to understand the flexibility of GP210 which acts like a belt allowing the NPC to open and close for nucleocytoplasmic transport.

Developing Optogenetic Control Over Gene Expression in *Pseudomonas aeruginosa* Biofilms to Understand the Role of the Extracellular Matrix in Biofilm Formation

Alika Ting
Mentors: Dianne Newman and Georgia Squyres

Pseudomonas aeruginosa is an opportunistic human pathogen contributing to persistent chronic infections by forming biofilms, aggregates of cells joined by a matrix of extracellular DNA and polysaccharides. The polysaccharide Pel plays a role in the structure of the biofilm, and we hope to understand how biofilms respond to perturbation of Pel spatial regulation. We use the optogenetic circuit pDawn to turn on expression of a gene of interest in *P. aeruginosa* using blue light. To characterize pDawn, we created a strain with optogenetic control over the gene mApple, exposed cells to blue light for varying amounts of time, and measured red fluorescence. We found that maximum optogenetic activation requires 9 hours of blue light exposure. We then patterned gene expression via red fluorescence on *E. coli* bacterial lawns using a projector to shine images in blue light, confirming that the pDawn optogenetic system can be used to spatially control gene expression. For the remainder of our project, we are cloning pDawn to the Pel biosynthetic operon, pelA-G, such that blue light will increase Pel production in *P. aeruginosa*. This will allow us to observe how the biofilm responds to changes in the spatial patterning of Pel production.

Split TurboID-based Proximity Labeling for Identification of Proteins at Mitochondria-Lysosomal Contact Sites
Natalie Tsubamoto
Mentors: David Chan and Zheng Yang

The mitochondria and lysosome are key organelles in the regulation of energy-production, autophagy, proliferation, and programmed cell death. Dysfunction in either has been closely linked with multiple neurodegenerative and metabolic disorders, including Charcot-Marie-Tooth Type 2, Parkinson's disease, and Gaucher's disease, among others. Due to their closely overlapping roles, it is unsurprising that the mitochondria and lysosome regulate each other in many of these key functions. Communication between these organelles was long believed to be indirect, however recent studies have observed the formation of mitochondrial-lysosome contact sites in healthy, untreated cells, mediated by the tethering protein RAB7 GTPase. Additional proteins are believed to be recruited to these contact sites for the exchange of metabolites critical for normal function in both organelles. Here, we report on the utilization of a Split TurboID-based proximity labeling system to isolate and identify these recruited proteins and further investigation of their role in cellular metabolism, as well as their pathological significance.

Deciphering Reanimation From General Anesthesia Using *Drosophila*
Heaven R. Varner
Mentors: Elizabeth Hong and Pratyush Kandimalla

Despite the centrality of anesthesia to modern medicine, methods that reliably promote reversal of the anesthetized state are lacking. Return to consciousness from anesthesia, termed reanimation, is an entirely passive process dictated by the pharmacokinetics of the agent in the bloodstream. The vinegar fly Drosophila melanogaster is a highly tractable experimental model that enables genetic dissection of neural circuit function in the brain. In Drosophila confined to a two-dimensional behavioral arena, exposure to general inhalation anesthetics such as sevoflurane, at concentrations similar to those used in humans, induces cessation of spontaneous- and stimulus-triggered walking. Preliminary work identified a population of dopaminergic neurons (DANs) whose optogenetic activation induced coordinated walking in the presence of anesthetizing levels of sevofluorane, suggesting that stimulating DAN activity may promote emergence from anesthesia in flies. To determine if DAN activation triggers true functional reanimation of the Drosophila brain, as opposed to simply eliciting motor commands, we adapted an optomotor behavioral task (the "stampede" assay) to determine if behaviors that require complex sensorimotor processing behaviors are intact in reanimated flies. This work also establishes a promising new experimental platform for a broader investigation of the neural mechanisms that could mediate reanimation from anesthesia, with the potential for advancing our understanding of the basic neural mechanisms that underlie the anesthetized state.

Investigating the Roles of the Ventromedial Hypothalamus and the Medial Preoptic Area in Aggressive and Sexual Behaviors
Madison Yee
Mentors: David J. Anderson and Jineun Kim

The ventrolateral subdivision of the ventromedial hypothalamus (VMHvl) and the medial preoptic area (MPOA) have been implicated in controlling mice's feeding, mating, and aggression. Glucose levels can affect these neurons' activity during combative interactions by influencing the mice's internal states. While current research at the David J. Anderson Lab investigates the roles of VMHvl and MPOA neurons in mediating aggression and sexual behaviors, little is known about how physiological homeostatic states, such as glycemia, influence their activity and thus the internal states that govern mice's social interactions. To analyze the relationship between behavioral changes and glycemia, we devised behavioral paradigms and employed machine-learning-based behavior analysis platforms including the Mouse Action Recognition System (MARS), the Behavior Ensemble and Neural Trajectory Observatory (BENTO), and Social LEAP Estimates Animal Poses (SLEAP) that track the mice's poses and movements. Preliminary analysis of the SLEAP model for single animal tracking indicates strong accuracy, as the 50th, 90th, and 95th percentiles of the difference between the model's prediction and the animal's true location were 5.085, 18.259, and 32.442 pixels respectively. We also used targeted recombination of active populations with cFos induction, in-vivo fiber photometry, and single-cell calcium imaging to monitor and analyze neural activity during mating and aggression across fasting-induced hypoglycemia and euglycemic levels. Future work will use the aforementioned tools to evaluate differences in mice's behaviors based on their internal states and develop a quantifiable, reproducible correlation between mice's glucose and aggression levels.

Modeling Binary Neutron Star Collisions With SpECTRE
Carter Anderson
Mentors: Isaac Legred and Katerina Chatziioannou

Neutron stars are some of the most extreme and relativistic objects in the known universe, with densities well beyond those of typical atomic nuclei. The multi-messenger detection of GW170817, the first measured binary Neutron Star merger gravitational wave event has given new opportunities to investigate these stars and the physics that govern them. However, at the moment, the post-merger signal carrying the greatest impact of the star's nuclear matter hasn't been detected with current gravitational wave detector sensitivities leaving numerical relativity simulations as the only form of investigation. Consequently, we aim to improve this avenue with SpECTRE, the simulation software developed by the collaborative Simulating eXtreme Spacetimes group (SXS), working toward more physical simulations to better understand Neutron Star's, their gravitational wave emission events, and extreme density nuclear physics.

Sensor Fusion for Improved Length Sensing and Control of the LIGO 40m Prototype
Deven Bowman
Mentors: Yehonathan Drori, Shruti Jose Maliakal, and Rana Adhikari

The length sensing and control (LSC) system of a gravitational wave interferometer is key to maintaining control of the detector and generating a linear response to the gravitational wave signal. In the LIGO 40m prototype and at the Advanced LIGO detectors, the controlled length degrees of freedom are outnumbered by the RF photodiode sensors sensitive to their motion. This generates an overdetermined system where virtual sensors, calculated from combinations of sensors, can be designed to reduce the noises contributed by the LSC system. This project studied sensor fusion techniques for the power recycling Michelson interferometer (PRMI) configuration of the LIGO 40m prototype interferometer. Measurements were made of transfer functions and closed loop noises of the 40m LSC system during a PRMI lock. These were used to evaluate several methods for sensor fusion with the eventual goal of implementing one of them at the 40m interferometer.

Using Multimessenger Synthesis to Constrain Core-collapse Supernova Distance and Orientation
Siddharth Boyeneni
Mentors: Michael Pajkos and Mark Scheel

Gravitational wave (GW) emission from the next nearby core-collapse supernova (CCSN) will be an important multimessenger, containing intrinsic properties of the CCSN and its progenitor star. Prior work has related expressions for the earlier GW "core-bounce" signal and later dominant frequency mode from the protoneutron star (PNS) to CCSN parameters like the rotation and density profile. Other work has shown similar relationships, including CCSN neutrino luminosities and mean energies. We run a set of 2D neutrino radiation-hydrodynamic CCSN simulations, via FLASH, to more precisely quantify relationships between neutrinos, GW observables, and CCSN properties: angular momentum and compactness. Likewise, we propose a new multimessenger-based method to break the existing degeneracy between CCSN distance and orientation, providing a constraint on both parameters in the event of a CCSN GW detection.

Inferring the Population of Merging Binary Black Holes with Astrophysically Motivated Models
April Q. Cheng
Mentors: Jacob Golomb and Alan Weinstein

Gravitational waves contain information about the properties of the binary black holes (BBHs) that produce them, such as their masses and spins. With 69 BBHs in the third Gravitational Wave Transient Catalogue (GWTC-3), it becomes possible to deduce bulk population properties of merging BBHs and hence probe their formation origins. Recent theoretical work has suggested that in certain field formation scenarios, it is possible for one of the black holes to attain spin via tidal spin-up, and that this spin should be correlated with its mass. Motivated by this finding, we fit a correlated model of masses and spins to GWTC-3 data using hierarchical inference. We find that the width of the distribution of the spin magnitude of the higher spinning black hole increases with its mass. We confirm the validity of our results with a simplified injection study.

Measuring Birefringence and its Fluctuations in Crystalline Silicon
Kushal Jain
Mentors: Yuta Michimura and Rana Adhikari

Gravitational wave detectors, like LIGO, require high-quality test mass mirrors to accurately measure the minute changes caused by gravitational waves. While fused silica has been the preferred material for test masses, the upcoming cryogenic upgrades of gravitational wave detectors require materials with exceptional properties at low temperatures and compatibility with 1550-nm laser. Crystalline silicon has emerged as a potential alternative to fused silica due to its mechanical, optical, and thermal characteristics. However, birefringence in silicon can negatively impact detector performance by reducing the signal-to-noise ratio. This project aims to investigate birefringence in crystalline silicon through laser depolarization techniques.

The experimental setup involves a 1550 nm laser, polarizers, a half-wave plate, and photodiodes. Lock-in amplifiers and low-pass filters are employed to enhance sensitivity and reduce noise in the measurement system. The project aims to achieve measurements of birefringence fluctuations at the order of 10^{-15}/rtHz at 100 Hz. The results will provide valuable insights into the suitability of crystalline silicon for future gravitational wave detectors and contribute to our understanding of material properties at extreme conditions.

Identifying Correlations in Precessing Gravitational-Wave Signals With Machine Learning
Karen Kang
Mentors: Simona Miller, Katerina Chatziioannou, and Deborah Ferguson

Binary binary hole (BBH) spins provide unique and important insights into the formation environments, evolutionary history, and dynamics of these objects. We would like to gain a better understanding of merger-dominated signals for highly massive highly spinning BBH systems, which are prone to spurious measurements due to their very short duration and low bandwidth. Astrophysical parameters from gravitational wave (GW) sources are extracted by match-filtering signals with numerical relativity (NR) waveforms templates. The degeneracies in waveforms, where dissimilar parameters yield similar waveforms, further complicates source identification. Using machine learning, we can visualize these degeneracies in the 14-dimensional BBH parameter space and develop models to quantify parameter correlations. We also propose enhancing existing mismatch-prediction neural networks with higher order modes and precession effects, thereby refining our ability to model these degeneracies. The results produced by this network will inform us about the measurability of spin parameters from inferred waveform signals of highly massive, precessing BBHs.

Glitch Reweighting by Glitch Parameter Simulation
Julien Kearns
Mentor: Sophie Hourihane and Katerina Chatziioannou

Gravitational waves are ripples in space-time caused by the acceleration of high mass objects. They were first observed by LIGO (Laser Interferometer Gravitational-wave Observatory) in 2015. LIGO utilizes highly precise instrumentation to detect the differences in length of its perpendicular, 4 kilometer "arms" when a gravitational wave passes through. LIGO is able to detect the inspiral and merger of orbiting black holes and neutron stars. The resulting waveform is dependent on the parameters of the system. After accounting for the noise in the detectors, the waveform can be matched to a model and the parameters can be estimated.

Transient noise artifacts in LIGO data are called glitches. These glitches differ from typical detector noise in that they are non-Gaussian. Glitches vary in sources, frequency, time, duration and strength. They can interfere with how we account for noise before parameter estimation and lead to biased parameters. BayesWave is a Bayesian algorithm that can produce a posterior distribution accounting for various glitch models, but it cannot construct a CBC (compact binary coalescence) waveform model that includes precession. Our objective is to reweight a set of posterior samples from a BayesWave CBC+Glitch run and obtain a posterior distribution with both the glitch model and a fully precessing waveform.

Frequency Stabilization of 2 Micron Lasers Using Optical Delay Self-Heterodyne Interferometry
Stella Kraus
Mentors: Aidan Brooks and Rana Adhikari

In the current LIGO design, 1064 nm light propagates through a Michelson interferometer and reflects off test masses. In order to accurately measure minuscule changes in the lengths of LIGO's arms, it is crucial to reduce various types of noise in the system, such as frequency noise. The next generation of LIGO detectors will likely switch from fused silica mirrors to crystalline silicon and will use a wavelength of about 2 microns in the interferometer; mirrors made of crystalline silicon have demonstrated lower levels of mechanical loss than fused silica mirrors and have low absorption of 2-micron light. Access to low-cost sources of stable 2-micron light is crucial for researchers to develop the next generation of LIGO detectors. This work will address the stabilization of a 2050 nm laser, and will focus on reducing the frequency noise of the laser with a self-delayed heterodyne interferometry technique. This low-cost method has the potential to facilitate further testing and development of 2-micron light for gravitational-wave detection.

Linking the Population of Binary Black Holes with the Stochastic Gravitational-Wave Background
Olivia Laske
Mentors: Patrick Meyers and Arianna Renzini

The astrophysical stochastic gravitational-wave background (SGWB) is the product of overlapping waveforms that create a single unresolvable background. While current LIGO sensitivity is insufficient to uncover the SGWB, future space-based detectors and Third Generation (3G) experiments are expected to probe deep enough for detection. In addition, predictions of the SGWB can still constrain future searches as well as provide insight into star formation, merger history, and mass distribution. Here, two different methods are used to calculate a theoretical SGWB. The first method employs Monte Carlo integration with simulated data, while the second method predefines a grid of mass distributions. After standardizing a prior dictionary across both methods, the output energy density spectra is analyzed with regard to parameters such as binary black hole mass and merger rate. Increasing the maximum merger mass shifts the gravitational-wave (GW) energy density peak to lower frequencies, while increasing the local merger rate proportionally affects the GW energy density.

Inferring Gravitational Wave Source Properties from Intermediate Pipeline Output with Machine Learning
Julianna Levanti
Mentor: Ryan Magee

The LIGO-Virgo-KAGRA collaboration provides low-latency (near-real time) localization using the signal-to-noise ratio measured for a single point in the search parameter space. Parameter estimation pipelines subsequently samples the full parameter space to obtain more accurate estimates of the localization. However, this process is computationally expensive. The multi-messenger detection of the binary neutron star merger GW170817 confirmed the need for accurate and fast data products. Some detection pipelines utilize singular value decomposition to reduce the filtering cost. This project uses machine learning to input signal-to-noise ratios from singular value decomposition time-series into simulation-based inference (SBI), a likelihood-free inference algorithm, which outputs a posterior with an accurate parameter estimation, such as a sky map, to localize compact binary coalescences and infer other source properties.

Leveraging the Stability of the Photon Calibrator X/Y comparison to Reduce System Uncertainty
Julianna Lewis
Mentors: Michael Landry and Richard Savage

All second-generation gravitational wave detectors use laser radiation pressure to calibrate the detector output signals. A significant source of uncertainty for these Photon Calibrator (Pcal) systems, one usually installed at each interferometer end station, is unintended rotation of the suspended mirrors. Comparing the two Pcal system calibrations enables reducing calibration uncertainty. At the LIGO Hanford Observatory (LHO), this X/Y comparison has been calculated continuously since May 2023 and has been stable within 0.05 %. This stability can be leveraged to quantify interferometer and Pcal beam position offsets. Reducing Pcal beam position errors minimizes unintended rotation. Moving the position of one Pcal beam by 2.5 mm at the LHO X-end station is expected to the change the X/Y comparison by as much as 0.0054, more than ten times the observed X/Y comparison variations. A second measurement with the Pcal beam displaced orthogonally can be used to quantify both the magnitude and direction of the interferometer beam position offset. Making similar measurements after known displacements of the interferometer beam can be used to quantify center of force offsets for the Pcal beams. This method would provide a means for minimizing one of the largest sources of uncertainty for the Photon Calibrator systems.

Taking It to the Next Level: Searching for Gravitational Waves With Eccentricity From Compact Binary Coalescences
Elwin K. Y. Li
Mentor: Alan J. Weinstein

Gravitational waves (GWs)[1, 2] are fundamental predictions of the General Theory of Relativity (GR). GWs detections have introduced a novel window into the universe and are revolutionizing our understanding of astrophysics. The motion of two massive objects in an eccentric orbit emits GWs which carry information about the eccentricity of the binary black hole (BBH) source. These waveforms are characterized by their eccentricity, which measures the deviation of the orbit from a quasi-circular orbit. Studying eccentric binary orbits provides evidence for the dynamic formation of the binary system. In this project, we study a new family of GWs waveforms from eccentric binaries and their implications for detecting and analyzing eccentric compact binary systems near mergers. I will develop eccentric waveform models and parameter estimation frameworksfor eccentric BBH and use these tools to analyze the data from current and upcoming GWs observations. Sinceeccentric waveforms are predicted to have similar waveforms with GWs from BBH systems with precessing,I will try to distinguish eccentric waveforms and precessing waveforms by investigating their differences. We will determine the minimum eccentricity that could be detectable with GWs as a function of SNR and other parameters.

Understanding Combined Results From Multiple GW Searches Using Information Theory
Oleksandra Lukina
Mentor: Derek Davis

Determining whether a gravitational wave (GW) signal is of astrophysical origin or is caused by terrestrial noise still presents a challenge to the GW community. Current searches estimate the significance of events by calculating the false alarm rate (FAR) and p_astro, but these results are limited to a single search pipeline. In this work, we suggest a method of combining GW information by calculating harmonic mean FARs for different groups of searches and using them as the basis for calculating a joint p_astro. Using this approach, we compare the effectiveness of different combinations of GW searches, revisit the significance of previously detected events, and investigate the correlations between pipelines using the language of information theory.

Testing Specific Theories Beyond General Relativity With LIGO
Natalie Malagon
Mentor: Ethan Payne

Gravitational waves observed by LIGO have allowed us to test general relativity in the strong-field regime with populations of binary merger events. Observations thus far are consistent with general relativity at both the individual and population level. Current tests of general relativity utilize a single deviation parameter rather than generic deviation parameters, which makes it difficult to map this information to specific theories and robustly test them over ensembles of events. We apply Bayesian inference to the inspiral phase of gravitational-wave signals in binary black hole merger events, to obtain posterior distributions for the 15 source parameters and 10 post-Newtonian deviation parameters. This parameter estimation involves the hybrid sampling method which uses nested sampling to seed parallel-tempered Markov Chain Monte Carlo (MCMC) ensembles and allows us to explore degenerate parameter spaces. We apply a Principal Component Analysis (PCA) to reduce the dimensionality of the parameter space, to understand the underlying correlations between the deviation parameters. Hierarchical inference could then be applied to ensembles of events to test specific theories beyond general relativity, such as the dynamical Chern Simons (dCS) and Einstein-dilaton Gauss-Bonnet (EdGB) theories. This would result in constraining the bounds on the coupling coefficients that characterize these specific theories.

Improving Frequency Stabilization for the Auxiliary Laser at the LIGO 40m Prototype
Reuben Mathew
Mentors: Radhika Bhatt and Rana Adhikari

The LIGO interferometers need to robustly lock its various degrees of freedom to be sensitive to Gravitational Waves. The LIGO 40m prototype uses an auxiliary (AUX) laser as a reference to lock the main laser to the arm cavity and stabilize it. The AUX laser is stabilized by locking it to the arm cavity using the Pound-Drever-Hall (PDH) technique. The stability of the AUX laser is crucial for the stability of the main laser. Mechanical resonances of the AUX laser's piezoelectric (PZT) actuator and the rigid nature of the currently implemented analogue PDH controller limits the performance of the system, hindering noise suppression especially at low frequencies. This project aims to develop a digital controller to replace the currently implemented AUX laser locking system. A digital controller will be more robust and easily customizable. Specifically, the features to be implemented include better controller performance in the 10Hz-20kHz range, where the AUX laser noise has greater contribution, supplying an increase in bandwidth over the current analogue system, enable fast lock reacquisition when lock is broken and adding resonant gain filters at specific resonant bands to facilitate calibration of the interferometer.

Bayesian Inference for Fast Scattering Glitches
Aislinn McCann
Mentors: Rhiannon Udall and Derek Davis

Data collected by gravitational wave (GW) interferometers such as the Laser Interferometer Gravitational-wave Observatory (LIGO) is permeated by noise as a result of various sources of environmental interference. Parameter estimation pipelines such as Bilby used to analyse LIGO data assume that the noise in GW data is Gaussian and stationary: an assumption contradicted by the nature of non-Gaussian transient noise “glitches” prevalent within the data. We have constructed a mathematical model that emulates the waveform of fast scattering glitches, which we implemented into Bilby to perform tests of the model’s robustness in glitch mitigation efforts. The incorporation of this model will facilitate the efficient subtraction of real fast scattering glitch instances from GW strain data, allowing for improved analysis for future observing runs.

Analyzing LIGO Ring Heaters: Investigating Electrical Shorting, Troubleshooting Mechanical Failures, and Modeling Future Designs
Rachel McQueen
Mentors: Camilla Compton and Michael Landry

LIGO interferometers use frequency and amplitude-stabilized lasers that are reflected using test masses (large, cylindrical mirrors) to detect gravitational waves. Because the laser light is stored in optical cavities within the interferometer, the test masses heat up. This physically deforms the surface of the mirror. Physical deformation causes the test masses to not reflect the laser optimally and the interferometer will not function at its highest sensitivity. Ring heaters are coils that heat the outside of a test mass through resistance to counteract this effect and allow us to control the deformation of the test mass surface. Our objective is to modify the current ring heater design and develop improvements to be implemented in future ring heaters. We accomplish this by troubleshooting issues in the current design, comparing designs between versions, and modeling different designs in COMSOL. We have built spare ring heaters, identified causes of grounding issues and weaknesses in the current design, successfully modeled how differently-sized heating elements heat the test mass, and compared their effectiveness to the current design. With these results, we are now able to avoid grounding problems observed at other LIGO locations, as well as improve the ring heater design for future use.

Implementing Nonlinear Control in a Classical Experiment to Reduce Measurement Noise
Advait Mehla
Mentor: Rana Adhikari

A central problem in control theory is that most of the field focuses on linear controllers, even though most of the systems we are aiming to control are nonlinear in nature. To circumvent this issue, control theory aims to approximate the behavior of the nonlinear system around the desired mode of operation by a linear function. This unfortunately creates a theoretical limit on the performance specification of the linear as it tries to control a nonlinear system with a linear control law. We aim to show that this limitation can be overcome with a nonlinear controller based on Reinforcement Learning (RL) methods. As a proof of our concept, we aim to implement the RL-based controller in a purely classical experiment: temperature stabilization of a test mass. Moreover, we explore the possible implications of such a nonlinear controller in the field of quantum mechanics and non-classical experiments, where nonlinearities can be encountered even in the vicinity of the desired setpoint/mode of action of the system, exacerbating the need for a controller that can manage such nonlinearities.

Enabling the Discovery of Kilonovae Associated with Neutron Star Mergers with Electromagnetic Follow-up
Marianna Pezzella
Mentors: Toḿas Ahumada and Shreya Anand

The Laser Interferometer Gravitational-Wave Observatory (LIGO) is designed to detect gravitational waves (GWs) produced by events such as merging neutron stars or black holes. The first detection of GWs and electromagnetic radiation (EMR) from a binary neutron star (BNS) merger occurred on August 17, 2017, with the discovery of GW170817. The merger was followed by a kilonova (KN), responsible for the synthesis of heavy elements, beyond iron, in the universe. During LIGO's fourth observing run, O4, ZTF produces candidates for which photometric and spectroscopic data analysis are performed. This candidate vetting aims to uncover the KN counterpart associated with a particular GW event. The DRAGONS pipeline will be used to re-analyze the spectrum of GW170817 that was taken with Gemini Multi-Object Spectrograph (GMOS). We adapt the DRAGONS pipeline to include black-body curve fitting and spectroscopic line identification for potential candidates detected in O4 and future observing runs. This automated pipeline will help reduce the data and determine the composition and temperature of KNe. By updating this pipeline, the candidate KNe sample will be analyzed more quickly and efficiently during transient searches for EM counterparts by eliminating any contaminants, such as Supernovae (SNe), active galactic nuclei (AGNs), or cataclysmic variables. This method will enable the detection of early KN emission, which is crucial for studying the synthesis of heavy elements and understanding the physics of BNS mergers. This data reduction pipeline for photometry and spectroscopy of KNe during O4 will be used to aid in the real-time study of heavy element nucleosynthesis.

Estimation of the Stochastic Gravitational Wave Background from Binary Mergers
Pritvik Sinhadc
Mentors: Alan Weinstein, Patrick Meyers, and Arianna Renzini

The ground-based International Gravitational-Wave Observatory Network (IGWN), including the Laser Interferometer Gravitational-Wave Observatory (LIGO) stations at Hanford and Livingston, Virgo and KAGRA, has detected gravitational waves (GWs) from Compact Binary Coalescence (CBC) sources in distant galaxies as far away as 8 Gigaparsecs, which corresponds to a redshift of slightly greater than 1. More distant sources are too faint to be confidently detected as individual events. However, they are expected to be so numerous that they can be detectable as a Stochastic Gravitational Wave Background (SGWB). While stringent upper limits on the strength of the SGWB as a function of frequency in units of the cosmological closure density of the universe, $\Omega_{GW}(f)$, have been made through the IGWN, there has been no observed detection of the SGWB as such. However, while this was overturned as per the June 28, 2023, announcement on the preliminary — not completely confirmed — detection of an SGWB from supermassive black hole mergers, the overall astrophysical background from all CBC sources is still to be detected. Early implications for the SGWB from the first observation of Binary Black Hole (BBH) mergers and more recent models from advanced LIGO and VIRGO data have all provided estimates of the CBC merger rate that suggest that we are close to detection of the SGWB. The estimates from the 'Regimbau method' come from simple simulations of many individual events, while the 'Callister method' is based on numerical evaluation on an analytical expression for the SGWB. We reproduce these estimates through a thorough analysis of the methods used by Regimbau and Callister and study the degree to which they agree with each other, as well as look at the extent to which the results depend on uncertainties in the merger rate as a function of mass and redshift distributions of the sources. Overall, we investigate the predictions on SGWB parameters and constrain its limits, thereby decoding how the background changes due to uncertainties in several important variables. This incorporation of the latest theoretical models, with a key understanding of the limits and constraints in these frameworks, will aid in the long-term goal of refining estimates on the SGWB, thereby detailing future goals in the study of astrophysical GW backgrounds, challenges, and expected outcomes.

Demonstration of Bayesian Transfer Function Fitting Method - A Potential Tool for Estimating Interferometer Uncertainty

Caden Swain
Mentor: Louis Dartez

The Response Function of the LIGO Interferometer is central to reconstructing the strain produced by incoming gravitational waves. A function of the interferometer's response to external stimuli, the Response Function is both analytically modeled and experimentally measured using excitations from the photon calibrator system at discrete frequencies. The uncertainty in each data point is propagated to the residual of the model and measurements, with both the uncertainty and residual being interpolated over a broadband frequency range. While valid, interpolation methods lack the accuracy to estimate measurement uncertainty at non-measured frequencies that fitting an analytical transfer function could provide. This project analyzes the results of fitting a series of transfer functions to the Response Function using Bayesian statistics as opposed to traditional transfer-function-fitting methods. We use data gathered from the OMC DCPD S2300004 whitening chassis at discrete frequency points, varying the signal-to-noise ratio as a proxy for varying the uncertainty in the measurements, and compare the results of each method.

Developing Methods to Characterize Frequency-Varying Combs in LIGO Strain Data

Joseph Talucci
Mentor: Ansel Neunzert

Narrow spectral artifacts in strain spectra pose a unique challenge to searches for continuous waves. They appear as small vertical lines, obscuring potential detections. Combs are patterns of equally-spaced narrow lines representing the harmonics of a fundamental frequency. Characterizing combs and identifying their individual causes is challenging and is made more difficult by the fact that some of them change in fundamental frequency over time. We call these roaming combs, as their narrow spectral artifacts appear to roam around spectra. The Fscan spectral monitor used for continuous-wave detector characterization can automatically identify combs present on a particular day, but lacks a method to analyze how combs have changed in frequency over time. Our objective for this project was to develop a method to analyze frequency-roaming combs. We produced a script which automatically detects when combs have changed in frequency since their last appearance and can also be used to examine known combs which are not detected by Fscans. We also present results on known, high-priority combs contaminating Hanford data.

Simple Photometric Models to Understand the Real Reflectivity of Planetary Surfaces
Anna Apilado, Wellesley College and Jet Propulsion Laboratory
Mentor: Bonnie Buratti, Jet Propulsion Laboratory, California Institute of Technology

Albedo, or reflectivity, can indicate important geological processes from spacecraft observations. Variations in albedo, as recorded on spacecraft images, rely on photometric methods due to their changing geometry in order to correctly understand the changes in their surface's reflectivity. Most of the change in an image of a planetary surface's intensity is not intrinsic, but due to changes in the solar phase angle (ɑ) and the radiance incident and emission angles. Photometric models for low-albedo objects are non-trivial and well-determined because of their similar abledo with the moon. Low-albedo objects are able to utilize a simple lunar-like photometric function to predict their specific intensity. Conversely, building photometric models for high-albedo objects pose a challenge due to their multiple scattering. A phase function f(ɑ), consisting of a fourth order polynomial and an exponential factor, which better accounts for the opposition surge, is tested out to verify if it can reproduce the specific intensity of observations. The model was applied to dark objects such as C-type asteroids, then applied to high albedo objects such as icy moons.

Effect of Lensing Magnification on Galaxy Clustering Using the Spherical Fourier-Bessel Basis
Sujay Champati, California Institute of Technology
Mentors: Henry Gebhardt and Olivier Doré, Jet Propulsion Laboratory/California Institute of Technology

This project aims to determine how gravitational lensing affects the galaxy-galaxy power spectrum to inform future galaxy surveys such as the SPHEREx mission and provide insight into the early expansion history of the universe. As opposed to other calculations of lensing magnification, this project uses the spherical Fourier-Bessel basis instead of the Fourier basis because the SFB basis separates the angular and radial systematics for a fixed observer and allows easier characterization of lensing. We first calculate how the path of light from a galaxy source is bent by the curvature of spacetime due to a gravitational potential. We use this to calculate the matter density contrast in the spherical Fourier-Bessel basis. Finally, we put this calculation into code using the Julia language and calculate the SFB power spectrum. We will use this to estimate the lensing effect on the power spectrum for SPHEREx.

Applied Science Support for the Earth Surface Mineral Dust Source Investigation (EMIT)
Ardra Charath, California Institute of Technology
Mentors: Dana Chadwick, Kelly Luis, and Regina Eckert, Jet Propulsion Laboratory, California Institute of Technology

The Earth Surface Mineral Dust Investigation (EMIT) mission's focus is to analyze visible to shortwave infrared (VSWIR) imaging spectroscopy data from the International Space Station (ISS) to identify the mineral composition of Earth's dust source regions. EMIT's goal is to better understand radiative forcing – the heating and cooling of the Earth's atmosphere from mineral dust – by studying the mineral composition of Earth's dust source regions. Another goal for EMIT is to explore how to use the data set in areas outside of the scope of EMIT's original mission. The project's focus is using EMIT's data set to conduct unsupervised forest/vegetation classification in the Jack and Laura Dangermond Preserve in Santa Barbara County, California. Using methods such as k-means clustering, principal component analysis (PCA), and endmember extraction, the vegetation in the area will be analyzed and put into groups based on reflectance wavelengths. Comparing the results to vegetation maps of the preserve will provide a heightened understanding of the accuracy of the EMIT data set.

Reduction and Analysis of Near-Infrared Images of Saturn: Examining Seasonal and Non-Seasonal Variability of Deep Clouds and Adaptation of Relevant Processes
Madeline Christensen, California Institute of Technology
Mentors: Glenn Orton and Thomas Momary, Jet Propulsion Laboratory, California Institute of Technology

As we look beyond our solar system to other exoplanets, we want more insight into the layering and structure of Saturn. The thermal radiation emitted by Saturn's atmosphere can be measured and analyzed to determine the planet's atmospheric composition and dynamics. 5.1-μm images of Saturn show this thermal radiation and can be reduced to provide unique insight into the planet's deep cloud structure which has been influenced by atmospheric disturbances such as seasonal variability and non-seasonal variability. Saturn was imaged in these wavelengths by both ground-based and Cassini near-infrared observations. The 5.1-μm images of Saturn must first be reduced and calibrated using standard stars of known brightness. To account for reflected sunlight, 1.58-μm images were also reduced and calibrated. These are used as a proxy for the reflected sunlight that needs to be removed from the 5.1-μm images. Then, the calibrated images are used as inputs into NEMESIS, a system that reverse engineers the light bouncing off of Saturn's atmosphere to better understand it's seasonal variability. Using this process, all images of Saturn have been reduced and calibrated and NEMESIS will be used to complete the research goals of this project.

Using Interior Models to Study the Tidal Deformation of Venus

Abigail Dunnigan, University of North Carolina at Chapel Hill
Mentor: Gregor Steinbrugge, Jet Propulsion Laboratory/California Institute of Technology

In this project we construct Venus interior models to compute the tidal deformation and inform the science goals of the Venus Synthetic Aperture Radar (VenSAR) instrument that will be on the European Space Agency's (ESA's) EnVision mission. Venus is considered to be the twin of Earth but has gone through a different evolutionary path leading to its vastly different habitability. These effects largely point to the interior and its interactions with the surface and atmosphere, however Venus's interior is poorly constrained. We apply interior models that have been previously used for Mercury, and modify them to fit the geodetic constraints and interior conditions of Venus. Using these models, we intend on exploring the parameter space of Venus's interior and see how tidal deformation may change with a dynamic mantle and the weight of its massive atmosphere. By using what we find, we intend on analyzing the capabilities of VenSAR and how it can get us the measurements we need to better constrain Venus's interior.

High-Accuracy Numerical Integration Methods for Obstructed View Factor Calculations

David Dye, Harvard University
Mentors: William A. Hoey, Gregory S. Shallcross, and John R. Anderson, Jet Propulsion Laboratory/California Institute of Technology

View factors are used in several academic and industrial fields to determine radiative heat transfer between surfaces, simulate lighting in graphics engines, and model line-of-sight molecular and particulate transport. At JPL, contamination control engineers require precise and accurate view factors to characterize molecular and particulate deposition onto mission-critical spacecraft components. A robust algorithm was developed for calculating view factors within arbitrarily-complex 3D geometric meshes while accounting for shadowing effects, where some mesh elements obstruct the view between others. The view factor between a source element and a target element was obtained by projecting obstructions onto the target element, finding the unshadowed portion of the resulting shape, and calculating the view factor to that unshadowed region using a 2D Gaussian quadrature over the source element. This algorithm was compared against two established procedures: the CERN Molflow+ Monte Carlo ray tracing method and the Siemens NX Space System Thermal hemicube view factor method. A confidence interval formula for Monte Carlo ray tracing algorithms was developed in order to quantify the accuracy and convergence of the Molflow+ ray tracing method. The view factor algorithm described in this paper is recommended for applications involving shadowed meshes where high accuracy is required.

RF Sputter Deposition and Characterization of Boron Nitride Thin Films for Superconducting Microdevices

Juan Escobar (Jet Propulsion Laboratory/California Institute of Technology)
Mentor: Changsub Kim (Jet Propulsion Laboratory/California Institute of Technology)

Current state-of-the-art superconducting quantum microdevices suffer from signal loss and noise from two-level systems (TLS) in dielectric layers. The TLS noise/loss tends to decrease with increasing coordination number. Boron nitride is a dielectric with coordination number higher than conventional dielectrics but has not been investigated before. Here, I deposited boron nitride thin films by RF magnetron sputtering using different deposition parameters, and characterized deposition rate and optical/dielectric constants. I found a positive relationship between bias power and deposition rate, and a negative relationship between the nitrogen partial pressure and refractive index.

Streaming Cat Videos From Deep Space With Lasers

Sam Foxman – California Institute of Technology
Mentor: Ryan Rogalin (Jet Propulsion Laboratory, California Institute of Technology)

Laser communication systems allow us to download 100x more data from spacecraft compared to traditional radio links. The Deep Space Optical Communication payload, launching on the Psyche spacecraft, will attempt laser downloads up to 2.8 AU from Earth. I wrote software that parses the incoming bitstream from the spacecraft, extracts files, and displays the data in real-time (including our test data, cat videos). A similar project, Optical-to-Orion, will use laser communications to provide high-speed internet to astronauts on the moon. I developed uplink and downlink framing software for the Optical-to-Orion project that transmits ethernet over the laser link. Furthermore, I created a video streaming app, and successfully livestreamed HD video through the laser link using the uplink and downlink software. Finally, I analyzed a MATLAB implementation of the laser modulation decoder and found that it performs equally well as the reference decoder.

VUV Spectroscopy of Hall-Effect Thrusters
Jessica Gonzalez, University of California, Los Angeles
Mentors: Lee Johnson and Mary Konopliv, Jet Propulsion Laboratory/California Institute of Technology

Hall-Effect Thrusters (HETs) operate by accelerating charged particles using an electric field. Accurate, atomic-level diagnostics of HETs are crucial to improving lifetime and efficiency. Optical emission spectroscopy (OES) is a non-invasive technique of characterizing plasma previously used in the visible and NIR spectrum to determine electron temperature with a collisional radiative model (CRM). Due to its high atomic mass and low ionization energy, xenon is a common propellant for an HET. Populating processes of the neutral atom's first excited state provide insight into thruster behavior. Observing this state of xenon requires OES in the VUV. Using known cross-sections of xenon, an extension to the VUV of a NIR CRM was made in MATLAB. VUV detectors and a monochromator were used to measure intensity of the 129 nm and 147 nm lines from an SPT-70 thruster. These results were compared to the intensity values produced by the model which correlate with the discharge current oscillations caused by the thruster's electric and magnetic fields. This extension of the CRM will allow for determination of optimal operation conditions and reveal life limiting processes for HETs. These results provide strong evidence of VUV spectroscopy as an effective in-flight diagnostic to evaluate thruster performance.

Additively Manufactured Oscillating Heat Pipes
Aidan Hamner – California Institute of Technology
Mentors: Scott Roberts and Taku Daimaru - Jet Propulsion Laboratory/California Institute of Technology

Oscillating Heat Pipes (OHPs) are a passive heat transfer technology that work by utilizing two-phase flow to move heat, with conductivity seen in lab of up to 40,000 W/m/K. Fabricating OHPs with additive manufacturing enables production of a wide variety of geometries, as well as production of parts that need cooling with OHPs directly inside them. Test setups were constructed and used to test the heat conductance of a wide variety of OHPs, with the effects of different materials, shapes, channel paths, and channel geometries all being examined. New OHPs were also designed and fabricated based on the test data as part of the process of finding out how OHPs can be best utilized. Based on the results of testing, OHPs could be a very effective addition to JPL's thermal management toolkit, capable of moving heat more effectively and with a smaller footprint than other solutions.

Explosive Disintegration and Wide-Angle Outflows in Massive Young Stellar Systems: Insights From IRAS05506+2414
Diya Kumar – California Institute of Technology
Mentor: Raghvendra Sahai - Jet Propulsion Laboratory/California Institute of Technology

An exciting development in the understanding of the early evolutionary stages of massive stars is that the disruption of a massive young stellar system can lead to an explosive event producing a knotty, wide-angle outflow. IRAS05506+2414 may be the second example of this phenomenon, thus the analyses carried forth are crucial to test the mechanisms for the explosive disintegration model for such sources. HST optical and near-IR images taken in 2002 show a fan-like spray of high-velocity knots which emanate from a bright compact source. Using WFC3 observations taken in 2021, we measured the proper motions of the knots of about 12-19 mas/yr. From the measured proper motions and expansion parallax, we determined the source distance (6 kpc) and constrained its luminosity and mass. Optical and deep emission-line imaging were used to probe the bullet spray and additional changes in the system. The YSO (young stellar object) evolutionary status of IRAS05506+2414 was confirmed using ALMA observations to derive a 12C/13C ratio ≈ 30-50, which is inconsistent with expected values for evolved stars. The 12CO J=2-1 data reveal that the previously unresolved, slow extended bipolar outflow (SEO) of IRAS05506+2414 consists of a pair of large (80,000 au) diametrically-opposed parabolic lobes.

Additive Manufacturing for Loop Heat Pipes
Isabella M. Kwaterski, California Institute of Technology
Mentor: Scott Roberts, Jet Propulsion Laboratory/California Institute of Technology

Due to the lack of an atmosphere, spacecraft rely entirely upon conduction or pumped fluid loops in order to move heat throughout their chassis. This makes heat pipes a crucial component of thermal management for spacecraft. By bonding heat pipes into the structure of spacecraft, we are able to significantly increase the rate of conduction within them. As a result, thermal management of spacecraft is directly correlated to the efficiency of the heat pipes that comprise their structure. However, despite the efficiency of heat pipes, they still pose multiple challenges; they are difficult to integrate, involve bond lines between their porous and solid regions which decrease performance, and rely on suppliers delivering custom, flight critical parts that are difficult to manufacture. Creating efficient heat pipes through additive manufacturing strives to address these challenges.

Design of a Testing System for MEMS Seismometer

Ethan Labelson, California Institute of Technology
Mentor: Mina Rais-Zadeh, Jet Propulsion Laboratory/California Institute of Technology

Having accurate seismic data about other planets is key to understanding how geological processes function throughout the solar system. Most seismic systems use the oscillations of a proof mass, a heavy object designed to move freely, to measure seismic activity. However, this is highly impractical for systems designed for space missions because the proof masses are heavy and often quite fragile. Thus, the design of a small scale, durable seismometer is key to understanding the geologic activity of other planets. The current crop of MEMS seismometers seek to solve this problem by scaling the proof mass, and associated components, down to tens or hundreds of microns. The small scale allows the seismometers to be lightweight, and because the proof mass is so small, the smaller amplitude of oscillation allows the MEMS seismometers to be much more durable than their full size counterparts. Unfortunately, these devices are hard to manufacture and there is often inconsistency between products, even within the same manufacturing process. Thus, the development of a highly accurate, convenient, testing setup is key to the practical production of such devices. We have developed such a setup designed to be used with an IR microscope. The setup consists of both a hardware shake component, as well as a computer vision software component. Put together, it should mostly automate the testing of MEMS seismometer devices, allowing for quick and consistent results when devices are finally delivered.

Leveraging Airborne Data to Enable Spaceborne Methane Plume Detection via Model and Data Driven Approaches

Vassiliki Mancoridis[1,2]
Mentors: Brian Bue[1] and Jake Lee[1]
[1] Jet Propulsion Laboratory, California Institute of Technology
[2] Princeton University

Prioritizing methane for near-term climate action is crucial due to its significant impact on global warming. Previous efforts at JPL and Carbon Mapper employed deep learning to detect methane plume sources using column-wise matched filter products from the AVIRIS-NG image spectrometer; however, the spatial coverage of the data was constrained by the geographical limitations of the airborne campaigns. We introduce methodology that leverages past airborne observations to enhance spaceborne methane plume detection through model and data adaptation approaches. We developed the first methane plume detector to use data from the EMIT spectrometer aboard the ISS. Directly applying existing state-of-the-art airborne models to spaceborne data yielded reasonable results (F1=0.64). Transfer learning improved these metrics; we refined our airborne model with a small sample of EMIT observations and found that the new model outperformed the standalone spaceborne model (F1=0.76). Finally, we assessed the viability of unsupervised image-to-image translation techniques such as CycleGAN to align airborne and spaceborne data distributions. Our best CycleGAN was able to map holdout EMIT tiles into simulated airborne tiles, which yielded our best results with the airborne model (F1=0.88. We also explored CycleGAN-simulated airborne products as a means of data augmentation and model regularization for the airborne classifiers.

Automated Stripe Noise Removal for Mid-Infrared Images of Jupiter

Naomi Park, Brown University
Mentor: Glenn S. Orton, Jet Propulsion Laboratory/California Institute of Technology

We present a method for correcting strong artefacts that plague the raw imaging data obtained by the Mid-Infrared Spectrometer and Imager (MIRSI) that is used at NASA's Infrared Telescope Facility to obtain mid-infrared images of Jupiter between 4.90 and 18.4 microns. These images contribute to a program to provide Earth-based contextual information for the Juno mission and the James Webb Space Telescope. Raw images from the instrument have strong, artificial 20 pixel-wide stripes as a result from the differences between offset voltages in column readout circuits of its mid-infrared sensors. We have developed an automated, mathematical approach to eliminating stripe noise in MIRSI's mid-infrared images. Such an approach removes the necessity for any user input or guidance and can be efficiently applied to an entire directory of images with a single command. The application of our efficient, automated approach to removing stripe noise was applied to unprocessed MIRSI data, and we ensure that an analysis can be properly practiced on the destriped images to determine the 3-dimensional temperature structures, optical thicknesses, and aerosol abundances. Our stripe-noise-removal algorithm presents a novel, innovative solution to expediting and enhancing the investigations of long-term variability in Jupiter's upper-tropospheric and stratospheric temperatures through the reduction and analysis of mid-infrared thermal images of Jupiter. The process could also be applied to other planets observed by MIRSI and to other imaging instruments with similar striping issues.

Improving Deep Learning Methods for Robust Methane Plume Detection Using Auxiliary Products
Anagha Satish[1,2]
Mentors: Brian Bue[1] and Jake Lee[1]
[1] Jet Propulsion Laboratory, California Institute of Technology
[2] California Institute of Technology

Methane (CH4) is a prominent greenhouse gas responsible for atmospheric radiative forcing. As we notice trends in increasing global temperatures, understanding and detecting these emissions has become increasingly important. Previous work at JPL has shown CNNs to be an appropriate solution to map methane sources from future imaging spectrometer missions, such as Carbon Mapper. However, current models suffer from a high rate of false positives due to false enhancements. We trained a GoogLeNet classifier on a newly compiled dataset of three airborne campaigns. We first note minimal improvement (1% increase in F1 score) between the Unimodal CMF model and a new Surface-Controlled CMF model, which removes enhancements not matching the absorption wavelength of methane. We then experiment with various auxiliary products measuring albedo (rgbmu, SWALB), vegetation (NDVI, ENDVI), and water (H2O, NDWI), designed to combat issues known to produce false enhancements. We find that the addition of any single auxiliary product improves the final model scoring, and that the model using all auxiliary products performs the best. We also explore adding auxiliary products to spaceborne data from the EMIT spectrometer aboard the ISS, observing the potential impact of albedo and water products on minimizing the impact of clouds as confusers.

Dominant Formation Mechanisms of Multi-Planetary Systems
Cheyanne Shariat (University of California, Los Angeles)
Mentors: Yasuhiro Hasegawa and Renyu Hu (Jet Propulsion Laboratory/California Institute of Technology)

Most, if not all, sun-like stars host one or more planets, making multiplanetary systems common in our galaxy. Characterizing multi-planet systems is, however, challenging because the number of parameters (e.g., radius, mass, orbital period) increases as the multiplicity increases. We leverage the results of hundreds of theoretical simulations to characterize multi-planet systems and constrain their formation mechanisms. Specifically, we train machine learning classifier models on our simulated data, with observational biases applied, to identify the major trademarks corresponding to the different formation mechanisms. We find that two features – mass concentration and orbital spacing – carry the greatest signature of the of the systems formation mechanism. With accuracies reaching over 95%, we then apply these models to a large dataset of observed multi-planet systems from the Kepler Space Telescope. After comparing our biased simulated systems to observations, we find that 21.5% of observed planetary systems are likely produced by in-place formation. 78.5% are more consistent with the migration model: the planets form farther out migrate towards the host star. Utilizing more simulation data available in the literature is desired to verify our preliminary findings.

Miniaturized Spectrometer - Instrument Performance Model
Jaylen Shawcross (California Institute of Technology)
Mentors: Vincent Tieu, Jake Clarke, and Sona Hosseini (NASA Jet Propulsion Laboratory, California Institute of Technology)

This project aims to create a noise model for an upcoming spectrometer, which aims to measure the D:H ratio on OH on the moon. This isotope ratio can provide critical insight into the evolution of water escape from the lunar exosphere. It can also better inform our knowledge of whether lunar water had a terrestrial or trans-Neptunian origin. When taking measurements, the spectrometer will also measure noise which will need to be accounted for in our final results. Sources of noise include zodiacal light, solar light, reflections off the earth, light from stars, and light from comets. Zodiacal light will be the most significant source of noise at the time we record our data, so we focused our efforts on predicting the sun's zodiacal light cloud. We modified Marc Kuchner's existing zodipic model to take parameters in accordance with the position of our spectrometer and its capabilities, generating zodiacal light grids for each possible wavelength detectable by our instrument at every possible inclination of our instrument relative to the sun for a total of 3,600 grids generated. We interface these with the existing instrument performance model which allows us to account for zodiacal light in our instrument's measurements.

Visualizing Ambient Magnetic Fields and Observing Field Information in a 3D Web/Virtual Reality Application
Angelo Ryan Soriano, California State University, Long Beach
Mentor: Benjamin Nuernberger, Jet Propulsion Laboratory/California Institute of Technology

Magnetometer based missions like that of NASA's Europa Clipper are burdened with the additional need to minimize interference from local magnetic sources, less they risk contamination. This design constraint is normally addressed through a magnetic cleanliness program, which seeks to find an optimal magnetic configuration that minimizes interference. Typically, static 2D images are generated and used to visualize the complex magnetic fields of spacecrafts to assist with these programs. The Jet Propulsion Laboratory is investigating the development of a tool

that would visualize spacecraft magnetic fields in a 3D web environment and an immersive virtual reality environment. Previous work has shown that such a tool may provide value to personnel working on electromagnetic cleanliness teams. In this work, we specifically investigate the how visualization of an ambient field and the ability to observe field information at specified locations adds value to such a program as a means to further guide development.

The Search for Consistent Patterns of Clouds in Jupiter's Atmosphere From JunoCam Images Based on Their Colors

Anna Szczuka, California Institute of Technology
Mentors: Glenn Orton and Tom Momary, Jet Propulsion Laboratory/California Institute of Technology

The Juno mission's JunoCam instrument (or JCM) is a wide-angle pushframe camera designed to capture the unique polar perspective of Jupiter and Jupiter's cloudtops. It provides a novel source of data to investigate the atmospheric conditions and processes on Jupiter. In support of the Juno mission, we use imaging from JunoCam to search for consistent patterns of clouds in Jupiter's atmosphere and establish a general classification of regions of the Jovian atmosphere by color. Since the JunoCam instrument has no absolute photometric calibration, we can determine ratios of red, green, and blue color channels or differences between them to search for consistencies between different types of clouds and detect relationships between cloud patterns through clustering analysis. This project involves selecting and analyzing JunoCam images, applying image segmentation and Minnaert correction techniques, and performing color index and clustering analysis. This project will contribute to the ongoing mission of understanding and classifying Jupiter's atmosphere. This project will also expand our knowledge about atmospheric conditions and processes on Jovian planets in our solar system and gas giant exoplanets.

Proper Motions in the Highly Collimated Jet and Temporal Variations in the Central Bipolar Nebula of the Dying Star Hen 2–90

Adelynn Tang – California Institute of Technology
Mentor: Raghvendra Sahai - Jet Propulsion Laboratory/California Institute of Technology

Hen 2-90 is a young planetary nebula that has a linear, bipolar jet with at least six pairs of emission knots positioned roughly symmetrically around the central star. The bipolar jet in Hen 2-90 was discovered in 2000 with the Wide Field Planetary Camera 2 of the Hubble Space Telescope, and second-epoch images taken two years later were used to find the proper motions of its jet knots. We have now used a 3rd epoch image taken 7.5 years later to study the longer time evolution of the jet and the central source. Intensity cuts through the jets were made to determine the proper motions of the knots over the three epochs. Aperture photometry of the knots and central source was used to examine the change in flux of the knots and central bipolar nebula over time. The knots were fitted using elliptical Gaussians to determine their shapes and sizes. The radial velocities of the jet knots were measured using Space Telescope Imaging Spectrograph data. Combining the radial velocity and the proper motions, the 3D velocities of the knots were calculated. These results were compared to simulations from a theoretical model.

The Importance of Vertical Resolution and Averaging Kernels When Comparing Lagrangian Model Results to MLS-observed Stratospheric Water Vapor Concentrations

Sasha Tolstoff (Jet Propulsion Laboratory, California Institute of Technology)
Mentors: Jonathan Jiang and Frank Werner (Jet Propulsion Laboratory, California Institute of Technology)

Stratospheric water vapor concentrations have a significant impact on the atmospheric radiation budget and stratospheric ozone, and an increase in H_2O concentrations can lead to substantial surface warming. A Lagrangian forward model simulates air parcel trajectories, including their H_2O content, which can be compared to NASA Microwave Limb Sounder observations. Monte Carlo sampling was performed on geolocated LM parcels to generate random H_2O profiles that represent a possible atmospheric state, which MLS could have observed. Convolution with vertical MLS averaging kernels that describe the contributions from all vertical levels to the retrieval at a target pressure level was applied to the LM simulations and resulted in improved agreement with MLS-observed monthly global fields and outlier frequency. Remaining discrepancies in the range of 0.3-0.5 ppmv can be attributed to the lack of parcel mixing and convection in the LM simulations and are in the range of previous scientific studies.

Describing and Simulating Rainbow Hazes on Jupiter's Surface Using JunoCam and ISIS

Erica Wang
Mentor: Glenn Orton, Jet Propulsion Laboratory/California Institute of Technology

We investigated potential correlations of the dispersion of red, green, and blue peaks of reflected sunlight as a function of distance along the Sun azimuth line for "rainbow" hazes. These are translucent hazes and linear bands with a distinct color separation, a phenomenon that occurs near the terminator of images of Jupiter made by the Juno mission's JunoCam instrument, a public-outreach camera. We used the Integrated Software for Imagers and Spectrometers (ISIS), a free and open-source software (FOSS) developed by the USGS Astrogeology Science Center for NASA and the planetary community. ISIS is a fundamental tool for processing raw archival data into analysis ready products and includes standard imaging processing tools such as contrast, stretch, image algebra, and statistical analysis. We used the ISIS qview Advanced Tracking tool to measure distances between the peak colors. We graph the DN values of the red, green, and blue pixels along the Sun azimuth line according to the LAT and LON distance using Jupyter Notebook and Python programming.

Characterizing the CHROMA-D Focal Plane Array for Next-Generation Imaging Spectroscopy Missions

Audrey Whitmer – Yale University
Mentors: Peter Sullivan and Shriya Nadgauda – Jet Propulsion Laboratory, California Institute of Technology

Comprehensive continuous observation of the Earth's surface is essential for tracking and understanding biological and geological changes as they happen. These air and space-based observations are undertaken with imaging spectroscopy, a unique form of imaging in which spectroscopy is performed on every pixel in an image, resulting in a "data cube" which reveals chemical compositions present in the ground area associated with each pixel. Central to many next-generation imaging spectrometers in development are high-performance mercury cadmium telluride (HgCdTe) focal plane array (FPA) detectors, which convert incident light into an electrical signal. These detectors have non-linear responses at low light levels that need to be understood and corrected for before they can be utilized in next-generation spectrometer technology. We designed a setup and method for exposing Teledyne's CHROMA-D FPA to varying light levels utilizing a nanosecond pulsed laser, and measuring the subsequent FPA response. We analyze the FPA response and present our results.

Improving Methane Plume Detection Capabilities With Source-Specific Context

Shujun Xiong[1,2]
Mentors: Brian Bue[1] and Jake Lee[1]
[1] Jet Propulsion Laboratory, California Institute of Technology
[2] Columbia University

Methane is one of the strongest commonly emitted greenhouse gases around the world, more than 4 times more potent at contributing to climate change than carbon dioxide. Although methods to contain and reduce methane emissions exist, it is often difficult to quantify and pinpoint sources of leakage and overall emission. Past work in airborne imaging spectrometers such as AVIRIS-NG and GAO have allowed for rapid, high-resolution mapping of methane plumes over large areas (Thompson et al, 2015). Recent advances in machine learning (ML) have taken advantage of these data sources, demonstrating that robust methane plume detection is feasible. Nevertheless, existing plume detection systems are source-agnostic interpreting heterogenous sourcing of data, which may lead to less-than-optimal performance. We propose a new ensemble model consisting of member models trained on specific source classes will improve our ability to detect methane plumes. In particular, we construct member models trained with respect to source sector and infrastructure type (e.g. oil/gas, landfills, agriculture, mining facilities, etc.). We demonstrate that ensembling a model together out of source-specific member models improves methane plume detection performance.