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STUDENT-FACULTY PROGRAMS

2022 STUDENT ABSTRACT BOOK

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2022 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 2022.

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Progress Toward Iridium-Catalyzed, Iodine-Mediated Cyclization of Allylic Alcohols for the Construction of Quaternary Centers
Lucas Abounader
Mentors: Brian Stoltz and Melissa Ramirez

The quaternary stereocenter motif is ubiquitous in bioactive natural products and often contributes to the unique medicinal properties of these compounds. Recently, allylic alcohols have been developed as enolate synthons in an iridium-catalyzed, iodine-mediated umpolung approach for C–O bond formation. The potential to use alternate substrates and catalytic systems for quaternary center generation makes the identification of new enolate synthons and enantioselective catalytic transformations for their functionalization highly desirable. We report substrate synthesis toward the development of a methodology for quaternary center synthesis via intramolecular, oxidative cyclization of allyl silanes to allylic alcohols. We attempt to forge a $C(sp^3)$-$C(sp^3)$ bond and generate an all-carbon quaternary center by allowing this substrate to react with an iridium (III) catalyst and iodine (III) reagent. The realization of this transformation will establish a new route to quaternary centers under catalytic control and allow for the development of a novel stereoselective reaction.

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

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

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

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

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

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

Solving Phase Retrieval Problems by Sampling From a Bias-Free Convolutional Neural Network Denoiser
Rohun Agrawal
Mentor: Oscar Leong

Recently, deep learning has made great strides in solving inverse problems. However, nonlinear inverse problems such as phase retrieval have still proven challenging. Phase retrieval is a nonlinear inverse problem that seeks to recover a true signal from the squared magnitude of its Fourier measurements. It arises in many applications such as astronomical imaging, X-Ray crystallography, coherent diffraction imaging, and transmission electron microscopy. A new stochastic gradient ascent algorithm that utilizes the mathematically justified implicit prior within a bias-free convolutional neural network denoiser has shown to be successful with solving linear inverse problems while being highly generalizable. We extend this algorithm to the phase retrieval problem by incorporating it into an alternating minimization framework. This framework allows our algorithm to alternate between solving for the missing phase and solving a linear inverse problem given the reconstructed phase. A large benefit of our algorithm is that it can handle different image distributions and sizes, eliminating the need to collect ground truth signals which may be impossible to obtain or to train a new network for each phase retrieval imaging task. We achieve promising results in the case when the measurements are Gaussian and explore the more challenging Fourier regime.

How Negative Regulators of Cilia Elongation Block Cell Proliferation in the Presence of Extra Centrosomes
Buraq Ahmed
Mentors: David Glover and Paula Almeida Coelho

Centrosomes are critical components of spindle organisation during mammalian cell mitosis, with supernumerary centrosomes being associated with poor mitotic fidelity and thereby often observed in tumour morphologies. Centrioles form the core of centrosomes, contributing to the basal bodies of different types of physiologically important cilia. Previous work in the Glover lab has shown that over-duplication of centrosomes, induced via Plk4 over-expression, prevents the generation of primary cilia and cell proliferation. As such, investigating ciliogenesis regulators provides therapeutic opportunity for both ciliopathies and cancers.

The lab has previously identified possible negative regulators of ciliogenesis, which we depleted in wild-type and Plk4 over-expressed cells using siRNA's, hoping to restore cilia generation and S-phase entry in the latter. We quantified cell proliferation recovery, cilia presence and cilia length for each of the knockdowns and found gene products potentially interacting with ciliogenesis and disassembly at different levels, including during Golgi-centrosome associations and causing stunted ciliary growth. All of our knockdowns also indicated increased proliferative ability after centrosome amplification, but a mechanism for this remains unclear. Future work involves characterizing the biochemical mechanisms of these observations and investigating the extent to which the consequences of these depletions can be overcome by preventing cilia growth.

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

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

Data-Driven Discovery of Differentially Flat Coordinates
Jedidiah Alindogan
Mentors: Soon-Jo Chung and Benjamin Rivière

The vast majority of dynamical systems found in nature are nonlinear and can consequently be difficult to control. Yet, the control of such high-dimensional and nonlinear systems is continuously sought. Using differentially flat coordinates is a well-known method to plan trajectories in such systems. Differentially flat coordinates are outputs that explicitly encode information from the state and control of a system without integration. Through these flat coordinates, trajectories for a system can be rapidly computed. However, the transforms between state and control space and flat space are difficult to discover. By improving the autoencoder previously designed by Rivière, this work will introduce a method to automatically discover the transforms between state, control, and flat space for a nonlinear dynamic system.

HOMES – Habitat Orientable and Modular Electrodynamic Shield
Nisreen AlSaud
Mentor: Charles Elachi

The objective of this project is to help the Caltech team manage their HOMES Big Idea Challenge project within the desired timeframe and cost. To that effect, I have used project management tools and techniques to better manage the project in terms of scheduling, budget tracking, milestones, risk management and have developed ways to visualize them easily. Managing HOMES and the team went very well, however, there were some challenging obstacles, such as miscommunication within the team, delays in shipments as well as defects in the design of the panels. All in all, I can confidently say that the team has surpassed the success criteria of the project (HOMES has been operated efficiently and effectively and has been completed on time) as HOMES has undergone the most testing and is the only working prototype out of all the contestants in the Big Idea Challenge.

Data-Adaptive Model Predictive Control of Linear Time Varying Systems With Imperfect Predictions
Emile Anand
Mentors: Adam Wierman and Yiheng Lin

Model Predictive Control (MPC) is a novel method used to control processes while satisfying a set of constraints, with the slated advantage that at each discrete time-step, the algorithm receives exact predictions of the costs, dynamics, and disturbances of the system for k future time-steps. These predictions are typically imperfect in real-world applications; moreover, the longer the predictive window, the noisier the predictions get. In this work, we propose an online pipeline and analysis framework to find the optimal prediction window even when the predictive errors accumulate with time. We generalize our work to apply for all controllers for which the trajectories of an initial state and its perturbed state exponentially converge to induce input-to-state stability. We then leverage existing algorithms for online convex optimization through multi-armed bandits for tackling the exploitation vs. exploration problem. Next, we propose a broader algorithm to dynamically tune the model's confidence of the predictions it receives. Finally, we prove that these online data-adaptive algorithms produce a bounded sublinear dynamic regret.

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

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

Hardware Design and Verification for Wireless Integrated and Implantable Brain Machine Interface
Joshua Archibald
Mentors: Azita Emami and Steven Bulfer

Our lab has designed a Feature Extraction Network (FENet) that uses a convolutional neural network to decode brain signals to determine a patient's desired movement of a computer cursor with an R-squared value close to 70%. Currently, the broadband raw neural data is sent, via a physical wire, from an individual's brain to a computer where FENet is run. The massive bandwidth of the raw neural data makes it impossible to send the data wirelessly without unreasonable power consumption and the wire to brain interface is not practical for everyday use and not the safest for the patient. We are designing a low power implantable FENet integrated circuit using Verilog Hardware Description Language so that only the most important features can be extracted from an individual's neural data and, due to the decrease bandwidth, can be sent wirelessly to control an external machine. We are also designing debugging hardware in order to verify and configure FENet once it is fabricated into an integrated circuit. Verification at the design level and hardware level using CAD tool Vivado and the debug hardware ensure that FENet works as a robust, accurate, and practical brain machine interface.

Enhancing Gamification Aspects for Mobile App ZTF Augmented Reality Transient Hunter (ZARTH)
Anika Arora
Mentors: Ashish Mahabal and Ivona Kostadinova

The Zwicky Transient Facility (ZTF) detects transients in the Northern sky using a 47-deg^2 CCD camera. Through the app ZTF Augmented Reality Transient Hunter (ZARTH), users can locate planets, stars, and transients found by ZTF. Upon locating transients, users earn points and view their properties, a concept similar to Pokémon Go. To improve ZARTH's UI, there must be a representative, sparse distribution of transients across the sky. Using Alert-Classifying Artificial Intelligence, a deep learning framework to classify ZTF alerts, we have created an algorithm which removes bogus transients and includes variable, orphan, hosted, and nuclear transients. This algorithm filters ZTF's 100,000 transients per night into a uniformly distributed subset of 1,000. A separate algorithm assigns points to transients in inverse proportionality to their rarity, which is calculated from their magnitude, classification, and spectra. We can improve these two algorithms by considering other transient properties, like its filter.

Learning Thermal Image Features for Nighttime UAV Visual Odometry
Nishka Arora
Mentors: Soon-Jo Chung and Connor Lee

Techniques of unmanned aerial vehicle (UAV) navigation are well-developed for RGB cameras but, such methods are a lot less studied in the infrared domain, which is the wavelength in which thermal cameras function. The project worked on by the research group is thermal image segmentation in riverine environments for UAV operation which is useful for bathymetry and nighttime navigation. How do you differentiate between the river and land parts of a video feed? The two approaches explored are i) improving thermal domain interest point detection for improved visual odometry ii) treating the camera domain (thermal/RGB) of an image as its style to learn style-invariant features for segmentation. After investigation, we assessed that the RMS Error for the thermal image-based odometry compared to the true path (transformed to the odometry coordinate frame) is more than the RGB image-based odometry error as expected. This result means that improving VIO-based odometry is an interesting direction for future work.

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

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

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

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

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

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

Using Natural Language Processing to Understand the Effect of Electoral Quotas on the Mexican Parliament 2006-2018
Beatriz Avila-Rimer
Mentor: Gabriel Lopez-Moctezuma

Globalization has given rise to various institutional changes towards gender equality in developing countries. In efforts to increase minority representation, countries have begun to introduce electoral quotas. However, the impact of these is difficult to gauge in party-centered systems, such as the Mexican system. Where legislative behavior provides minimal information about a legislator's preferences. Thus, speeches may provide an alternative source of information to analyze signals sent to their constituents or co-partisans, while also allowing us to understand how they diverge from their party platform. We analyzed how the introduction of these quotas have affected legislators' rhetoric and their policy implementation. Specifically focusing on the conflict of personal ideology derived from scaling methods and party alignment. The objective is to expand upon the current models that predict ideology from text data and contribute by scaling ideological points. Our work contributes to the growing literature of computer linguistics in the field of political science and economics by applying machine learning models to analyze political outcomes such as policy enforcements and polarization. Additionally, it contributes to the literature on the effects of electoral reforms and accountability, focusing specifically on the effectiveness of introducing gender quotas into electoral reforms.

Stellar Radio Transients in the Very Large Array Sky Survey
Carlos Ayala
Mentors: Gregg Hallinan and Dillon Dong

Stellar radio transients can be attributed to radio-emitting mechanisms associated with stellar magnetic activity. We present a sample of stellar radio transients brighter than 1 mJy in VLASS Epoch 2.1/2.2 but absent from VLASS Epoch 1.1/1.2, observed over the 34,000 square degree field of the Very Large Array Sky Survey (VLASS). We cross matched these transients with stars in Gaia DR3 to identify those with a low chance association probability, taking into account changes in proper motion and astrometric uncertainties. Our angular resolution of ~2 arcseconds accompanied by the low areal density of transients decreases the likelihood of false associations with background sources, allowing us to identify a robust sample of stellar radio transients. The high sensitivity and large sky coverage of VLASS further make this the largest blind search for stellar radio transients by volume. To better classify these stellar radio transients, we identified infrared and X-ray counterparts from WISE and ROSAT, while also obtaining Gaia properties and TESS lightcurves. The final sample consists of 75 stellar radio transients, including close binaries, young stellar objects, M dwarfs, and other classes of radio-emitting stars. Our sample will facilitate in-depth studies of radio-emitting systems, including young stellar objects and chromospherically active binaries, particularly with regards to the rate of the most energetic radio flares from these classes of objects.

Development of Hyperspectral Spectroscopy Data Processing and Visualization Modules for the Workbench for Imaging Spectroscopy Exploration and Research (WISER)
Sahil Azad
Mentors: Rebecca Greenberger and Bethany Ehlmann

Hyperspectral images store multiple electromagnetic radiation spectra within each pixel of an image, providing a high spatial resolution mapping of chemical properties of surfaces. The use cases of imaging spectroscopy are varied, ranging from characterization of ecosystems, geology, and atmospheric properties, to being a tool for exploration of other planetary bodies. Current software designed for analysis of these images is obsolete, using outdated algorithms with high memory and time complexities, and are locked behind expensive licensing fees. As a free alternative, the Ehlmann group has developed WISER, a modular workbench for hyperspectral image analysis. In this project we look to develop statistical analysis plugins that can perform dimensionality reductions, endmember extractions, and other utilities to increase WISER's capabilities. Five plugins (Principal and Independent Component Analysis, Matched Filtering, Linear Unmixing, Minimum Noise Fraction) have been developed and profiled with low memory and time overheads, with plugin-specific user interfaces in WISER to allow for end-user access. We show that the plugins have accuracies similar to software currently on the market and use minimal computational resources.

Reduction Kinetics of Hydrogel-Based Additively Manufactured Copper, Nickel, and Copper-Nickel Oxide(s) Under Forming Gas
Maria Azcona Baez
Mentors: Julia R. Greer, Thomas Tran, Seneca Velling, and Wenxin Zhang

A novel technique known as hydrogel infusion additive manufacturing (HIAM) has been developed for printing 3-D metal architectures with feature sizes as small as 10um. This process involves four steps: printing the polymer gel, swelling the blank gel in a metal ion solution, calcining the metal-infused gel to form metal oxides, and reducing the oxide to form metal, all while maintaining the original architecture. The reduction kinetics of HIAM are explored for the first time in the present study, mapping out the influence of reduction temperature on the formation, sintering, and annealing of copper, nickel, and copper-nickel alloys created with the technique.
Previously calcined copper, nickel, and copper-nickel oxide(s) samples were reduced under forming gas (95% N_2, 5% H_2) at 300, 350, 400, and 900°C . X-ray powder diffraction has been used to quantitatively determine the phase assemblage of each sample at the bulk level, and energy dispersive X-ray spectroscopy has enabled qualitative compositional analysis to confirm chemical homogeneity in local regions. From the characterizations, the copper oxide samples were completely reduced by 350°C, while the nickel oxide samples were reduced by 400°C. Copper-nickel oxides were only partially reduced by 400°C, requiring further studies to determine the minimum temperature for complete reduction.

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

Animal behavior recognition and classification has become increasingly prominent within the rapidly growing field of computer vision. Typical machine learning algorithms used for this task involve large amounts of manually annotated data, often proving an expensive and time consuming process. One such model is the Mouse Action Recognition System (MARS), which provides a pipeline for the classification of social behavior between interacting mice and may take hundreds of thousands of annotated frames to accurately predict behavior. The Trajectory Embedding for Behavior Analysis (TREBA) attempts to address this issue with the use of small expert-defined programs that characterize animal behavior, trading off substantial amounts of annotation effort for a small amount of these "tasks" with little to no loss in accuracy. In this study, we integrate TREBA's functionality within MARS, allowing for a streamlined way to take advantage of expert-defined tasks and reduce total annotation requirements. Our results show a noticeable improvement in the accuracy of our MARS model when trained using TREBA. The next steps in our research involve retraining TREBA using novel machine learning models, such as the transformer, to see if these can further improve performance.

Development of Electronic Systems for Novel Multi-fan Water Tunnel
Sarah Bass
Mentors: Mory Gharib and Sean Devey

In recent years, the use of fan arrays as an alternative to large wind tunnels has increased due to their ability to simulate a variety of wind conditions. This is advantageous for the testing of Unmanned Aerial Vehicles (UAVs) since ground conditions can be produced. The development of a multi-fan water tunnel seeks to create a smaller and cheaper alternative to large water tunnels, with the reliable ability to simulate a wide variety of environments. It will maintain the ease of analyzing flow using Particle Image Velocimetry (PIV), while also increasing applications. We seek to apply it to a wide range of aerospace applications. For the development of this project, we began with the construction and testing of a small 3x3 fan array. This array was used to develop wiring as well as simulate the expected flow from the full 9x9 fan array. Testing the array in a water tank, we analyzed the flow using PIV data and demonstrated uniformity. We will continue to collect data from the small 3x3 fan array in the form of sensor feedback and by taking that into consideration, we will be able to improve and accurately simulate different flow environments.

Probing CDM Interactions in High-z Galaxy Clustering With the BUFFALO HST Survey
Adele Basturk
Mentor: Charles Steinhardt

Analyzing the clustering behavior of galaxies across a wide redshift range allows us to model the gravitational assembly of such structures over cosmic time. We achieve this by measuring the 2-point correlation of galaxies at $0.01 < z < 8.5$, gravitationally lensed by the foreground cluster Abell370 in BUFFALO. With this understanding, we can probe our current model of Cold Dark Matter (CDM), specifically the assumption that it interacts solely through gravitation. More importantly, studying galaxies at high redshift gives us a more complete picture of clustering at various snapshots in time. In this talk, I will summarize how the correlation function informs us about galaxy clustering behavior, my results from running correlation functions in both the COSMOS 2020 and BUFFALO surveys, and share how predictive clustering calculations at different redshift and mass bins compare to measured correlations.

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

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

High-Resolution Molecular Spectroscopy for Fundamental Physics
Nachiket Bhanushali
Mentors: Nicholas Hutzler and Phelan Yu

Searches for new, beyond Standard Model (BSM) physics can be conducted through precision measurement of fundamental symmetries in heavy, metallic molecules. Ytterbium (Yb)-containing molecules such as YbF and YbOH are highly sensitive to symmetry-violating effects induced by high-energy particles and forces. A prerequisite to manipulating and controlling these molecules for symmetry-violation measurements is a detailed understanding of their internal structure. The vibronic structures of YbF and YbOH, in particular, are known to be heavily perturbed due to the presence of inner-core excitations from submerged f-electrons of Yb, whose impact on the excited electronic structure of these molecules is not yet fully understood. This project explores this f-perturbed electronic structure using laser-induced fluorescence (LIF) on cold, supersonic molecular beams of YbF and YbOH. We discuss the production and optimization of both molecular signals in a supersonic beam machine, as well as the implementation of both broadband, dispersed fluorescence and high-resolution photon counting techniques to characterize internal structures of YbF and YbOH molecules.

Towards an Occurrence Rate of Transiting Planetary Debris Around White Dwarf Stars
Soumyadeep Bhattacharjee
Mentors: Shrinivas R. Kulkarni and Zachary P. Vanderbosch

White dwarf systems hosting debris formed from planetary remnants have recently become a subject of interest. Atmospheric pollution of white dwarfs can be used to study the composition of the accreted planetary material, while the rare systems showing photometric variability due to transits caused by orbiting debris clouds place constraints on the physical mechanisms governing debris generation and transport. In this work, we present an exhaustive magnitude-limited search for transiting planetary debris systems using the Gaia EDR3 white dwarf catalog and the corresponding Zwicky Transient Facility (ZTF) light curves. We apply several variability metrics to the data and concentrate on the most variable sources. Till now, we have successfully identified three new strong candidates for such systems, supported with follow-up observations from the Keck and Palomar Observatories using the LRIS and DBSP spectrographs and the CHIMERA high-speed photometer. We are also partially successful in grouping transiting debris systems, and also several other kinds of variable white dwarf systems, in a multidimensional variability metric space, which helped us in our search for transiting debris candidates. We plan to perform further analysis of the three candidates and also work on calculating an occurrence rate of such systems.

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

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

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

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

Implicit Surface Optimization for Mechanical Material Design
James Bowden
Mentors: Ryan Adams, Deniz Oktay, Mehran Mirramezani, and Yisong Yue

Designing an optimal structure or material with respect to a certain task or criterion is one of the central challenges of engineering. Traditional approaches to topology optimization, such as the classic Solid Isotropic Material with Penalization (SIMP) algorithm, rely on calculating sensitivities explicitly in order to optimize design parameters (e.g., where/how mass is distributed over a domain). Modern automatic differentiation packages such as JAX allow derivatives to be computed easily and in a general, abstract manner through arbitrarily complex (differentiable) functions, and often much more quickly via just-in-time (JIT) compilation. These advances allow for the practical integration of recent machine learning methods. We provide a modular implementation of SIMP using JAX automatic differentiation, and explore the use of implicit surfaces parametrized by neural networks and Gaussian processes in order to model more complex topologies and encode functional priors such as smoothness or geometric symmetries. We utilize implicit surface optimization (ISO) to discover optimal topologies for 2-D mechanical materials, and plan to expand this approach to work generally with more complex physical models such as nonlinear elasticity, as well as create difficult-to-design multi-stable metamaterials.

ZTF Spectroscopic and Photometric Analysis of Type Ia Supernovae for Progenitor Model Separation
Siddharth Boyeneni
Mentors: Mansi Kasliwal and Abigail Polin

The Chandrasekhar progenitor model for a white dwarf star supernova is outdated, with current research implying the existence of other pathways. This project considers a sub-Chandrasekhar detonation pathway, with the understanding that a distinction between this pathway and the standard Chandrasekhar model in observed populations likely comes from the presence of a carbon absorption feature in the spectra. We develop a spectroscopic analysis code capable of fitting spectra and extracting relevant parameters (carbon and silicon features, line velocity, etc.) and test it on several known Ia supernovae (SNe) spectra. This code will then be applied on a significant Zwicky Transient Facility (ZTF) dataset to extract carbon and silicon absorption features, which will then be compared along with photometric data to prior research separating white dwarf supernovae populations by progenitor model using Si II velocity and B-band brightness to see if a similar relationship holds on a larger scale. The results of this relatively large population analysis will aid in disentangling possible progenitor models for these transients, with direct implications for SNe Ia as tools for cosmology.

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

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

Spatial Profile of Topological Edge States in Twisted Bilayer Graphene
Oliver Breach
Mentors: Gil Refael and Iliya Esin

Periodic driving with a circularly polarised laser in the mid-IR range is capable of inducing non-trivial topology in twisted bilayer graphene (TBG). Here, we study the spatial profile of chiral edge states that emerge at the boundary between opposite chiralities of the spatially-modulated driving field. We find that at small twist angles, the induced gap is highly renormalised by interlayer coupling, and the resulting edge states have a large spatial width of order 10-100 nm, which is in the experimentally detectable range. We establish an analytical model based on a continuum approximation about the Dirac points, which predicts the properties of the edge states as a function of twist angle, driving amplitude, and 'sharpness' of the edge. Surprisingly, we found that despite the decrease in moiré unit cell size, increasing twist angle above 1.1° increases the edge state width. We support our analytical predictions by a numerical study based on the Bistritzer-MacDonald continuum model, accounting for the drive through both an effective Hamiltonian and a full Floquet approach. The large size of the edge states may provide a feasible route towards the direct detection of Floquet edge states using time and space-resolved spectroscopic probes.

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

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

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

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

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

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

Mesoscale Modeling of Microstructure Evolution Using Massively Parallel Phase Field Simulations
John (Jeb) Brysacz
Mentors: Brandon Runnels and Melany Hunt

Microstructure evolution at the mesoscale examines the migration of individual grains and their boundaries in a material when stressors are applied. At a point where three grain boundaries meet, a triple junction (TJ) is formed. We use a multiphase field simulation to simulate this migration, where each grain represents a phase and grain boundary energy was taken from molecular dynamics data. We implement TJ functionality into the model to study migration of TJs in a multiphase field simulation. Analyzing triple junction migration is key to understanding the evolution of a material's structure and has major implications for further understanding of the grain structure of polycrystalline materials, such as metals and ceramics that are use extensively in modern technology. Another application of a robust simulation of materials at the mesoscale includes grain boundary engineering, in which grain boundaries are manipulated to improve the properties of a material.

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 at Caltech is currently capable of rapidly performing a massive number of electrochemical processes that could potentially produce ammonia. Designing a Robot Solution Handling System to automatically prepare the resultant samples with the indophenol method and spectrometrically analyze them 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 660nm LED light shining through a 3" long optical absorption path to be measured by a spectrometer on the other end. Python code was written to record the absorption spectrum from the spectrometer. Going forward, the flow cell will need to be implemented into the RSHS. Then, code must be written to make the sample-handling robot prepare samples and then inject them into the electrolyte flow path, and to record the absorption spectrum of each sample to characterize the corresponding electrochemical process on its ability to generate ammonia.

The Effect of Cultivation Season on Mechanical Properties of 3D Printed Spirulina Biomass
Amelia Burns
Mentors: Chiara Daraio and Israel Kellersztein

Spirulina (blue-green algae) is a cyanobacteria which has been identified as a potentially valuable biomass source to replace plastics and wood in the packaging and construction industries, due to its abundance and environmental sustainability. This project uses 3D printing to produce samples of pure dehydrated spirulina biomass. Samples undergo 3-point bending tests to obtain measures of their mechanical properties. We compare properties of samples printed from two different crops of spirulina that were cultivated during two different seasons (spring of 2022 and summer of 2021). We found compositional variations between the different spirulina crops: the crop cultivated in the summer had a significantly higher proportion of proteins, and a slightly higher proportion of carbohydrates. These compositional differences are concluded to be the main contributor to differences in the flexural and rheological properties of 3D printed samples; the spring crop had a higher yield stress and produced samples with a flexural modulus and a lower work to fracture and maximum deflection. Additionally, morphological analysis was performed by scanning electron microscopy to characterize the structure of the fractured surfaces of the final 3D printed samples before and after mechanical testing.

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

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

High Performance Interpolation Strategy for the Interpolated Factored Green Function Method

Joseph Cachaldora
Mentors: Oscar Bruno and Christoph Bauinger

We are concerned with the problem of scattering of electromagnetic and acoustic waves---a problem of fundamental importance in science and engineering, with applications to simulation, design and optimization. More precisely, we focus on the problem of parallelization of electromagnetic solvers based on use of Green functions. This is a well-known problem for which existing algorithms (such as FFT-based methods, or approaches such as the Fast Multipole Method) do not parallelize well---since the communication cost rapidly overwhelms the advantages provided by parallelization. A recent development at Caltech has significantly altered this scenario: the Interpolated Factored Green Function (IFGF) method provides acceleration on the basis of techniques that do not require use of FFTs. This method has been implemented in serial and massively parallel fashion, and we now seek to demonstrate parallelization in systems including GPU hardware (Graphical Processing Unit). In this SURF, we implement a critical component of that method, namely, a recursive local interpolation technique, as an offload to GPU hardware in the context of the overall existing CPU parallel implementation. The approach promises very significant additional acceleration, and should allow for solution of a wide range of important and challenging problems.

Towards Producing Realistic LHC QCD Simulation Using Quantum Generative Adversarial Network Through a Quantum Circuit Ansatz Search

Yiyi Cai
Mentors: Maria Spiropulu, Jean-Roch Vlimant, and Samantha Davis

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

Predicting the Rate of Direct Detection of Dark Matter Using Semiconducting Materials From EXCEED-DM Data

Chi Cap
Mentors: Sunil Golwala and Osmond Wen

We improve the sensitivity estimation of semiconducting (silicon and germanium) dark matter detectors using the improved EXtended Calculation of Electronic Excitations for Direct detection of Dark Matter (EXCEED-DM) data, which recover higher momentum components of electronic transition by implementing all-electron (AE) reconstruction and extending calculation to more electron bands than previously. This result in a more accurate and higher detection rate, especially for experiments with higher energy thresholds and scattering with a heavy mediator. We compare the effect of this improved sensitivity estimation with the previous estimation, by integrating the pre-calculated EXCEED-DM data into the larger sensitivity estimation program and comparing the output detection rate. We expect the direct detection rate will increase with the EXCEED-DM data, and there is subsequent work to be done to reach the final goal, as well as running the EXCEED-DM program to obtain data for a larger range of masses and energy thresholds.

Characterizing Hazardous Near Earth Asteroids Observed by NEOWISE Using an MCMC Thermophysical Model

Joahan Castaneda Jaimes
Mentor: Joseph Masiero

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

Characterizing the Continuum-limit Behavior of Connected Components in the Barely-subcritical Erdos-Renyi Random Graph
Ali Cataltepe
Mentor: Thomas Hutchcroft

Sequences of uniform random graphs on the complete graph have been a popular object of study in combinatorics and probability theory. It is an established result that sequences with edge probabilities that decay harmonically display markedly different asymptotic behavior when the constant in their numerator is greater or less than one, with a giant component existing in the former and all components being identically distributed trees in the latter, with probability approaching 1. While combinatorial methods have been used to great success in classifying such supercritical or subcritical (respectively) sequences, the asymptotic behavior of sequences that are subcritical (resp. supercritical) while decaying slower (resp. faster) than any subcritical (resp. supercritical) harmonic sequence, which we call "barely sub/supercritical," has mostly required probability theory and couplings to better-studied stochastic processes, namely branching processes.

Of interest to us is the "continuum-limit" behavior of a barely subcritical sequence--since component sizes are identically distributed and have a tight asymptotic bound on size, we can interpret the set of components as a collection of compact metric spaces by interpreting them as a path metric space "shaped" like each component and then shrinking them by the asymptotic bound to obtain a sequence of sets of components that do not diverge in diameter. As a component's size is the sole determinant of the distribution of shapes it can take, we can interpret each random graph in the sequence as a discrete point process on measures on measured metric spaces--the number of occurrences of a point, or measure, simply corresponds to the number of components of the size corresponding to that measure. We apply a coupling to Galton-Watson trees and the weak law of large numbers to prove that the limit of these point processes is degenerate, i.e. that the limit of any sequence of measures obtained by picking an arbitrary measure from those obtained in the point process is the Brownian Continuum Random Tree.

The so(8,C) Large Color R-matrix for Quantum Knot Invariants
Alberto Cavallar Oriol
Mentor: Sergei Gukov

Back in 1989, Edward Witten showed how the Chern-Simons Topological Quantum Field Theory recovers polynomial invariants appearing in Knot Theory, such as the well-known Jones polynomial. In the past years, further research in this field has led to stronger invariants of links and 3-manifolds. Among these, the Gukov-Manolescu series proposed recently in 2020 —denoted Fk(x,q)— is a conjectural invariant of knot complements that, in a sense, analytically continues the colored Jones polynomials. Shortly after, Sunghyuk Park introduced the Large Color R-matrix approach for sl(2,C) to study Fk for positive braid knots. At present, this procedure has in turn been extended by Angus Gruen to all other Lie algebras sl(n+1,C) beyond sl(2,C). In this project, after a review on the above-mentioned background and most recent progress, we move on to study the Large Color R-matrix for the family so(2n,C) of complex semisimple Lie algebras in Cartan's classification. Attracted by the three-fold symmetry in the Dynkin diagram D4, we mainly focus on the r-th symmetric representations of so(8,C) through a suitable polynomial representation and explore the corresponding quantum representation to be employed in the Large Color R-matrix.

Feature Selection Using Explainable AI to Refine Associations Between Prominent Genes and Alzheimer's Disease Neuropathology
Aditi Chandrashekar
Mentor: Su-In Lee

A critical focus of Alzheimer's Disease (AD) research is the development of a generalized understanding of the genetic and molecular mechanisms involved in AD. The Multi-task Deep learning for Alzheimer's Disease neuropathology (MD-AD) model, proposed by Beebe-Wang et al. (2021), learns interrelationships between brain gene expression data and neuropathological phenotypes related to AD in a multi-cohort setting. Leveraging Explainable AI (XAI) gives insight into how the model makes these associations. There is reason to believe that reducing the number of genes inputted into the model as features could result in clearer explanations of the model. Here we compare several methods to reduce the number of input genes to the model and discuss their tradeoffs. We show that using post hoc XAI-based gene selection methods to reduce the size of the feature space results in comparable performance to the original, more comprehensive MD-AD model, suggesting that, within the context of this task, the genes most strongly associated with the presentation of neuropathological phenotypes are representative of the full set of features.

Exploring Habit Formation Theories With Large Scale Data for Travel Behavior
Katherine Chang
Mentor: Colin Camerer

Humans regularly make choices influenced by habits. The neural autopilot model for habit formation states that decision-making agents are either in the habit mode and repeat the previous choice if predicted rewards are reliable, or in the goal-directed mode and choose an action probabilistically based on projected reward otherwise. Previous studies applying the neural autopilot model to occurrences in the real world suggest that choice persistence is influenced by habituation and consistent moments of reward. To continue exploring these outcomes, we applied the neural autopilot model to large-scale data for travel behavior in Pasadena over the COVID-19 lockdown from 2019 to 2021. We aim to replicate the neural autopilot habit formation theory under consideration of forced exploration from pandemic restrictions by first examining the travel data for model parameters then replicating results in simulations of individual-level behavior defined by the model. Successful application of the neural autopilot model to the travel data further confirms support of the neural autopilot model in modeling real world activity.

Trail Blazing the Permanently Shadowed Regions of the Moon
Sean Chang
Mentor: Soon-Jo Chung

Lunar permanently shadowed regions (PSR) are areas near the poles of the Moon that never receive direct sunlight. PSR craters contain large quantities of volatiles, making them prime mining targets, and motivate robotic exploration and terrain mapping. However, current wheeled mobility systems utilized by rovers have trouble operating in these regions without solar recharge capabilities. Previously, we proposed a system of cabled paths, marked by carbon fiber stakes at the nodes, which can transfer power and various payloads along the paths. Here we show that rotary drilling stakes is feasible in conjunction with a capstan elevator design. A high-fidelity prototype of the capstan elevator is mounted onto an iRobot ATRV-JR with a custom designed support structure. Prototype testing in Lucerne Valley suggests that cabled exploration of lunar extreme terrain is a possible alternative to traditional wheeled locomotion.

Understanding the Interactions Amongst Solvents, Dispersants, and Powders in Suspensions for Tape/Freeze-Cast Battery Separators
Shivani Chatterji
Mentors: Katherine T. Faber and Chun-Wei (Vince) Wu

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

Creating a Universal Locking Solution for Optical Systems
Rahul Chawlani
Mentor: Alireza Marandi

For many experiments, lasers need a well-defined frequency. Thus, we can stabilize the frequency of the laser by locking the cavity length via a piezocontroller. However, current systems are inefficient and slow. We propose a system to dither lock a laser at a desired frequency in a simple and efficient manner. To achieve this, an FPGA will scan the cavity resonances and then select a desired resonance, dithering the cavity to lock it. A GUI that allows it to be customizable by the user will be created. This locking setup will be continuous and easy to use, with the ability to export to a wide variety of optical setups.

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

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

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

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

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

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

Extension of Shannon Entropy to Finite Categories
Stephanie Chen
Mentor: Juan Pablo Vigneaux

Given any finite set equipped with a probability measure, one may compute its Shannon entropy or information content. The entropy is algebraically characterized by a recursive property known as the chain rule and becomes the logarithm of the cardinality of the set when the uniform probability is used. Tom Leinster introduced a generalization of cardinality for certain finite categories through the Euler characteristic. Our project aims to extend the concept of entropy to finite categories. We first generalize the category of finite probability spaces by endowing finite categories with object and transition probabilities. We experiment with notions of marginalization and conditional probability under probability-preserving functors. We explore functions defined for the finite probabilistic categories that share the recursive property of entropy and further coincide with Shannon entropy for finite sets and relate to the Euler characteristic for a "uniform'' assignment of probabilities.

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

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

Learning to Optimize with Preference Feedback
Chu Xin Cheng
Mentors: Yanan Sui and Yisong Yue

The *Dueling Bandits* problem is a stochastic Multi-Armed Bandits framework for learning from preference feedback, where the learner hopes to choose the optimal action with data given in the form of comparisons from the user. SELFSPARRING is an algorithm for the *Dueling Bandits* problem which views the optimization process as a multi-player cooperative game and can be easily generalized to a setting in which the arms are dependent with each other. *Coactive Learning* is another online learning framework that, instead of receiving preference feedback, obtains suggestions from the user in each round. Combining these two frameworks, the COSPAR algorithm can be implemented in situations with preference or coactive feedback and has seen its application in exoskeleton gait optimization. We provide theoretical analysis for the algorithms KERNELSELFSPARRING and COSPAR and attempt to generalize these algorithms to different online learning settings.

Understanding the Role of Individual Neurons in Visual Perception by Inverting Deep Neural Networks
Emily Choe
Mentors: Ueli Rutishauser and Varun Wadia

As the natural world is made up of objects, understanding how objects are encoded in the brain will open the door to a deep mechanistic understanding of sensory perception. Visual perception (like all sensory perception) arises from the electrical activity of individual neurons in the brain. Therefore understanding how individual neurons encode visual features is a crucial problem in systems neuroscience. Prior work in non-human primates and functional magnetic resonance imaging (fMRI) in humans have revealed that the inferotemporal (IT) cortex harbors a high-level code for visual objects. In this project, we took recordings from the IT cortex in humans as they viewed a wide array of visual objects. We attempt to determine the features of those objects that drive the responses of individual cells. To that end, we reverse engineer the encoding process and produce artificial images based on the neural responses to the stimulus set via a deep generative neural network model. In addition, a closed loop experiment is being attempted to test whether neurons in the IT cortex of a patient show the expected responses to the generated images.

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

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

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

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

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

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

Using CO_2 Ground Flux to Examine Salton Trough Seismic Activity
Norman Chung
Mentors: Joann Stock and Alex Berne

In the past, examining CO_2 degassing has allowed geologists to learn about underlying fault structures. We perform a similar analysis on the faults located around the seismically active Imperial Valley and Salton Trough by looking at the CO_2 flux coming from local mudpot zones. Mudpots are crater-like, geothermal features made when water and/or gas gets forced upwards through soil and sediments. They emit CO_2 and can provide information on fault structures by showing where exactly degassing takes place. Commercial CO_2 fluxmeters, or devices which measure CO_2 degassing rates, can measure CO_2 flux rates but are prohibitively expensive to use at a cost of around $20,000 per commercial unit. We designed working fluxmeters about two orders of magnitude cheaper, used them to take ground and air flux measurements at various Salton Sea mudpot sites, and inverted the data to learn more about the local degassing structures. We hope to facilitate future degassing investigations by making fluxmeter technology more accessible.

RhyoliteMELTS Default Trace Element Partition Coefficients
Griffin Clevenger
Mentors: Paul Asimow and Paula Antoshechkina

RhyoliteMELTS is a thermodynamic modeling program that models phase relations within hydrous silicic systems. RhyoliteMelts can be used to predict the crystallization proportions of high silica rocks as they experience variable low pressure and temperature conditions. As it stands, the rhyoliteMELTS program lacks a default set of partition coefficients for the trace elements present during the crystallization of plagioclase and alkali-feldspars, deterring use of the system from casual users who are not motivated to calculate/input their own partition coefficient values. To combat this issue, the TraceD's data base was used to compile trace element partitioning coefficient data from all existing and pertinent experimental studies. From this data, partition coefficients were averaged for each trace element that is relevant to the crystallization of plagioclase feldspar and alkali-feldspar. These averaged coefficients will be coded into the rhyoliteMELTS software as default partition coefficients allowing the program to be utilized by a more inclusive population while still allowing the option for advanced users to upload their own unique partition coefficient values.

LATTICE: System Integration of a Driving Module for a Stake-Cable Network
Kaila M. Y. Coimbra
Mentors: Soon-Jo Chung, Matt Anderson, and Lu Gan

The Artemis Mission is NASA's next endeavor to bring humans back to the Moon. One of the key pillars of the mission is to expand the range of surface exploration and in-situ resource utilization (ISRU) demonstrations. Craters at the lunar South Pole are of particular interest for ISRU because the permanently shadowed regions (PSRs) likely contain volatiles, such as water ice, carbon dioxide, etc. Robotic technologies capable of navigating extreme lunar terrains, such as steep craters, are now in need. Thus, we present the development of a robotic system, the Lunar Architecture for Tree Traversal in-service-of Cabled Exploration (LATTICE), which utilizes a stake-cable network and tensioning robots for terrain agnostic traversal. This presentation focuses on the system integration of the driving module that will drill three 2 m long stakes into sloped ground for the final technology demonstration in October. This paper also discusses some of the side projects I have been working towards as part of developing skills that are necessary to tackle the technological challenges that arise with robotics projects such as LATTICE.

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

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

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

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

Morse Index of Infinite Families of Minimal Surfaces in the 3-torus
Miles Cua
Mentor: Antoine Song

By rescaling the fundamental domain of a triply-periodic minimal surface, we construct infinite families of minimal surfaces immersed in the 3-torus. To study the asymptotic behavior of the Morse index, area, and genus for these families, we obtain rough estimates with an argument using Schoen's curvature bound for stable minimal surfaces. We then apply the Courant nodal theorem and a domain decomposition method to obtain stronger estimates. In particular, we obtain results for the families obtained from the Schwarz *P* surface and *D* surface.

The Role of Input Time Scaling in Reservoir Computing With Nanoelectromechanical Systems
Isaiah Curtis
Mentors: Michael Roukes, Warren Fon, and Scott Habermehl

Recent advances in nanoelectromechanical systems (NEMS) allow for the construction of scalable and controllable networks of coupled oscillators which serve as promising candidate systems for studying physical reservoir computing (RC). As an approximation to the dynamics of the physical NEMS oscillators, we simulate a network of oscillators with explosive Kuramoto coupling. We use the network of coupled oscillators to do RC by perturbing an oscillator in the network according to an input signal; we then train a linear readout layer to map the resulting response of the network to the input signal in the future. A priori, we expect that the chosen time scale of the input signal that we inject into the network plays an important role in the performance of RC. To test this hypothesis, we use an input signal that is generated by the Mackey-Glass (MG) delay differential equation. By manually adjusting the time scale of our MG signal as we inject it into the network, we compute RC performance as a function of time scale. Although we find an optimal time scale for the MG signal, the network performs well over a broad range of time scales.

2D Dynamic Frame for Flexible Phased Array Shape Calibration Algorithm Development
Saren Daghlian
Mentors: Ali Hajimiri and Oren Mizrahi

Phased arrays, unlike single-radiator, mechanically-steered antennas, are comprised of multiple individual antenna elements that generate interference patterns to electronically steer electromagnetic waves. These arrays have historically been built on thick, rigid PCBs and have been used in a variety of applications, including early radar technology and 5G communication. With the advent of thinner, more flexible PCBs, there has been a growing interest in the development of flexible phased arrays. Unlike their static counterparts, flexible arrays could be used, for instance, in small, implantable biodevices and large, in-orbit power arrays for wireless power transfer. However, since precise antenna element-to-element spacing is crucial for proper beam-steering, the shape of the flexible array must be determined. Therefore, to determine these shapes, researchers in the Hajimiri lab used mutual coupling (inter-element power receiving) by mounting a one-dimensional phased array on different-shaped wooden frames to develop a shape calibration algorithm. Since a two-dimensional flexible array has many more shape conformations than a one-dimensional array, wooden frames can be inefficient and limiting. Therefore, we designed a two-dimensional dynamic frame with a grid of linear actuators as a testing frame for shape calibration algorithm development.

Modular Design of a Rotating Detonation Combustion Chamber With a Premixed Ethylene-Oxygen Mixture
Robert Daigle
Mentor: Joseph E. Shepherd

Rotating Detonation Engines (RDE) are a novel propulsion device utilizing highly energetic detonations to sustain combustion. Experimentation concerning the efficiency, performance, and injector design of an RDE are often segmented into separate experiments. We have designed a modular RDE experimental setup that will allow the varying of several parameters of the injector design while also allowing visualization of the flow within the chamber, differential pressure measurements, and visualization of backflow prior to the injector geometry to help further characterize both the engine performance and the fluid dynamics of the engine.

Engineering an Ultrasound-based Cancer Antigen Detection System Using Gas Vesicle Proteins
Sophie Dalfonzo
Mentors: Mikhail Shapiro and Nivin Nyström

Non-invasive cancer diagnosis methods are important in detecting cancer in its early stages and accelerating treatment. Detecting membrane antigens using synthetic Notch (synNotch) receptors specific to cancer antigens is one way to detect cancer; when paired with a biosensor that gives ultrasound contrast, such as gas vesicles (GVs), synNotch cells can be used with ultrasound imaging to view the presence of antigens. This study designed T cells to respond to cancer antigens such as CD19 by releasing the protein gvpC, which binds to GVs in the cells and changes the GVs', and thus the cells', ultrasound contrast. Cells that release the Gal4 transcription factor to promote production of gvpC and cells that release gvpC directly upon contact with CD19 were engineered. The next step in this project is to test the ultrasound signals of these two types of cells when cocultured with CD19-expressing cells.

Investigating Genotype-Microbiome Interactions on Immune Cells in Mouse Models of Parkinson's Disease
Suchitra Dara
Mentors: Sarkis Mazmanian and Aubrey Schonhoff

Studies have shown that the gut microbiome has a significant impact on the immune, metabolic, and nervous systems through what is termed the 'gut-brain axis'. The microbiome is implicated in the pathogenesis of Parkinson's Disease (PD), as patients develop constipation, dysbiosis, and alpha-synuclein protein pathology in the enteric nervous system. Chronic inflammation has been shown to contribute to the development of PD; studies have identified reactive microglia, the most abundant antigen-presenting cell in the central nervous system, in postmortem brain tissue and alpha-synuclein-reactive T cells in circulation of PD patients. The microbiome is critical for developing the nervous and immune systems, so oversimplified microbiomes in lab mice incompletely model human disease and immune responses. Combining genetic models of PD with complex microbiomes may lead to more accurate phenotypes and reveal roles for interactions between the microbiome, immune system, and genetic risk. The objective of this project is to determine the effect of genotype and microbiome interactions on immune activation in the brain and periphery of genetic mouse models of PD. We investigated microglial activation, T cell infiltration into the brain, and the composition of T helper cell subsets in circulation using fluorescent microscopy, microglial morphology analysis, and flow cytometry.

Doubling Visual Consciousness Using Virtual Reality (VR) for Long-term Adaptation
Anwesha Das
Mentors: Shinsuke Shimojo and Daw-An Wu

Consciousness of one's surroundings, that have a visual origin, is visual consciousness. As illustrated by previous studies, visual consciousness can be manipulated. However, to the best of our knowledge, few, if any, previous studies have explored expanding visual consciousness through systematic manipulation. Attempting to achieve this is, therefore, the primary focus of our study. Additionally, visual consciousness is closely linked to self-location/orientation perception. Therefore, our secondary focus is to investigate changes in bodily self-perception caused.

An initial experiment was implemented: two cameras, mounted at varying distances (that effectively increase interocular distance), capture the participants' surroundings. This feed is rendered individually to each eye using a VR headset. Distances between the cameras are varied across trials, and the participants' task is to achieve fusion of their surroundings.

Exploratory observations suggest that one is able to fuse their surroundings at significantly large effective interocular distances, and that the observed surroundings get smaller with increased interocular distance. Consequently, we suggest that this experiment will serve as training between a pre/post test experiment for depth disparity. A changed threshold will indicate that basic changes in stereo fusion mechanisms have occurred. Additionally, qualitative observations will be collected to summarize changes in bodily self-perception.

On the Secular Dynamics of Putative Primordial Scattered Disk in the Outer Solar System
Arnav Das
Mentor: Konstantin Batygin

The trans-Neptunian scattered disk exhibits unexpected dynamical structure, ranging from an extended dispersion of perihelion distance to a clustered distribution in orbital angles. Self-gravity of the scattered disk has been proposed in the literature as an alternative mechanism to Planet 9 for sculpting the orbital architecture of the trans-Neptunian region. The numerics of this hypothesis have hitherto been limited to $N < O(10^3)$ super-particle simulations that omit direct gravitational perturbations from the giant planets and instead model them as an orbit-averaged (quadrupolar) potential, through an enhanced J_2 moment of the central body. Such simulations reveal the onset of collective dynamical behaviour—termed the "inclination instability"—wherein orbital circularisation occurs at the expense of coherent excitation of the inclination. Here, we report $N = O(10^4)$ GPU-accelerated simulations of a self-gravitating scattered disk (across a range of disk masses spanning 5 Earth masses to 40 Earth masses) that self-consistently account for intra-particle interactions as well as Neptune's perturbations. Our numerical experiments show that even under the most favourable conditions, the inclination instability never ensues. Instead, due to scattering, the disk depletes. While our calculations show that a transient lopsided structure can emerge within the first few hundreds of Myr, the terminal outcomes of these calculations systematically reveal a scattered disk that is free of any orbital clustering.

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

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

Chiral and Mass Corrections to $B \to D^* X$ Decays
Mentor: Michele Papucci

We determine chiral and heavy quark mass corrections to the decays of B mesons into D^* mesons and pions. To that end, we write the most general Lagrangian for the ground state heavy spin-flavor multiplet up O(1/M) and O(1/Λ), and also match the weak flavor changing quark current to HQET at that order. By integrating out the excited degrees of freedom, we gain an improved effective Lagrangian, and the current gains chiral corrections. We use that to compute amplitudes and display the corrections to the Isgur-Wise functions at that order. Corrections due to SU(3) chiral symmetry breaking are also envisioned.

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

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

Minimization of the *E. coli* Genome
Maya de Luis
Mentors: Kaihang Wang and Russell Swift

Minimizing an *E. coli*—a model organism for synthetic biology—genome involves taking out all the nonessential genes (genes not necessary for the organism's survival), while keeping the essential (those necessary for survival) and quasi-essential (those necessary for *E. coli* growth) genes. A minimized genome creates a greater opportunity for genetic reprogramming as well as gaining new insights in bacterial physiology. REXER/GENESIS is a process created by Dr. Wang to introduce synthetic DNA fragments into *E. coli* genomes. This is achieved by using CRISPR/Cas9 to generate double stranded breaks in genomic DNA and homology directed repair to integrate synthetic DNA (REXER). Doing this iteratively (GENSIS) can result in a completely synthetic genome. Although typically used to insert synthetic fragments into a genome, this process has been adapted for large segment deletions.

Tracing the Evolution of Chloride Channels
Lily DeBell
Mentors: William Clemons, Jr., and Shivansh Mahajan

ClC proteins are a superfamily of chloride/hydrogen antiporters, including both chloride channels and transporters. These proteins play a central role in biological processes by enabling transport of chloride ions into cells across a proton gradient. The structure of the *E. coli* ClC consists of an inverted-repeat topology in which the N- and C- terminal subdomains are nearly identical but flipped relative to each other. Such topology is believed to have arisen from an ancient gene duplication. We aim to determine if there exist bacteria and archaea which possess "half-repeat" ClCs which lack inverted topology and therefore the gene duplication. Multiple sequence alignment between the *E. coli* ClC and bacterial and archaeal genomes revealed many ClC candidates. Some candidates appeared to have half-repeat subunits which could dimerize to form a full-length ClC. Ongoing work focuses on performing expression and purification of half-repeat ClC candidates to demonstrate the existence of half-repeat ClCs.

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

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

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

Abstract withheld from publication at mentor's request.

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

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

The New Face of Political Advertising: Using Image Sentiment Analysis to Classify Tone in Political Campaign Ads
Sreemanti Dey
Mentor: R. Michael Alvarez

The current political climate of the US naturally induces questions regarding partisanship and voter turnout. In recent times, the role of political ads on social media and other sources of content in influencing voting decisions such as turnout and candidate choice has become an important area of political science. According to Brader, there are two main strategies employed by political ad videos to influence potential voters: positivity, to inspire enthusiasm in voters about their own party, or negativity, to encourage vigilance against the opposing party. We thus arrive at a need for a scalable method to assess the emotional content in political advertisement videos. Our contributions are to develop such a method, and to assess the emotional content of political ads from the 2020 presidential election. The method developed involves using a 3-stream transformer-CNN network to do sentiment analysis on the frames of ad videos, and then aggregate them into a total binary classification of positive or negative. The transformer-CNN network consists of 3 streams: ResNet101 on full image, ViT Transformer on full image, and ViT on RCNN-recognized objects. Several results about political ads in 2020 are drawn after applying the method to a comprehensive ad dataset.

BURST Imaging in Gas Vesicles
Marama Diaz-Asper
Mentors: Mikhail Shapiro and Rohit Nayak

Gas vesicles are protein nanostructures filled with gas, found naturally in bacteria, with the purpose of serving as a regulator for the depth position in water. These structures provide significant potential for improving ultrasound imaging results. These vesicles can act as contrast agents in noninvasive ultrasound imaging and allow for a greater depth in the patient, visualizing much farther versus conventional imaging techniques, therefore allowing access to what would be other accessible tissue. This project works to explore possible variables which might improve, inhibit or otherwise affect in some way the quality of the image produced by the ultrasound. The focus has been primarily using BURST imaging to take either ANA wild type or stripped gas vesicles to try and observe subharmonics within their corresponding received wave.

Optimization of Autonomous Vehicles Testing Through Symmetry Mapping
Andy Dimnaku
Mentors: Richard Murray, Josefine Graebener, and Apurva Badithela

Testing of autonomous vehicles has become increasingly important in safety-critical environments requiring several rigorous tests to ensure safety. However, running through all these is expensive and time consuming. In order to test efficiently, it is necessary to make it so that tests do not overlap in what they cover. Symmetry mapping allows for a way to recognize if tests are equivalent. Symmetries map the states of different tests and check if they are similar by comparing the internal parameters and robot pos trajectories. They can be tested through simulation by setting up the different tests and using the results to find the relation between the parameters and how to map

them against one another. This allows for a mapping to be created between a static open loop test (e.x. car stopping at a barrier) and a dynamic open loop test (e.x. 2 car avoiding a head on collision).

Self-Supervised Discovery of Robust 3D Keypoints
Amil Dravid
Mentors: Pietro Perona and Jennifer Sun

Studies of animal behavior often require 3D pose estimates at each frame, which are difficult and expensive to obtain either through human annotations or motion capture setups. Self-supervised learning can potentially alleviate this burden due its ability to make use of the representations it learns from its inputs without labels. We propose a self-supervised framework for 3D keypoint discovery. Our method relies on a multiview stereo setup where an encoder-decoder architecture learns to reconstruct the spatiotemporal difference between video frames. The network's geometric bottleneck outputs 2D keypoint information as well as depth, which can be combined with the camera parameters to construct 3D keypoints which are consistent among all views. We find that our framework can capture semantically meaningful keypoints on the Human3.6M Dataset. We envision that this method can be applied to extract meaningful representations on biomechanical or laboratory animal datasets, such as Rat 7M, for successful downstream applications.

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

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

Neural ODEs for Latent Feature Recurrence in Streaming Perception
Zack Dugue
Mentors: Yisong Yue and Ivan Jimenez

Streaming perception is a type of computer vision used to label the location and class of objects in a stream of video in real time. Current streaming perception architectures rely on rapid inference that can be completed before the next frame of video is available. This means that, for each frame, a great deal of latent feature extraction occurs, but these latent features are essentially thrown away when the next frame is considered. We propose a novel architecture which utilizes a neural ODE to maintain a continuous state between frames, thus allowing features from prior frames to impact the inference of the current frame. By training and testing this architecture on the ArgoverseHD streaming dataset, we hope to show improved performance on streaming perception benchmarks. We hope that this architecture will allow for more parameter-light, more accurate streaming perception architectures for applications such as autonomous driving.

Laboratory Investigation of Dust Impact Ionization Charge Yield on Gold Target
Katy Edwards
Mentors: Zoltan Sternovsky, Jonathan Katz, and Libor Nouzak

Impact ionization is an important concept for cosmic dust impacts. Cosmic dust can strike mechanical bodies in space at extremely high speeds causing particles to partially ionize. The resulting charge from this ionization on a specific target can be found. A certain relation between a particle's mass and velocity gives charge yield of the impact. The dust accelerator operated at the University of Colorado is used to investigate impact ionization properties including charge yield of iron dust particles impacting a gold target surface. A grid with an applied bias voltage of either -230V or +230V was attached above the target in order to separate out specific particles, ions and electrons respectively. By shooting particles with the same velocity ranges for different signs of bias voltage, differences in data can be observed. The data collected showed there were only slight differences in charge yield for each bias voltage.

In Silico and In Vitro Determination of Autophagy Initiation Protein Binding Motifs
Nohami Elias
Mentors: Tsui-Fen Chou and William Rosencrans

Mitophagy, selective autophagy, is the process by which cells isolate and degrade damaged or superfluous mitochondria. Defects in mitophagy are particularly deleterious in neurons given the high energy demands of the cells; the resultant accumulation of impaired mitochondria–which heightens production of damaging chemicals such as reactive oxygen species, ROS levels and inhibits mitochondrial biogenesis– has been implicated in the development of neurodegenerative diseases. Inducing mitophagy may therefore represent a therapeutic avenue towards treating neurodegenerative conditions like Alzhemier's and Parkinson's Disease, and, in restoring mitochondrial homeostasis, may allow for reversal. Current mitophagy-inducing drugs are either nonspecific, or directly damage healthy mitochondria.Without harming mitochondria or the cell as a whole, the proposed therapeutic, a mitochondria targeting chimera (MitoTac), relies on exploiting native pathways to specifically induce mitophagy. To begin the development of the autophagy initiating protein directed portion of the chimera, a DNA encoded library screen was conducted wherein small molecule and fragment binders to three constructs of the protein were determined. Disparity was observed in the set of binders for theC-terminal/Leucine-zipper domain of the protein with and without a known binding partner, further motivating a structural analysis of binding mechanisms. In Silico modeling was conducted utilizing AutoDock, a ligand-protein docking engine; rescoring and hit validation was completed using deep-learning generated property matching decoys (DeepMOL) and the CNN-network generated kDeep program. For in vitro studies, crystal complexes were generated via hanging-drop vapor diffusion method. Models from X-ray crystallography results are to be generated via Pan-Dataset Density Analysis (PanDDA), which has the potential to exceed the accuracy of conventional methodologies given the deduction of ground state charges. Docking simulation output (visualized in Pymol) suggests that binding primarily occurs in the dimer interface of the protein, and the bound state opens a deep hydrophobic pocket within said interface where fragments bind to with moderate affinity. Merging and linking of co-localized and adjacent fragments, respectively, will be conducted to form a potent small molecule.

Time-Bin Quantum Key Distribution Key Exchange
Ismail Elmengad
Mentors: Maria Spiropulu and Anthony LaTorre

Quantum Key Distribution (QKD) enables two parties, Alice and Bob, to achieve information-theoretic secure communications. This means that no amount of computational resources will allow a third party access to Alice and Bob's communications. Qubits can be encoded in several ways. This project will use a time-bin protocol to exchange qubits. Photons are prepared either in the time basis where they fall into an early or late time-bin analogous to 0's and 1's in classical information, or they are prepared in the phase basis which is a superposition of early and late states. By characterizing the various factors that affect Qubit Error Rate (QBER) such as dark counts, pulse width, QBER stability, phase modulation etc. we hope to achieve efficient key exchanges of arbitrary length through fiber optic mediums. QKD is an exciting prospect for secure communications both through fiber optics and in line-of-sight free space environments.

Developing a Quantum Key Distribution System at Caltech
Gabriel Fabre
Mentors: Maria Spiropulu, Anthony LaTorre, and Raju Valivarthi

The BB84 protocol for quantum key distribution allows for secure transmission of a cryptographic key. Ideally, single photon qubits are used, but this is difficult in practice. Because of this, photon number splitting (PNS) is a viable attack, among others, as duplicate qubits can be measured by an eavesdropper after the encoding basis is revealed. We are upgrading and testing a quantum key distribution system involving time-bin qubits. This involves programming updates to the software for generating sequences, interfacing with detectors and displaying measurement correlations, and performing fitting of phase error that is used to detect the presence of an eavesdropper. Setup, characterization, and calibration of optics equipment is required. Having a working, customizable system will allow for further research on attacks, such as by implementing the decoy state protocol to prevent PNS attacks, optimizations of equipment and software, and interfacing with other systems that would form a quantum network.

Analyzing Surface Starspot Coverage of Young Stars Using Simultaneously Taken TESS and Veloce Data
Elizabeth Field
Mentors: Benjamin Montet and Nick Hutzler

In 2020, Michael Gully-Santiago et. all found the surface starspot coverage of the young star, LkCa4, to be approximately 80%. Considerably higher than the less than 10% expected from sun-like stars, we studied 11 young stars simultaneously surveyed by the Transiting Exoplanet Survey Satellite (TESS) and Veloce Spectrograph on the Anglo-American Telescope to analyze the continuation of this trend and how it may affect the stars and their systems. Each star's coverage is determined by a ratio of relative cool and warm spots. This ratio is displayed by the changes in flux as a function of wavelength near each of the 15 strongest TiO lines within Veloce's range and their corresponding times of observation on their TESS-found light curves, where greater changes in flux indicate cooler surface temperatures and evidence of star spots. Thus, we averaged the changes over these 15 lines at multiple points in each stars' rotational phase to reveal trends in spot coverage, yielding discernable results for 9 of the 11. We will use this spot coverage data to understand how starspots size changes on low mass stars throughout their first 100 million years of life.

Genetically Encoded Reagentless Nicotine-Sensing Current Reporter (rNicSnCR)
Eve Fine
Mentor: Henry Lester

Nicotine, the addictive substance in tobacco, is present in many products such as cigarettes, cigars, chewing tobacco, and electronic nicotine delivery systems (ENDSs). Approximately 50 million Americans frequently use one or more one of the nicotine-containing products, making nicotine addiction the most common addiction in the United States[1]. Nicotine addiction underlies tobacco smoking; more than 16 million Americans suffer from a smoking-related disease, which makes smoking the leading cause of preventable health problems. Treating tobacco addiction is becoming an example of personalized medicine. The most effective technique for recovery is determined best when the pharmacokinetics of nicotine in an individual is known (personal pharmacokinetics). For example, those with defective cytochrome P450 2A6 have better success quitting smoking with drugs (such as bupropion) rather than the use of nicotine patches. How can one measure nicotine pharmacokinetics in an individual? The Lester lab develops biosensors for various drugs, including nicotine. These biosensors typically include a periplasmic binding protein (PBP) which can bind the drug of interest with its 'Venus fly trap' mechanism. In previous work, when the PBP binds the drug, a GFP region of the biosensor fluoresces. Essentially, this protein acts as a switch; when it is on and glowing there is drug bound, when it is off there is no bound drug. Now, the Lester lab aims to invent a more robust, less invasive biosensor, by retaining the PBP "switch" but eliminating the fluorescent group. Such a protein molecule will have a biosensor that has a PBP with a redox center attached to one flap of the "Venus flytrap". The movement of the PBP due to drug binding would cause the redox group to approach the electrode. This change in distance would result in a change in current, as when it is closer more current will be produced. Overall, the mounting of this PBP with a redox group onto an electrode will result in the ability to continuously monitor the nicotine concentration in a solution, with the ultimate goal being to use this as a way to detect nicotine concentration by sweat as a wearable device.

Program Learning for EKG Heart Attack Detection
Joshua Flashner
Mentors: Yisong Yue and Jennifer Sun

Deep learning provides valuable tools for diagnosing heart disease in a clinical setting. In this study we seek to implement an interpretable model for detecting myocardial infractions from EKG readings and predicting the localization of these infractions in the heart. A baseline result is determined using a one-dimensional convolutional neural network with patient data provided by Cedars-Sinai Medical Center. We then use the neurosymbolic model NEAR to learn an interpretable program for detecting myocardial infractions and localization. Our model selects relevant leads from EKG readings and performs segmentation on each peak. We then learn filters corresponding to important indicators of myocardial infraction. Performance of this model has yet to be tested on patient data. Possible improvements can be made to the DSL by including hand crafted segmentations and peak statistics.

An Analysis of the Magnetic Field of the Floor in EB1
Jessica Fox
Mentors: Bradley Filippone, Alina Aleksandrovna, and Marie Blatnik

At the SNS at ORNL, we are working to find the neutron electric dipole moment (nEDM). The magnetic field gradient must be minimized to prevent a false positive in our search for the nEDM. For the experiment, the cryostat is shielded by a mu metal shield. This shield is necessary to prevent the interaction between a superconducting magnet and the external magnetic field. However, the rebar in the floor became magnetized with field strengths unacceptably high and non-uniform, specifically in places overlapped by the shield and the cryostat. This can cause saturation of the shield, which will in turn affect the magnetic field inside the cryostat. To dampen the effects of the magnetic field from the rebar, and to make it more uniform, we placed .25-inch-thick steel plates over the floor. We then carried out a magnetic field map and plate characterization, including an analysis of perturbations due to imperfections in the steel, both at ground level and one foot above the ground.

Using Remote Sensing to Monitor Changes in Groundwater Storage at Local Scales
Tea D. Freedman-Susskind
Mentors: Rosemary Knight, Bethany Ehlmann, and Aakash Aahamed

Recent changes to temperature and precipitation patterns have resulted in severe drought in many parts of the world, in turn limiting surface water availability in these regions. During droughts, communities in arid regions rely on groundwater to satisfy water needs. However, if groundwater consumption outpaces recharge, groundwater storage will decrease over time. Due to on-the-ground data requirements, current methods to assess changes in groundwater storage are often years out of date. For local scale applications, these methods include (1) well-based estimates and (2) groundwater flow models. Up-to-date estimates of changes in groundwater storage are crucial to ensure water security in a warming world. A promising novel approach is to use a combination of remote sensing and ground based data to estimate changes in groundwater storage through solution of the water balance equation. This technique benefits from rapid computation, transferability, and a reduced need for ground based data. The goal of this study is to apply the remote sensing-based water balance technique to estimate changes in groundwater storage in a small (2846 km^2) region of the Central Valley of California, and compare the results to independent estimates derived from wells and a groundwater model. Preliminary results exhibit modest agreement with well-based and model-based estimates, but are very sensitive to changes in the surface water boundary conditions which account for rivers and aqueducts transporting water to and from the region. . Further work will focus on the transferring and comparing the model to independent estimates of changes in storage to other subregions within California's Central Valley.

Supporting UAV Autonomy With Application to Volcanic Sciences
Diana Frias Franco
Mentors: Soon-Jo Chung and Matt Anderson

Volcanoes are one of nature's most colossal forces. Observing and measuring topographic changes of a volcano is key to helping scientists understand the processes that cause eruption and erosion of landforms. To achieve this, volcanologists study maps of the ground surface called Digital Elevation Models (DEMs). DEMs can be produced through UAV-based photogrammetry, in which UAVs are used to capture aerial images of the surface of interest and then the images are processed through a Structure from Motion (SfM) pipeline to perform topographic reconstructions of a terrain and measure distances between objects in the photographs. This research focuses on using the existing image-capture and GPS capabilities of our current fumarole-sampling Volcano Drone and the SfM workflow from OpenDroneMap, an open source photogrammetry tool, to georeference the 3D point cloud model SfM produces and then generate these DEMs. To evaluate the results, flight paths with varying overlap and sidelap percentages were flown for testing of the Caltech North Field, and the produced DEMs were compared with satellite images of the terrain surface and elevation data. Encouraging results demonstrate that our open-source DEM generation workflow is comparable to commercial photogrammetry softwares for larger terrains, ultimately providing a means for generating high-quality, low-cost DEMs.

Structural and Functional Analysis of the Assembly Sensor for the CFNC Hub of the Nuclear Pore Complex
Jessie Gan
Mentors: André Hoelz and Si Nie

The Nuclear Pore Complex (NPC) is a protein complex that is the sole pathway through the nuclear envelope, a key regulator for gene expression. Elucidation of its molecular structure has implications in the function of the NPC and disease mechanisms. The majority of the cytoplasmic filament nucleoporin complex (CFNC) and outer membrane coat nucleoporin complex have been reconstructed, however, the CFNC with its assembly sensor linker, Nup37, in *Chaetomium thermophilum* (ct) has yet to be elucidated. We produced, purified, and complexed the CFNC-hub and Nup37 using standard bacterial expression systems and purification methods. In order to obtain the crystal structure, we conducted hundreds of crystal screens with the hanging vapor drop diffusion method. We observed one possible crystal hint and performed additional refinement screens. We continue to refine the crystal conditions, and are working towards obtaining diffractable crystals for x-ray crystallography and structure refinement, with the ultimate goal being to uncover the molecular mechanism behind the CFNC-hub and assembly sensor interaction.

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

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

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

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

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

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

GPU-accelerated Monitoring of High-rise Building Motions and Deformations
Diego Garcia
Mentor: Monica Kohler

Interest in providing continuous insights on structural health monitoring have led to the contribution to a project aiming to create a proof of concept for a new system that assesses structural damage in buildings. This project is part of the Community Seismic Network. Currently, it is unclear how to accurately and consistently quantify the probability that an earthquake caused extensive damage to a building for people that may be inside, in order to conduct rapid emergency response. The aim of this project will be to provide a system to accurately provide feedback on the state of the structural integrity of the building, and help prevent disasters and to provide immediate response to extensive damage. This method takes advantage of the development of GPU algorithms so that they can be applied to multiple buildings in parallel without needing extensive information or physical modeling specific to the building in advance.

Validating Variable Star-formation Conditions in Galaxies
Ethan Garcia
Mentors: Charles Steinhardt and Dave Stevenson

The stellar initial mass function (IMF) describes how many stars at different masses are formed in a galaxy. The IMF should not be expected to be universal across galaxies based on theoretical models, but due to a lack of observational evidence, codes that determine galactic properties from photometry such as redshift, stellar mass, and star formation rate implicitly assume a certain IMF for all galaxies, an incorrect approximation. To resolve this, recent research parameterized the IMF in photometric template fitting of galaxy catalogs with the EAZY fitting code, suggesting that most galaxies form less light-mass stars and more higher-mass stars than in the Milky Way. In this paper, we also implement a parameterization of the IMF in photometric template fitting using "Le Phare", a separate fitting code that fundamentally differs from EAZY. The best fit Le Phare templates on the COSMOS catalog suggest systematic variations in the IMF over redshift consistent with the population distributions found with EAZY, verifying this relationship. Furthermore, not only does the fitting yield modified values for various key galactic properties, but it also validates a more complete picture of galactic evolution.

Characterizing the Photometric Variability of AGN and Starburst Galaxies With ZTF and NEOWISE
Martin Gascue
Mentor: George Helou

We study the 5MUSES sample of 330 galaxies, which contains active galactic nuclei (AGN)-dominated sources and star formation (SF)-dominated galaxies, as well as SF-AGN composite galaxies. After careful recalibration and derivation of extended photometry from the original database images, the light curves for both infrared (WISE/NEOWISE) and visible light (ZTF) are generated. Statistical analysis of the light curves allows to quantify and characterize the variability signatures of the 5MUSES sources in both bands. In addition, a qualitative classification made by eye is performed to verify the relevance of the quantitative analysis. We compare the variability in the infrared and the visible, and identify galaxies with extreme behaviors such as strong variability in both bands (3 %) or strong variability in one band and no variability in the other (7.8 %). We study the relation of the variability to the spectral signatures of AGN/SF source of luminosity, using in particular the 6.2 μm polycyclic aromatic hydrocarbon equivalent width (PAH EW). The correlation between the luminosity source of the galaxies and their variability confirms that AGN dominated sources tend to show more variability than star-forming galaxies, presumably due to the modulation of black hole accretion. We find that photometric variability alone in either visible or IR band is not sufficient to predict the source of luminosity of galaxies, but the variability behavior of galaxies is fully consistent with spectroscopically identified AGN activity being the only source of photometric variability. Variability is also a promising tool for the study of AGN-SF composite galaxies.

Characterizing Autonomic Dysregulation by Inter-ictal Epileptiform Discharges With Intracranial Recordings in the Human Brain
Mahideremariyam Gessesse
Mentors: Ueli Rutishauser, Chrystal Reed, and Clayton Mosher

While abhorrent electrical activity has been connected with cardiac dysfunction in the literature, the exact relationship between inter-ictal epileptiform discharges (IEDs) and cardiac function is not well understood. My previous work indicated that the transient cardiac dysregulation around the time of an IED seen in cats can also be observed in humans using metrics of cardiac function calculated from 2 lead EKG recordings and EEGs scored for IED occurrence within a 60-second window. This project aimed to test the preliminary findings of my last SURF. After increasing the patient population included in the study and improving the time frequency analysis methods used, I found that with IED events pooled from 27 separate recording trials, parasympathetic activity, heart rate, and heart rate variability increase in a window around an IED (window size= 240s, 60s, and 60s respectively). These findings are self-consistent since heart rate variability is expected to increase with increased heart rate and high parasympathetic activity is correlated with increased heart rate variability.

The next steps are to confirm the transience of the observed effects by increasing the window sizes used and to further test the significance of these findings by bootstrapping. This project, if transience is confirmed, will be the first to characterize the effect of IEDs on autonomic control at this time scale in humans.

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

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

An Improved Inpainting Technique to Separate the Kinematic Sunyaev-Zel'dovich Effect From Millimeter Observations of Galaxy Clusters
Max Gilligan
Mentors: Sunil Golwala and Junhan Kim

Cosmic microwave background (CMB) photons experience inverse Compton scattering by electrons in the intracluster medium of galaxy clusters. The peculiar velocity of these electrons causes millimeter-wave spectral distortions of the CMB spectrum. This phenomenon, known as the kinematic Sunyaev-Zel'dovich (kSZ) effect, provides a means to calculate the peculiar velocity of the intracluster medium. The inpainting technique isolates the kSZ signal from the CMB signal by reconstructing the undistorted CMB map throughout the galaxy cluster using the CMB data from surrounding regions. We used simulated galaxy cluster data to improve the inpainting technique. Firstly, we apodized the combined CMB and kSZ map, which eliminated edge effects. Secondly, we employed the kSZ covariance matrix to estimate the CMB modes by finding the amplitudes that minimize the chi-squared of the arising CMB power spectrum to the known CMB power spectrum. We then reconstruct the CMB map by using the estimated mode amplitudes and remove it to get the kSZ map. This process allows us to use the entire combined map by giving a "weight" to each pixel. We worked out the formalism analytically and are continuing to program for implementation. Once the kSZ effect data is isolated, it can be used to study the motion and behavior of galaxy clusters, which will further the understanding of the formation and evolution of individual galaxy clusters as well as the large-scale structure of the universe.

Graphene Growth and Strain Engineering
Ben Gladwyn
Mentors: Nai-Chang Yeh and Yinan Chen

Monolayer graphene has been synthesized by single-step plasma enhanced chemical vapour deposition without active heating and optimized by tuning the duration, microwave (MW) power and feedstock gas ratios. The as-grown graphene has been characterised by Raman spectroscopy, and the strain-free and defect-free monolayer graphene sheets selected from Raman spectroscopic studies will be used for nanoscale strain engineering by placing them on SiO2/Si substrates with nanostructures developed by electron-beam lithography. The architected nanostructures on the SiO2/Si substrates will be imaged by scanning electron microscopy (SEM). LAMMPS ('Large-scale Atomic/Molecular Massively Parallel Simulator') has been used to model the deposition of monolayer graphene onto silicon nanostructures arranged in a Kagome lattice. The strain induced by periodic nanostructures will be determined and the associated pseudo-magnetic fields calculated.

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

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

Environmental Simulation of Spatially- and Temporally- Varying Conditions for Underwater Navigation
Shir Goldfinger
Mentors: John Leonard, Brendan William O'Neill, and Melany Hunt

Underwater navigation lends itself to inherent obstacles, as the undersea environment severely limits the senses that humans typically use to navigate and thus makes it difficult for a diver to know his/her position as well as any target destination's location during a dive. In understanding a diver's desired target and physical limitations/preferences, an Autonomous Underwater Vehicle (AUV) can work together with a diver by bringing more reliable navigation and robustness to a particular mission. To offer the most efficient path, an AUV must incorporate changing environmental conditions into its localization and mapping algorithms in order for a diver to successfully and efficiently navigate to a target. And so, we developed an environmental model of spatially- and temporally- varying current conditions in simulation software. By utilizing an AUVs sensor data on ocean currents and bathymetry from an initial survey, the environmental model could be used to allow for more robust diver localization and navigation. With more precise planning to a particular target, divers could participate in more complex diving missions in a safe and efficient manner, as well as gain flexibility in choosing a mission path.

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

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

Improving UAV-Based Volcanic Lake Sampling Methods
Michael Gonzalez
Mentors: Soon-Jo Chung and Matthew Anderson

Volcanic eruptions can seriously damage human establishments and natural ecosystems. One way of preventing this is to predict eruptions early enough to evacuate at-risk areas. A well-documented prediction method involves sampling water from volcanic lakes using passive sleeves. However, these sleeves are prone to degassing during collection and transportation. In this presentation, we propose a collection system utilizing actuated flasks to collect and store samples without risk of degassing. We implement several improvements on an existing UAV intended to deploy the sampler. We then perform field tests with the sampler and UAV to assess its reliability and success rate relative to current methods. We find that the prototype system is adequately suited for UAV deployment and reliably produces higher quality, more representative water samples than from passive sleeves. With further development, volcanic activity predictions can improve in both consistency and timeliness, saving lives in the process.

Universality Theorems for Random Groups
Elia Gorokhovsky
Mentors: Melanie Wood and Omer Tamuz

In probability theory, universality is a widespread phenomenon where combining many independent variables in particular ways results in a "universal" random variable which is essentially independent of the distributions of the constituent random variables. Universality is very broadly useful because it helps us understand complex systems with lots of moving parts, despite not having complete information about smaller-scale randomness. We aim to use the same approach to understand groups, foundational mathematical structures that have been the source of open problems for decades.

Prior work (Wood, 2019) has shown that there is a form of universality for random finite abelian groups arising as cokernels of random matrices. This work has remarkable applications to number theory, topology, and combinatorics. There is a conjectural universal distribution on general random groups, which agrees with known results for abelian groups. We consider random nilpotent groups, obtaining a strict generalization of the abelian case that further supports the conjecture, and explore generalization to random non-nilpotent groups. Our future work will build on these results to establish universality theorems for general random groups.

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

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

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

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

Uncertainty Quantification in Machine Learning With Applications in Aerospace
Hannah Grauer
Mentors: Soon-Jo Chung, Sorina Lupu, and Kai Matsuka

Uncertainty Quantification (UQ) can lead to better trained and optimized networks by providing information about the uncertainty in the machine learning algorithm. We apply UQ in machine learning to vision-based inspection of a formation flying spacecraft to classify spacecraft parts. We show how BNNs using Monte Carlo and variational inference can be implemented as part of a Convolutional Neural Network (CNN). We compare the performance of the BNNs with Deep Ensembles and deterministic CNNs. Additionally, we investigate the role of prior functions in BNNs. These results are important in aerospace applications for implementing autonomous algorithms on costly missions.

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

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

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

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

Enhancing Hydrogen Adsorption Enthalpy via Atomically Dispersed N/Cu Sites on Carbon
Tomas Grossmark
Mentors: Brent Fultz and Cullen Quine

Sorbent based hydrogen storage is a promising option for long duration renewable energy storage. Activated carbon is a strong candidate as a hydrogen storage adsorption material due to its high specific surface area and porous structure. However, it is necessary to increase the sorbent sorbate bond strength to create an activated carbon with a sufficient uptake of hydrogen at ambient conditions. Previously, the addition of copper into super activated carbon was shown to form copper nanoclusters when heated. These nanoclusters chemisorbed hydrogen more strongly than desired. In this study, the effect of adding various concentrations of copper into multiple activated carbons is studied, as well as the effect of nitrogen doping before copper functionalization to pin down copper atoms and create single atom metal sites. It was found that copper functionalization caused a decrease in

BET surface area pore volume, however functionalization without nitrogen doping did not significantly modify the pore size distribution of MSC30. Additionally, MSC30 had a larger hydrogen uptake than ACF25 when functionalized.

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

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

Self-Supervised Learning on Surgical Datasets
Eshan Gujarathi
Mentors: Anima Anandkumar and Dani Kiyasseh

There is an abundance of surgical data and applying Machine Learning techniques to this data can help surgeons in providing surgical step recommendations and analyzing useful information from the data. But most of this data is unannotated, which restricts the use of traditional machine learning paradigms like supervised learning. Data labeling is expensive, time-consuming, and needs specialized experts, particularly in the surgical domain. Thus people adopt self-supervised pre-training followed by fine-tuning on smaller datasets. Self-supervised learning methods aim to provide powerful deep feature learning without the requirement of large annotated datasets, thus alleviating the annotation bottleneck that is one of the main barriers to the practical deployment of ML today. This also makes it easily scalable to larger datasets. Since surgical images are a lot different from natural images, it intuitively makes more sense to pre-train on surgical data. We thus explore the use of self-supervised pre-training on surgical images using Vision Transformers and compare it with other pre-training approaches on natural images, which is the current go-to approach for any task in the surgical field.

Self-supervised Greedy Learning for Dynamic-Contrast-Enhanced MRI Reconstruction
Arushi Gupta
Mentors: Shreyas Vasanawala, Batu Ozturkler, and Katherine Bouman

Magnetic Resonance Imaging (MRI) plays a vital role in medicine and aids in the detection, diagnosis, and treatment of diseases. However, MRI suffers from long scan times which may cause distress for patients who need to hold still for an extended period of time. Deep learning based methods in MRI reconstruction have been widely successful in accelerating MRI. They rely on large amounts of fully-sampled data to perform standard supervised training with undersampled data as inputs and fully-sampled data as ground truth labels. Furthermore, they require a significant amount of memory, which can make training infeasible for high-dimensional imaging applications. We explore self-supervised and greedy learning as a possible solution to these challenges. In self-supervised learning, the acquired undersampled k-space indices (Fourier domain data) is split into two disjoint sets. One set of k-space locations is used during training as network inputs, and the second set serves as pseudo-labels for calculating the loss function. In greedy learning, we split the standard network into smaller network modules and independently calculate a loss for each subnetwork. We demonstrate that a self-supervised method with greedy learning achieves strong performance without requiring fully-sampled data and with lower memory usage compared to standard self-supervised learning.

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

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

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

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

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

The Partially Observable Monte Carlo Planning, Marginalized Filtering (POMCPMF) fault detection algorithm has been proposed to increase the robustness of autonomous spacecraft in time-critical settings (Ragan et. Al). This algorithm finds any combination of sensor- and actuator-failures on a spacecraft by sending a set of control commands, or actions, and evaluating the resulting observations determine the failure. To determine the best actions to take, a Monte Carlo Tree Search is used. This algorithm has been shown to work in non-real-time simulation, in the sense that the belief on the failure converges to the correct failure. The next step in validating the robustness and performance of this algorithm is implementing it in a more realistic setting. The main goal of this project has therefore been to build a Hardware-in-the-Loop simulator for spacecraft, as well as implementing the algorithm as a controller. Doing this brings the fault detection algorithm one step closer to being implemented in a real autonomous spacecraft. Another aspect of this project has been to improve the time the Tree Search needs to find a promising action by using heuristics and prior knowledge of the system's dynamics and the nature of the possible failures.

Generation of Optical Barcodes for Use in Multiplexed Cellular Imaging Assays
Jadon Hale
Mentors: David Van Valen and Morgan Schwartz

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

Updating M-Mode Mapping With the New OVRO-LWA
Xander Hall
Mentors: Gregg Hallinan and Ruby Byrne

The Owens Valley Long Wavelength Array (OVRO-LWA) is a low frequency radio interferometer. It is composed of 288 crossed broadband dipole antennas and cover 58 MHz of bandwidth below 88 Mhz. By utilizing Tikhonov-regularized m-mode analysis imaging we have been able to produce all sky radio maps. These maps provide valuable insight into the cosmic dawn of the universe and offer a powerful tool to identify radio transients.

Acoustic Cavitation-Induced Mechanochemistry in Hydrogels
Tiba Hamza
Mentors: Mikhail Shapiro and Yuxing Yao

Abstract withheld from publication at mentor’s request.

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

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

Experimental Analysis of Thermoelastic Deformations in Tape-Spring Booms
Alexandra Haraszti
Mentors: Sergio Pellegrino and John Pederson

Tape-spring booms that are several meters in length support many lightweight space structures such as solar sails and solar arrays. These booms are favorable due to deployability and high stiffness-to-weight ratio but can develop large surface temperature gradients from directional exposure to sunlight. At this scale, thermal gradients can induce significant deflections in boom shape, as well as instabilities such as thermal flutter, which degrade mission performance. It is important to develop accurate models for such effects in order to avoid unexpected deformations and instabilities in orbit. In this project, thermoelastic deformations of a steel tape spring sample under radiant heating were measured using digital image correlation. Experiments were performed at various angles of heat incidence and in a vacuum chamber to minimize the effects of convection. Out-of-plane deflections on the order of 0.1mm were observed in a 256mm sample. Results of this work will be used to validate multiphysics simulations of thermoelastic tape spring deflections and to enable future experiments with composite tape springs.

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

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

Reducing Drag With Machine Learning: Fourier Neural Operator for Opposition Flow Control
Kimia Hassibi
Mentor: Anima Anandkumar

Opposition flow control is a method of reducing skin-friction drag that can be applied during airplane flights to decrease fuel usage and shorten flight durations. Fluid is sucked in or shot out of the wall's surface to exactly counteract the wall-normal velocity of the fluid in the buffer layer. This wall-normal velocity can be calculated by measuring the pressure along the wall and by using this pressure to solve the Navier Stokes equations (NSE). However, solving the NSE is time-consuming, and the wall-normal velocity must be counteracted instantaneously. Here we use the Fourier Neural Operator to learn the velocity outputted when a pressure is inputted to the NSE. We are able to find a fairly accurate estimate of the wall-normal velocity in real-time. This accomplishment will allow for the practical implementation of opposition flow control.

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

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

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

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

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

Ordered Product Factorizations in the Tropical Vertex Group
Melchor Herrera
Mentor: Tony Yue Yu

The general objective of this project is to use computational evidence to generate conjectures on the structure of factorizations of elements of the tropical vertex group. Relationships have been discovered between factorizations of commutators of the tropical vertex group, Euler characteristics of the moduli spaces of quiver representations, and Gromov-Witten counts of rational curves on toric surfaces, but the computational structure of the tropical vertex group itself has not yet received intense study. The factorizations are generated using a pre-existing algorithm implemented in C using the FLINT library. Further research would involve using the explicit formulas for factorizations in the tropical vertex group to yield explicit formulas for Gromov-Witten invariants.

Fine-Tuning Evolutionary Scale Modeling Transformer Through Command Line Tool Development
Martin Holmes
Mentor: Matt Thomson

Transformer models are a hot topic in natural language processing due to their success and ability to perform at top NLP benchmarks when analyzing human language. Proteins are ideal candidates for obtaining meaningful information from these transformers because, like words in natural language, the amino acids that makeup proteins are arranged in meaningful orientations. Several iterations of a pre-trained transformer model called Evolutionary Scale Modeling (ESM) have made considerable strides on many metrics for protein structure prediction and remote homology detection. Although fine-tuning ESM on specific properties or functions may result in improved representations of those properties during the protein embedding process, fine-tuning ESM on selected protein families has resulted in uncertainty on emerging taxonomic information in the model’s high dimensional output. Work on a command line tool to improve the scale at which fine-tuning ESM may occur will lead to a better understanding of how different protein taxonomies are ordered across protein spaces when fine-tuning occurs.

Developing a Bio-inspired Robotic Fin for Autonomous Underwater Propulsion and Maneuverability
Maven Holst
Mentors: Morteza Gharib, Meredith Hooper, and Noel Esparza-Duran

Traditional automated underwater vehicles (AUVs) are typically driven by screw propellers. While an efficient means of forward propulsion, these vehicles struggle with maneuverability. Bio-inspired AUV designs have attracted research interest due to the observed underwater maneuverability exhibited by fish. A mechanism is proposed that combines the traditional screw propeller design with a caudal fish-like fin, capable of rotation about three axes, in order to provide capability for both efficient propulsion and maneuverability. This mechanism is attached to an AUV chassis and submerged in a water tank, where the fin autonomously follows trajectories generated in MATLAB. Particle image velocimetry (PIV) and force sensors are used to determine how closely the mechanism follows the desired trajectories, and the thrust forces that are generated thereb. Testing suggests that this mechanism and its automation software are capable of conforming to trajectories, and are an effective means of combining efficient propulsion with quick maneuverability.

Synthesis, Characterization, and Reactivity of Heavier Pnictogen Analogues to Fe(III) Imido Complexes
Alexandria Hong
Mentors: Theodore Betley, Erika Amemiya, and Theodor Agapie

Selective C-H functionalization has dramatically altered the way chemists map efficient synthetic routes towards desired targets, but remains a challenging task owing to the strength of the C-H bond. Inspired by biological systems, the Betley group has designed transition metal complexes containing metal-ligand multiple bonds reactive towards C-H bonds. Modification of the electronic structure of the coordination complex is effective in producing species such as the previously-reported Fe(III) imido complex, which demonstrates H atom abstraction and C-H amination activity. This work aims to synthesize heavier-element analogues to the Fe(III) imido complexes via the use of dibenzo-7λ^3-phosphanorbornadiene group transfer reagents, and to investigate the electronic and magnetic effects of substituting Bi/P on the anisotropy of the metal ion while preserving the original system's geometry. We report that the synthesis of aryl phosphinidene transfer reagents remains a challenge; however, we have been able to form a key intermediate necessary to arrive at the target phosphinidene complex. Further work will focus on investigating the synthesis and reactivity of the Bi-containing group transfer reagent, as well as probing alternative ways to access iron phosphinidene complexes.

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

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

Characterization of Stellar Magnetic Variability Using Random Forest Classification
Emily Hu
Mentors: Benjamin Montet and David Hsieh

Though the behavior of stellar surface activity is known to influence its short-term magnetic variability, little is known about the effects of intrinsic stellar properties on long-term, periodic magnetic variability. Using photometric data as a proxy for stellar magnetic activity, we extract long-term flux curves from *Kepler*'s full-frame images and analyze them for their type of flux variability—types of variability consider the length of a star's flux variation period and the shape of its long-term flux curve. We use a random forest to classify these stars by flux variability type; input parameters of the model are basic stellar properties including effective temperature, rotation period, mass, gravity, and metallicity. Trends and importances of each of these parameters will contribute to further discovery on a star's intrinsic influences on long-term stellar magnetic variability. The result will be a stronger characterization of stellar variability that provides more information about the evolution of magnetic fields over the lifetime of a star.

Subliminal Priming on Prosaccade and Antisaccade Trajectories
Jennifer Hu
Mentors: Shinsuke Shimojo and Daw-an Wu

Subliminal visual stimuli can decrease reaction time in simple and complex motor tasks, and induce deviation in saccade trajectories when presented as a prosaccadic target in the opposite visual hemifield. In a pilot study, a subliminal visual prime applied to an antisaccade task showed that a subliminal prime has no effect on reaction time but increases deviation in antisaccade trajectories. In this study, participants were asked to either to prosaccade or antisaccade to/from a target stimulus appearing randomly on the left or right of the screen. In 50% of the trials, a location-valid metacontrast-masked prime stimulus was presented prior to the target stimulus. The prime stimulus was shown for an individually calibrated prime duration. Reaction times and eye movement trajectories were measured. We found that a valid prime decreased reaction time by ~68 ms (15%) in the prosaccade task, and decreased reaction time by ~33 ms (7%) in the antisaccade task. Examining eye trajectories found that a valid prime had no effect on the magnitude and frequency of deviations in both the prosaccade task and the antisaccade task.

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

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

Improve Online Optimization With Uncertainty-Quantified Advice
Jerry Huang
Mentors: Adam Wierman and Nicolas Christianson

We study the problem of online optimization, in which an agent must make sequential decisions such that the sum of per-round costs is minimized. The agent is aided by advice from an oracle paired with quality hints, such as the predictions from an uncertainty-quantified machine learning model, which provide potentially untrusted information on the optimal decision for the given round along with the oracle's confidence in its proposed decision. We explore how hints can be used to improve performance while maintaining robustness guarantees in the classical problem of prediction with expert advice and convex function chasing.

Ultrasound Imaging of Cellular Function in Mammalian Cells
Isabella Hurvitz
Mentors: Mikhail Shapiro and Shirin Shivaei

Difficulty visualizing the function of natural and engineered cells noninvasively inside intact organisms poses a key challenge for the development of cellular medicine. Ultrasound imaging has the potential to address this challenge as a widely available biomedical technology that enables noninvasive imaging with high spatial and temporal resolution. Recently, bacterial gas vesicles have been engineered as acoustic reporter genes (ARGs) inside immortalized mammalian cell lines using transfection based methods. However, achieving expression in primary immune and neuronal cells, as would be desired in clinically relevant neuroscience or cell therapy contexts, has been found more challenging. Here, we focus on realizing the imaging capabilities of ARGs in more complex cellular contexts such as in cultured murine hippocampal neurons and patient-derived T cells using an optimized set of lentiviral vectors that efficiently co-deliver 8 gas vesicle genes. Furthermore, we develop acoustic reporters of cellular state utilizing immediate early genes (IEGs) to control ARG expression. IEGs are genes which are transiently and rapidly activated in response to a wide variety of cellular stimuli during neuronal activity. Therefore, an IEG-ARG coupled expression system aims to allow noninvasive ultrasound imaging of gene-expression in the brain.

Capillary Feeding System to Test Diet Induced Limb Regeneration in *Drosophila*
Justin Hyon
Mentors: Lea Goentoro and Yutian Li

Unlike many animals, humans naturally have very little capacity as adults to regenerate lost body parts. However, previous results from the Goentoro Lab suggest not only the existence of a conserved but unused pathway for limb regrowth across many non-regenerating animal species, but also that this pathway can be triggered solely through a modified diet containing growth factors L-leucine and insulin. This study suggests that a regenerative phenotype can be induced in adult *Drosophila melanogaster* through diet alone, via a method of administering modified food while preventing local contact of regenerative factors to the severed limb tip. This was achieved through a modified capillary feeding (CaFe) assay which allows for isolation of individual flies and thorough tracking of food on the body, as well as future precise measurement of food intake in individual animals.

Design, Development, and Characterization of Novel Visual Hotwire Anemometry
Makoa Inciong
Mentors: Morteza Gharib and Alejandro Stefan Zavala

Caltech's Center for Autonomous Systems and Technologies (CAST) specializes in research on small fliers operating close to the surface of the Earth. This requires the replication and study of such flight conditions, which are characteristically non-uniform in both space–in the streamwise and spanwise directions– and time. CAST is uniquely equipped for this task by way of its fan-array wind tunnels and aerodrome facilities. However, there remains a need for corresponding quantitative measurement techniques which are spatially and temporally resolved and can be sampled in real time in air outdoors. In this project we present a novel wind velocity measurement technique that addresses these criteria, consisting of an array of electrically heated wires spanning the length of the test section and sampled by an infrared camera. Much like with a traditional hotwire, the wind convectively cools the heated wires and wind velocity can be backed out through the measurement of wire temperature. Unlike the traditional hotwire, these wires are long enough for their temperature distribution to be nonuniform, thus by sampling from the infrared camera downstream and interpolating, we obtain a continuous velocity field. We design and manufacture a research grade prototype for characterization, publication, and subsequent use in active research.

Temporal Analysis of Deep Sea Vent Microbial Communities

Emma Isella
Mentors: Victoria Orphan, Rebecca Wipfler, and Kriti Sharma

Deep-sea vents are one of the most biologically intriguing sites on Earth, as microbial communities in vent regions represent a plethora of novel species that continue to shape our understanding of unique metabolic processes and inter-species interactions, global chemical cycling, and the origin and evolution of life on Earth. However, because they are so difficult to reach, deep-sea vent regions have not been thoroughly explored, so exactly how these incredibly dynamic locations and their associated microbiota change over time is unknown. This project aims to characterize the change in environmental conditions through time and how this affects the microbial community in the sediment of both a hydrothermal vent site, Pescadero Basin in the Gulf of Mexico, and a cold methane seep site, Santa Monica Basin. Here we show – through the analysis of geochemistry, temperature data, and 16S DNA sequencing data from samples collected *in situ* across eight years – that changes in the hydrothermal activity of a site led to changes in the abundance of species, particularly in families of ANME (anaerobic methanotrophs), in different depths in the sediment column. We also incubated sediments from both a very hydrothermally active site (at around 80°C) and a colder background site (at around 4°C) at various temperature conditions to attempt to mimic this microbial community shift *in vitro*. As one of the first temporal studies of vent site sediment microbes, this project will contribute to developing a general understanding and prediction of vent community stability in the face of environmental change and will set a standard method for performing these kinds of analyses in the future.

Developing a Multi-fidelity Approach to Numerically Optimize Stochastic Variance Reduced Gradient Descent

Neymika Jain
Mentors: Elizabeth Qian and Pan Xu

Stochastic gradient descent (SGD) is a commonly used optimization method for regression problems but has a sublinear convergence rate due to variance introduced by random data selection. Stochastic variance reduced gradient descent (SVRG) achieves linear convergence for strongly convex functions by correcting SGD's update rule using the full gradient. This method of correction is similar to principles used in multifidelity Monte Carlo methods, which reduce Monte Carlo estimator variance. We empirically test different theoretically-supported choices of SVRG hyperparameters to achieve the optimal convergence results for a given computational budget. We then compare these results with SGD and other SVRG estimators with different hyperparameters for a strongly convex function using a linear loss function.

Delay-Doppler Radar Imaging of Near-Earth Asteroid 2022 BH7

Mehul Jangir
Mentors: Charles Elachi and Mark Hayes

We report radar observations of Near-Earth Asteroid (NEA). The observations were conducted at Goldstone (8560 MHz, 3.5cm) on February 19, 20, and 21, 2022, shortly after 2022 BH7's discovery on January 26 by Pan-STARRS. High-resolution delay-Doppler images for the asteroid were obtained. Due to an unknown rotation period and insufficient data, 3-D shape and spin estimation could not be carried out. Features in the delay-Doppler images were not prominent enough for precise estimation of the rotation period. 2022 BH7 has an absolute magnitude 21, which suggests a diameter of roughly 200 meters. Constraints were obtained on the diameter and shape for 2022 BH7, as well as the radar cross section, which was then used to constrain the radar albedo. Furthermore, the optical albedo and spectral class of 2022 BH7 were also constrained. The circular polarization ratio (SC/OC) was also estimated and its implications discussed. Furthermore, the SC/OC images were checked for features and compared with those of other NEAs.

Developing an Absolute Quantitative Sequencing Framework for Fungi

Jenny Ji
Mentors: Rustem Ismagilov and Reid Akana

Fungi are instrumental players in the functioning of many ecosystems and biological systems, yet tools for quantitative analysis of fungal community composition are lacking. To address this need, we developed a quantitative-sequencing (Quant-Seq) method for fungi. Fungal Quant-Seq leverages the Quant-Seq method the Ismagilov Lab previously developed for absolute quantification of bacteria and archaea by combining highly

sensitivity digital-droplet PCR with next-generation sequencing. To extend the Quant-Seq method to fungi, we explored numerous potential genes and identified the ubiquitous single-copy *TEF* gene as the most promising. However, primers for the *TEF* gene also bind to the human genome, limiting the utility of quantitative sequencing in samples with large amounts of human DNA. To mitigate this problem, we used restriction enzymes to selectively cleave sections of the human genome capable of producing amplicons. By performing an initial restriction digestion with HpaI, amplification of human DNA was reduced to nearly zero whereas efficiency of fungal amplification was only reduced by a factor of two. Fungal Quant-Seq will next be validated on a range of complex sample types, including clinical samples to survey fungal communities associated with disease.

Divalent Ion Conduction in Solid-State Zn-P-S Phases
Abigail Jiang
Mentors: Kimberly See and Zachery Iton

Next-generation batteries based on divalent cations (M^{2+}) have the potential to achieve higher energy densities using cheaper, more sustainable materials compared to traditional Li-ion chemistries. Solid-state batteries are safer and may outperform their liquid counterparts, but M^{2+} conduction is particularly difficult in the solid-state due to higher charge density. Thus, there is significant interest in realizing solid-state divalent ionic conductors (ICs) that operate at ambient conditions. $ZnPS_3$ is one such IC that demonstrates H_2O-facilitated Zn^{2+} conductivity. We investigate other chemically similar Zn-P-0S phases as IC candidates, specifically $Zn_3(PS_4)_2$ and $Zn_2(PS_3)_3$. Both materials are prepared via solid-state synthesis and structurally characterized with X-ray diffraction. Electrochemical impedance spectroscopy is used to probe bulk conductivities. Upon air exposure at ambient conditions, we observe high ionic conductivities and relatively low activation energies, suggesting that H_2O may similarly facilitate ion conduction in these phases. Our results highlight $Zn_3(PS_4)_2$ and $Zn_2(PS_3)_3$ as promising solid-state Zn^{2+} ICs. In addition to first-principles calculations, future experiments will utilize electrochemical and spectroscopic techniques to determine the specific effect of humidity on conduction, and further identify which ions are mobile in each material.

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

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

Molecular Dynamics Studies of Modified RNA Structures for Novel Therapeutics
Rachel Jiang
Mentor: William A. Goddard, III

Recently there has been progress in developing pro-drugs that combine small interfering RNAs (siRNAs) with riboswitches. When the riboswitch is in the presence of its specific cellular RNA biomarker, it turns the siRNA from an "off" state to an "on" state. The siRNA can then go on to activate RNA interference (RNAi) in the cell. Selective activation by RNA biomarkers gives the construct the potential for high specificity, allowing targeting of a specific RNA sequence. These conditional siRNA constructs have been tested experimentally and shown to be effective in knocking down the targeted genes, however, we are interested in investigating further the structure and interactions of the construct. In this project, we used Molecular Dynamics, specifically LAMMPS, to simulate the behavior of the modified RNA structures.

Computing Tri-Partitions and Bases of an Ordered Complex
Erick Jimenez Berumen
Mentor: Peter Schröder

Given an ordered complex, K, for any dimension, p, the set of p-cells of the complex can be partitioned into three disjoint sets: (1) a maximal p-tree set, (2) a maximal p-cotree set, and (3) and set of remaining p-cells whose cardinality is the p-th reduced Betti number of K. This partition directly leads to a construction for bases of p-th cycle, boundary, and homology groups. Interestingly, the structure of this partition closely mimics the Hemholtz-Hodge decomposition of differential forms. We implement an algorithm introduced by Edelsbrunner and Ölsböck to compute tri-partitions for surface and volume meshes, and for the case of surface meshes, we use build on this algorithm to construct harmonic differential forms on the complex *K*.

A Diphenyl-Substituted Acridane PNP Ligand Platform for Small Molecule Activation
Yunha Jo
Mentors: Jonas Peters and Yunho Lee

Carbon monoxide dehydrogenase (CODH) chemistry has recently been brought to attention as a possible way to employ carbon dioxide as a reusable C1 source. In CODH, a biological conversion between carbon dioxide and carbon monoxide happens at the metal center, supported by a metalloenzyme. Using anionic tridentate diary lamido diphosphine (PNP) ligand attached to a nickel complex for the reaction, it was found that rigidifying the structure allowed for better selectivity of CO_2 addition to a low valent Ni-CO species. Dimethyl-substituted carbon moiety (-$C(CH_3)_2$-) was added to the existing PNP ligand, creating PNP-Me pincer ligand (^{acri}PNP-Me^{-} = 4,5-bis(diisopropylphosphino)-2,7,9,9-tetra methyl-9H-acridin-10-ide). CO_2 activation of zerovalent nickel complex showed the selective formation of desired nickel(II) carboxylate species, which was in contrast to previous PNP ligand, where multiple products were formed. Based on this observation, diphenyl version of ^{acri}PNP-Me ligand, ^{acri}PNP-Ph was explored. Structural difference between the two ligands were observed, with ^{acri}PNP-Ph ligand complex showing more distorted tetrahedral geometry than that of ^{acri}PNP-Me analogue. In order to understand the impact of this structural difference between the two ligands, ^{acri}PNP-Me complex will be reacted with small molecules then compared with the same reactions involving ^{acri}PNP-Ph complex.

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

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

Analysis and Development of Models for Carbon Dioxide Sequestration by Concrete
Miles Jones
Mentor: Melany Hunt

Cement undergoes a process called carbonation, which is where multiple chemical reactions occur between main components in set cement and carbon dioxide. Recent studies estimate 0.25 gigatons of carbon are sequestered in cement-based material annually; however, this estimate is based on a simplified model of the carbonation process. By comparing this simplified model with existing data, we found that the model worked best under highly controlled conditions in which the rate of carbonation is limited by diffusion of carbon dioxide into the concrete. To improve the carbonation modeling, we developed a finite difference analysis that included the unsteady diffusion of carbon dioxide and the rate of reaction of carbon dioxide with the various constituents of cement. This improved modeling allowed us to examine a range of conditions, finding that it provided a more complete estimate of the reactions. For continuation of this project, the models can be further improved to include more complex aspects of the process such as the change in porosity of cement.

Template-Free Generation of Mesostructured Interfaces With Defined Wetting Anisotropy via Inorganic Phototropic Growth
Sarah Kabboul
Mentors: Nathan S. Lewis and Madeline C. Meier

Many photosynthetic plants exhibit a phototropic growth response by which the addition of new biomass is directed to optimize collection of solar insolation, e.g. the growth of palm trees in the northern hemisphere directs the crown to the southern sky. Analogous inorganic phototropic growth has been demonstrated via the light-mediated electrochemical deposition of semiconductor materials and can generate highly ordered mesostructures with anisotropic nanoscale features conformally over macroscopic length scales. No structured light field (no photomask) and no physical or chemical templates are needed. The deposit morphology is defined by the characteristics of the illumination inputs to the growth. The input polarization, wavelength, and incidence direction define the structure anisotropy and orientation in-plane, the pitch, and the out-of-plane growth direction, respectively. Illumination inputs can be defined to generate a variety of ordered interfaces including isotropic hole arrays and highly anisotropic ridge and trench motifs as well as tuning fork and aqueduct structures. These ordered mesoscale structures are similar to many biological interfaces with unique wetting and liquid transport properties including rice leaves and butterfly wings. The wetting behavior of an array of structures generated via inorganic phototropic growth with water was examined. Ridge and trench structures with a series of different heights and pitches were assessed as well as similar structures generated with inclination relative to the substrate. Complex three-dimensional structures were also evaluated. Asymmetric wetting was observed wherein liquid water droplets spread along the long axis of the anisotropic structures. The degree of wetting anisotropy was correlated with the structure geometry which could be tuned by changing the optical inputs to the phototropic growth process.

Using a Beta-Binomial Bayesian Model to Analyze the Impact of Stereotype Threats on Penalty Shot Performance

Shevali Kadakia
Mentors: Nils Rudi, Yetsa A. Tuakli-Wosornu, and Tapio Schneider

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

Modeling Habit Formation Using Novel “Neural Autopilot” Model

Ishan Kalburge
Mentor: Colin Camerer

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

Decoding Cellular Basis for ‘Fight or Flight’ Response in Sympathetic Ganglia

Elin Kang
Mentors: Yuki Oka and Tongtong Wang

The presence of a stressor mobilizes the ‘fight or flight’ response, leading to increased activity of the sympathetic nervous system. In the sympathetic system, post-ganglionic neurons receive input from preganglionic neurons in the spinal cord and innervate peripheral organs. When post-ganglionic neurons get activated, they stimulate downstream cells with different receptor expression, regulating diverse homeostatic functions. Recent studies have suggested a degree of specificity in the sympathetic ‘fight or flight’ response, recruiting distinct organs and signaling pathways. However, little is known regarding the cellular composition of the sympathetic ganglia, and anatomical innervation and homeostatic function of diverse classes. Here, we use single cell sequencing to identify cell types and in situ hybridization to spatially visualize gene expression, showing molecular diversity of the prevertebral sympathetic ganglia. Dissecting the cellular organization of the sympathetic ganglia will potentially allow us to distinguish cell types activated under different stressors or regulating distinct homeostatic functions.

Using Out-of-domain Data to Improve Few-Shot Classification Performance With Limited Human Labeling

Sara Kangaslahti
Mentors: Anima Anandkumar, R. M. Alvarez, and Rafal Kocielnik

Labeling new classification dimensions is a challenging task, especially in settings such as social media, where the context of discussion changes quickly and where the large volume of data makes it necessary to incorporate automated techniques. Previous methods for classifying new dimensions have either relied on the use of large labeled training datasets, which requires extensive human labeling, or fine tuning large language models (LMs) for each dimension, which is computationally costly. To label new dimensions with minimal labeling effort and computational resources, we prompt pretrained LMs using a few-shot instruction-based method and leverage out-of-domain data as part of the support set for choosing shots. Therefore, we combine information from existing labeled datasets and the context present within pretrained LMs in a novel technique, which we can use to label new dimensions with minimal human labeling and without fine-tuning. We find that using out-of-domain data helps increase the AUC and F1 scores when few in-domain samples are labeled in the few-shot setting, although the

impact diminishes as the number of in-domain samples labeled increases. We also demonstrate new insights into the importance of in-domain data versus in-domain labels when doing transfer learning with few-shot instructions.

Approximate Ground States of the Quantum Heisenberg Model Through a Modified Quantum Approximate Optimization Algorithm
Ishaan Kannan
Mentors: John Preskill and Leo Zhou

The Quantum Approximate Optimization Algorithm (QAOA) is a promising algorithm for approximate combinatorial optimization on near-term quantum computers whose performance improves with circuit depth parameter p. However, its computational power applied to QMA-hard problems is largely unexplored. We modify the QAOA for application to Quantum MaxCut (QMC), a special case of the local Hamiltonian problem related to finding ground states of the antiferromagnetic Heisenberg model. We then provide an iterative formula to evaluate the expected performance of our modified QAOA on high-girth D-regular graphs whose complexity scales as $O(16^p)$, and hypothesize that in the limit as D approaches infinity this iteration can be modified to scale as a polynomial in p multiplied by 4^p. Looking at optimal QAOA parameters at small p, we propose heuristic parameter guesses to potentially allow classical numerical optimization up to $p \sim 20$. Though obtaining ensemble-averaged performance from our iteration relies on a locally high-girth assumption, we hope to find a similarly motivated iteration for graphs with loops, such as lattices of relevant crystal structures. We are optimistic that our modified QAOA will perform better than other approximate algorithms for the QMC model and provide a benchmark for emerging algorithms for QMA-hard problems.

Learning Meaningful Representations of Cellular Dynamics With Deep Convolutional Variational Autoencoders
Manav Kant
Mentors: David Van Valen and Uriah Israel

With the increasing scale of modern biological imaging data, new methods are required to interpret images with single-cell resolution. Furthermore, as imaging data can be converted to spatio-temporal graphs, there is a need for methods to learn representations on these graphs for downstream tasks such as the identification of cell behaviors. In this project, the usage of variational autoencoders (VAEs) and self-supervised learning were explored for this task. A deep convolutional autoencoder with an encoder, indeterministic embedding layer, and decoder was constructed to learn representations of images collected from movies of 3T3 cells, a line of mouse fibroblasts. A t-SNE plot of the resulting encodings revealed that the encodings were clustered by cell age, demonstrating that the model could recapitulate the cell cycle, and thus that the encodings are meaningful with respect to cell behaviors.

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

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

Adapting Generative Adversarial Networks to Learning From Hints Paradigm
Abdullah Yusuf Kavranoglu
Mentor: Yaser S. Abu-Mostafa

Machine Learning is the concept of estimating a function from some data points that are outputs of that function. In addition to training data at hand, some known properties, or hints of the target function can be taken advantage of for a better estimation of it. Learning from hints concept has widespread use for image classification problems in the form of data augmentation, where some transformations which don't change the label of an image are applied to duplicates of the original training data, or duplicate examples, to get a larger training set and to reduce overfitting. However, duplicate examples have the constraint of being in the vicinity of input data in the input space, which limits a more general learning of hints. We propose to use virtual examples, which are artificial data that resembles input distribution but with no labels, for a better learning of hints. We hypothesize that with the ability of GANs to capture input distributions perfectly, virtual examples generated through GANs can span a greater portion of the input space and can encompass a more generalized version of hints, with transformations. Our results show that virtual examples generated with GANs can be used for learning from hints.

Class Number Sums and the Prime Geodesic Theorem
Necef Alp Kavrut
Mentor: Alexander Dunn

The asymptotic behavior of the class number function for primitive binary indefinite quadratic forms is a long-standing problem in number theory. In a 1944 paper, Siegel proved Gauss' conjecture that sums of class numbers, when ordered by discriminant up to x and weighted by the logarithm of their fundamental units, grew like $x^{3/2}$. Fundamental units are erratic in size however, so separating the two summands remains a tall task. In 1982, Sarnak observed that if class numbers are instead ordered by fundamental unit sizes, then analyzing sums of class numbers is equivalent to analyzing the prime geodesic theorem on the modular surface. A subsequent breakthrough paper by Iwaniec utilized Kuznietsov's sum formula to retrieve sharper bounds for the prime geodesic theorem by working on sums of kloosterman sums and the Rankin zeta function. We investigate these two avenues for sharpening of the error term for the prime geodesic theorem.

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

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

Designing and Testing Aortic Endografts That Prevent Endoleaks
Mehmet Naci Keskin
Mentors: Chiara Daraio and Connor McMahan

Every year, aortic aneurysms are responsible for thousands of deaths, if not successfully treated. Endovascular aneurysm repair (EVAR) entails the implantation of an endograft within the artery and is the most successful treatment available. However, it often causes serious post-operative complications: Endoleaks entail the flow of blood into the aneurysmal sac, diminishing the effect of the endograft. They occur when blood leaks through the endograft seals or due to backward blood flow to the aneurysm from the local smaller branching arteries. In our project, we aim to develop a new endograft that will prevent endoleaks and prevent further progress of the aneurysm. This endograft will change shape into a variable-radius cylinder during the deployment process to take the shape of the aneurysm. The aim is for this new endograft to exert enough outward radial force against the arterial wall to create a powerful seal between them. This project uses previous work done by the Daraio Group on shape-changing architected materials. The initial prototypes suggest that this type of endograft is possible. With further work, the endograft could be applied to the treatment of aortic aneurysms.

Two-photon Volumetric Imaging of Fly Brain to Identify Aggression Circuits
Joseph H. Kim
Mentors: David J. Anderson and Shuo Cao

Aggression is an innate robust behavioral state conserved from humans to flies, making aggression a promising behavior to study the circuits underlying internal states. A few neurons (e.g., P1 and AIP in males and aIPg in females) have been shown to promote aggressive behaviors in *Drosophila* in a scalable or persistent manner. However, we know little about the downstream circuits of these aggression-promoting neurons and how the features of scalability and persistency are encoded. Therefore, we image the pan-neuronal activity *in vivo* with two-photon microscopy in response to optogenetic stimulation of key aggression-inducing neurons. We have developed an analysis pipeline that has identified several responding downstream neurons. We aim to elucidate the dynamics in which persistence and scalability, among other characteristics of aggression, are encoded at the circuit level and then reference populations of interest to the fly connectome.

Bringing Machine Learning to Planetary Protection Analysis
Subin Kim
Mentors: Ashish Mahabal and Nitin Singh

As humans continue to explore outer space, it is crucial that we are conscious of the impacts we make on the outer space environments such as the interplanetary contaminations. JPL generates a multitude of biological data from spacecraft-associated environments and organisms, however, currently there is no database that can be used to derive Planetary Protection relevant information from all these different databases. In our project, we aim to standardize these data, which can be partly achieved through the development of datasheets, which describe a species and its biological properties that are relevant to the measurement of the contamination risk it poses. Even with data sheets that compile multiple biological databases, a huge portion of our data sheets are incomplete due to the difficult nature of measuring data on the vast number of bacterial species. Thus, in our project, we develop a machine learning model to predict these missing data using data present for other species.

Exploring the Dynamic Infrared Universe: Development of the Wide-Field Infrared Transient Explorer (WINTER) Data Pipeline
Sulekha Kishore
Mentors: Mansi Kasliwal and Viraj Karambelkar

Soon to be deployed at the Palomar Observatory, WINTER will be the most sensitive all-sky infrared time-domain survey and will search for exotic transients such as kilonovae accompanying binary neutron star mergers. WINTER will generate thousands of potential infrared source candidates per night. Real-time effective filtering and visualization of this enormous data set is necessary to identify transients of interest to conduct follow-up science.

To this end, we built a modular data pipeline that can process, detect, and visualize candidate transients. This data pipeline utilizes Apache Kafka, an open-source distributed event streaming platform, and Kowalski, a multi-survey data archive. All candidates observed by WINTER are broadcast using the Kafka alert stream, which is ingested into Kowalski. On Kowalski, each alert is cross-matched with astronomical catalogs, filtered using user-defined criteria, and saved into MongoDB, a database architecture.

This filtered, augmented data is integrated with Fritz, a science data platform used by the astronomical community to manage and visualize large sets of observational data. Astronomers will use Fritz to scan potential transients from WINTER, identifying those best suited for further study.

Hosted on Github, this modular data processing pipeline is open-source and can be used by other time-domain surveys to process data.

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

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

Detecting and Manipulating Squeezed Light for Quantum Metrology and Communications
Esme Knabe
Mentor: Maria Spiropulu

Squeezed light is a sub-Poissonian non-classical state of light with numerous applications to fields such as precision measurement and quantum communication. Because of its relevance to real-world systems, the development of squeezed light processes that can integrate with existing optical and photonic devices is crucial. To this end, this project aims to demonstrate the measurement and manipulation of the phase space of squeezed light using tabletop devices and integrated photonics. Some of the contributions of this work will be, but is not limited to, phase locking of a squeezed state for deterministic phase rotation, generating displaced squeezed states by mixing coherent light with squeezed light, and optimizing experiments for practical quantum applications with squeezed light.

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

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

Quantifying Clusters Around Herbig Ae/Be Stars
Viktor Koehlin Lovfors
Mentor: Lynne Hillenbrand

The goal of this project has been to investigate how one distinguishes physically associated young stars from field populations, with an intended application to clusters around Herbig Ae/Be stars. To this end, we have developed a framework for establishing cluster membership and drawing conclusions about cluster parameters given an arbitrary point on the sky. We have written code that queries Gaia, 2MASS and AllWise, crossmatches these catalogs, and provides tools for data cuts and visualization. We differentiate cluster members from field stars using kinematic cuts based on Gaia data and color cuts, both in terms of color magnitude diagrams and IR excess cuts.

We are in the process of validating our code's capabilities on known clusters. Once this is done, it can be used on the full Herbig Ae/Be sample.

Mean-Field Characterization of Strongly Interacting Graphene Multilayers With Spin-Orbit Coupling
Jin Ming Koh
Mentors: Jason Alicea and Étienne Lantagne-Hurtubise

Graphene multilayers have been of enormous interest to the condensed-matter community due to their rich physics and extraordinary tunability of electronic properties. While spin-orbit coupling (SOC) in graphene is intrinsically weak, layering graphene in proximity to heavy element substrates allows an enhancement of SOC by several orders of magnitude. In this study, we investigate the phase diagram of graphene multilayers in the presence of induced SOC, using a self-consistent Hartree-Fock treatment of gate-screened Coulomb interactions. An understanding of the different symmetry-broken phases of graphene multilayers may provide insights on a broad range of interesting electronic phenomenology, including unconventional superconductivity in hole-doped untwisted graphene bilayers and trilayers found in recent experiments.

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

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

Designing Composites With Spatially and Temporally Programmable Fracture Behavior

Athena Kolli
Mentors: Chiara Daraio and Tommaso Magrini

Composite materials are ubiquitous, due to their high mechanical performances combined with their light weight, making them the material of choice in many structural applications in the civil, automotive, and aerospace sectors. Nevertheless, composites have limited fracture resistance and suffer from poor defect tolerance. To address these problems, we aim to intelligently design materials that have programmable damage behavior and whose fractures can be designed in both the spatial and temporal regimes. In this study, we created a model composite, reinforced across different lengthscales, using a polyjet 3D printer and we performed Single Edge Notched Tension tests to probe the evolution of fractures. Digital Image Correlation was used to retrieve the strain fields during testing and gather useful insights on the interactions of the damage process with the reinforcing elements of the composites. Through our observations, we have gained an understanding of the fracture behavior of these hierarchically reinforced polymer composites. Building up on the knowledge we have acquired during the project, we plan on designing a new hierarchical architecture which exhibits fracture behavior that can be reliably predicted. My project demonstrates that by understanding the role of hierarchical mechanical reinforcement in a composite material, one can design materials to have specific mechanical properties and fracture behavior.

Human Impacts on Coastal Eutrophication

Ethan Kondev
Mentor: Rob Phillips

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

Drone Flights Over Venus-Analog Terrain: Preparing for the VERITAS Mission

Alexander Koutsoukos
Mentors: Joann Stock, Daniel Nunes, and Sue Smrekar

With Venus' thick atmosphere and clouds obscuring visible observation of its surface, all surface mapping missions, such as Magellan in the 1990s and VERITAS starting in 2028, must use radar. There remain unknowns about the projected capacity of the VERITAS radar datasets to be able to determine important geological qualities such as surface roughness that need to be better understood before the spacecraft launches. Here we assess digital elevation maps taken by drone flight over terrain in the Mojave Desert geologically analogous to what has been observed on Venus. These DEMs can be manipulated through ArcGIS to create a map detailing surface roughness – lateral variation in the topographic expression of a surface. Surface roughness can be used to detail eruptive and geological characteristics of lava flows. Studying and fine-tuning VERITAS' radar mapping abilities allows for a better understanding of surface roughness and, by extension, Venusian geology.

Development of Non-Intrusive Microwave Radar Measurements of Shock Speed for the Hypervelocity Expansion Tube at Caltech

Levente Kovacs
Mentors: Joanna Austin and Ying Luo

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

Development of a Technique for Direct Measurement of Residence Time in a Simulated Human Aortic Root
Lilith Kreutzer
Mentors: Morteza Gharib and Alexandros Rosakis

Residence Time describes the time a particle spends in a specific area. It serves as an indicator how well the blood moves and mixes in a defined domain. A long residence time and low velocity is connected to the development of thrombosis and an increased risk of stokes and embolisms. For conducting research about the hemodynamics around the aortic valve, we want to measure the residence time in vitro by using a reconstruction of an aorta and a pulsatile heart pump. We used a glycerol-water-dye solution injected through a port into a system with a valve imitating the cardiovascular system. We tested different valves to be able to compare their residence time. By tracking the dye in port and under the valve, we can measure different quantities such as the volume exiting the port, velocity, lateral movement, concentration in the port and the ejection by calculating the mean intensity of the dye. The information is used to determine the residence time and provides knowledge about the washout rate in the aortic root. A Particle image velocimetry (PIV) will need to validate the new method. The development of the new technique will allow us to measure residence time in an area where it was difficult to measure before.

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

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

Connecting Galaxy Evolution to Black Hole Spin With the *Chandra* X-Ray Telescope
Shalini Kurinchi-Vendhan
Mentors: Francesca Civano, Laura Brenneman, and Philip Hopkins

The last two decades have revealed a strong connection between the cosmic evolution of galaxies and their central, supermassive black holes. Through constraining their spins, we can obtain a measure of the accretion and outflow processes by which black holes influence their host galaxies. However, current spin measurements are largely biased toward the nearest and most luminous black holes, which constitute only a small fraction of the entire population of active black holes in the Universe. In this project, we probe the full range of masses and accretions of active supermassive black holes by performing a spectral analysis of >3,000 sources from the newest release of the *Chandra* Source Catalog, covering a broad range of luminosities and cosmological distances. With this spectral analysis, we aim to obtain an average measurement of black hole spin as a function of several source properties, shedding light on their growth and co-evolution with galaxies.

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

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

A Program to Automatically Detect Bubble Sizes in a Three-Phase Fluidized Reactor
Albert Kyi
Mentors: Jess Adkins and Sijia Dong

Surface area is essential to mass transfer across gas-liquid interfaces. Predicting bubble size distributions is extremely difficult because of various physics phenomena, including pressure drop leading to bubble expansion and mass transfer to surrounding liquid. This work establishes a method for lighting a reactor column and develops a program for detecting bubble sizes within a three-phase fluidized bed column, consisting of sea water, calcium carbonate, and carbon dioxide gas. Our MATLAB program automatically crops and scales an image, binarizes it, uses various adjustment and opening transforms, and fills holes before detecting the boundaries present within the image and categorizing them into bins based on diameter and an assigned circularity score. The program demonstrates accuracies of up to 75% in ideal conditions, but is significantly hampered at small gas flows, where solid grains add noise to images, and at large gas flows, when slugging results in large bubbles that obscure most of the image frame and also add noise. We can apply this program towards our construction and optimization of a fluidized bed reactor to capture carbon dioxide using Accelerated Weathering of Limestone (AWL).

Evaluating the Effects of Deep Tropical Circulation on the Subtropical Jet Using the Earth System Model
Navya Lam
Mentors: Tapio Schneider and Lenka Novak

The subtropical jet (STJ) is the jet stream located at roughly 30°N latitude, acting as a semi-permeable barrier for the large-scale eddying motions of the two regions that it separates, the tropics and midlatitudes. The characteristics of the STJ are modified by deep tropical convection, a theory for which is not completely developed. This is due to the overall breakdown of some of the simplifications that can be assumed only in the tropics. One hypothesis claims that poleward flowing filaments of tropical air retain their characteristics as they reach the subtropics, indicating that theories of tropical circulation may be locally relevant in the subtropics. To test this hypothesis, we used the Earth System Model (ESM) developed by the CliMA lab, which simulates tropical conventions, to evaluate how the tropical circulation affects the subtropical circulation and the STJ. We have verified that the ESM produces vertical velocity and divergence close to the observed. These variables can in turn be used as a basis for an index to study the effect of maximum tropical convection on the midlatitude circulation. We conduct such a study using time-lagged composites of temperature, zonal wind, eddy kinetic energy, and moisture fluxes centered on this index.

A Total Synthesis of Sparteine
Pik Hoi Lam
Mentors: Sarah Reisman and Jeff Kerkovius

Sparteine was a popular chiral auxiliary for enantioselective lithiations that had gone scarce and expensive since 2010. This work describes a multigram scale total synthesis of sparteine. Starting from the abundant glutaryl chloride and pyridine, a rapid collection of the sparteine carbons led us to an unprecedented 6 step synthesis, which was further improved to be industrially scalable with respect to prices of reagents. All in all, we hoped to contribute positively to the long-term shortage of these chiral auxiliaries.

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

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

Prediction of Psychiatric Drug Behavior via Integration of High-Dimensional Data From Multiplexed Fluorescence Imaging Into a Predictive Causal Network
Anna Lapteva
Mentors: Mark Bathe, Reuven Falkovich, and Lulu Qian

The central nervous system is the most sophisticated computer found in biology. Its fundamental computing unit is the synapse, whose information-processing abilities are largely facilitated by a compartmentalized, dynamic system of hundreds of proteins across pre- and post-synaptic sites. Prior studies suggest that chemical and genetic perturbations can significantly alter this network, but it is typically difficult to study the effects of these perturbations at the synaptic level. We are interested in determining the influence of psychiatric drugs and other chemical treatments like tetrodotoxin, bicuculline, harmine, and D-2-amino-5-phosphonopentanoate (APV) on the synaptic protein network of rat hippocampal neuronal cultures. To simultaneously measure multiple proteins in the same sample, we utilize PRobe-based Imaging for Sequential Multiplexing (PRISM), a technique that involves DNA-conjugated antibodies interacting with fluorescent oligonucleotide imaging probes. Preliminary results have shown significant network changes in response to APV, harmine, and several psychotropic agents, including fluoxetine and phencyclidine (PCP). The high-content data provided by PRISM, and a framework for integrating this data, will offer valuable insights into convergent molecular mechanisms contributing to chemical and drug responses; this may revolutionize the improvement of existing drug therapies, and encourage the discovery of novel drug candidates for treated and untreated disorders.

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

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

Vertical Flow Equilibrium Model Applied to CO_2 Storage
Thomas Ledevin
Mentor: Jean-Philippe Avouac

CO_2 capture and storage has become a serious source of interest over the past years as it is considered as a promising method to reduce the amount of CO_2 into the atmosphere, and underground reservoirs therefore represent suitable candidates for CO_2 storage sites. Furthermore, as industrials experienced it during extraction activities, reservoir operations may cause seismic activity and surface deformation, and preliminary investigation and forecasts may therefore become necessary. In this context, reservoir models coupled with surface displacement and seismicity models remain a powerful tool for forecasting and evaluating the underground activities effects. Here, we develop a simplified and efficient two-phase flow model based on vertical flow equilibrium assumption (VFE) to compute pressure variations into the reservoir due to CO_2 injection. The VFE assumption consists in neglecting any vertical flow against lateral flows and thus allows us to reduce the number of dimensions of the problem from three to two. When applied to mass conservation law coupled with Darcy's law, this assumption results to a remarkable efficiency model in terms of computing speed. The model is implemented using the FEniCS library coded with Python. In parallel, we compare the model with other reservoir simulations using Machine Learning or full 3D model approaches to demonstrate its validity and to allow us to implement it on real case studies. Thereafter, we implement the model in the case of an underground reservoir located in Alberta in Canada and managed by Shell. Using a mechanical model whose goal is to estimate surface subsidence from pressure depletion in the reservoir, we are able to compute surface deformation from different injection scenarios and then illustrate the model's abilities and interest.

NB: we are waiting for data from Shell to compare the surface deformation values obtained by the model with InSAR measurements. The abstract may therefore be completed with some comments about the results.

Compact and Efficient Chemical Boltzmann Machines With an Autonomous Learning Rule
Inhoo Lee
Mentors: Erik Winfree and Salvador Buse

Stochastic chemical reaction networks (CRNs) – a model of computation describing molecular systems with limited counts of species - can perform complex computations. CRNs can capture how biological cells are able to navigate, understand, and manipulate their environments, using species with counts often as low as one or several. In particular, stochastic CRNs are well-suited to behaving as stochastic neural networks, which are of interest due to their high computational power relative to the size of their chemical implementations. The Boltzmann Machine is a stochastic neural network capable of representing distributions, performing inference, and learning from data. Chemical Boltzmann Machines are stochastic CRNs that either exactly replicate or approximate the behavior of an abstract Boltzmann Machine. Our work proposes a new stochastic CRN implementation of a Chemical Boltzmann Machine, with an autonomous learning rule and a lower molecularity (fewer species per reaction) than prior work. The lower molecularity increases the plausibility of physical realizations of the CRN. An autonomous learning rule, with learning from data happening end-to-end within a chemical system, can further our understanding of how intelligent chemical agents such as cells can come to understand and make decisions.

Autonomous Cell Organization in Regenerating *Drosophila* Tibia
Iris Lee
Mentor: Lea Goentoro

The Goentoro lab has observed that regeneration of amputated tissues can be induced in common fruit flies by adding leucine, glutamine, and insulin to the growth medium. This regeneration occurs in a self-organized manner; though no structural or organizational instructions are given, regenerated tissue in amputated legs often appears indistinguishable from pre-amputation tissue. Distal joint regrowth has also been observed, demonstrating a cell organization and differentiation mechanism. To observe self-organized growth, we localize cells within regenerative tissue and compare this to localization within non-regenerative tissue. We marked cell nuclei using flies fluorescently marked for Histone H2B (His2B) and imaged amputated tibia using confocal microscopy at several time points. These images showed that muscle spindle organization is lost in both regenerative and non-regenerative tissue soon after amputation. In regenerative tissue, large numbers of nuclei have been observed around the amputation site and surrounding amputated leg in disorganized clusters at five days post-amputation, suggesting early cell proliferation. Lack of structure and dense packing of nuclei suggests small, possibly de-differentiated cells. In non-regenerative tissue, His2B signal is lost altogether. In subsequent work, we will localize nuclei at later time points to see changes across time, and examine the loss of cell signal in non-regenerative tissue. Additionally, we aim to observe mitotic events, which would definitively show that our solution can induce cell proliferation in post-mitotic adult flies.

CRISPR Plasmid Verification for Genes DLX 1 and DLX 2
Natalie Lee
Mentors: Marianne Bronner and Tatiana Solovieva

Schwann cell precursors (SCPs) are a derivative of neural crest cells, which are a migratory cell population. DLX 1 and DLX 2 are genes linked to the development of SCPs. Using the single-plasmid CRISPR delivery method on chicken embryos, we conducted a CRISPR Cas-9 knockdown for each gene, targeting cells that would migrate to the trunk or the branchial arches. By performing in situ hybridization, we determined where the embryo is expressing each gene. If the cells with the DLX 1 or DLX 2 knockdown plasmid match the location of their respective gene's lack of expression in the embryo, we can conclude that our CRISPR plasmids successfully knocked down their respective gene. This verification will allow us to further study the development of SCPs.

New Methods for Modeling Surface Deformation and Seismicity in Greenhouse Gas Reservoirs
Nicole Huimei Lee
Mentors: Jean-Philippe Avouac and Mateo Acosta

With the world's ever-growing energy demand, it is imperative to execute sustainable and long-term solutions to the harmful effects of carbon dioxide and natural gas in fossil fuel combustion. The Quest Carbon Capture and Storage site captures, injects, stores, and monitors CO_2 to effectively reduce greenhouse gas emissions. Here, we introduce an interface between strain-volume formulation mechanical code, and systems modeling and simulation Petrel software. By processing detailed fault data, this functions as an accurate 3-D model of the subsurface geometry in the reservoir and can be applied to further projects such as the Groningen reservoir, the largest natural gas field in Europe. The result is a comprehensive simulation of an all-powerful software that can be used for development design, production assessment, reservoir characterization, and performance.

Implementing Feedback Control Systems in Synthetic Cells
Trinity Lee
Mentors: Richard Murray and Abhishek Dey

Negative feedback is very common in nature, especially in cell signaling and growth. A major goal in synthetic biology is mimicking the autoregulation in living cells and cell communication. Previous work in Murray Lab has shown that a protein circuit in living cells can maintain a desired output with robust negative feedback. This project aims to implement that protein circuit in synthetic cells to maintain a concentration of a fluorescent reporter protein. The circuit is first modeled with BioCRNpyler and subSBML, Python packages that model chemical reaction networks and compartmentalization. We encountered several challenges while trying to express the circuit in cell-free TXTL extract. The TXTL extract needed to be made from the cell strain in the previous study, which resulted in weaker expression. The circuit was also dependent on inducible promoters, which did not express in the extract. We replaced them with constitutive promoters using cloning. Once the circuit expresses strongly in cell-free, it can be encapsulated in liposomes. After the feedback system is functioningin synthetic cells, it can be used in future experiments to control the export and exchange of small proteins in synthetic cells.

Simulating Gas Giant Entry With Multiphysics CFD
Kyle Lethander
Mentor: Guillaume Blanquart

Atmospheric probing of Saturn and Uranus was cited as a high priority mission in the 2013-2022 Planetary Science Decadal Survey, but entry conditions are difficult to predict due to coupling between fluid physics, chemical dissociation, radiative heating, and surface ablation. Therefore, multiple phenomena must be simultaneously modeled to predict the thermochemical environment of entry. The multiphysics CFD code NGA is used to simulate a hypervelocity reacting hydrogen flow over Galileo's entry probe using actual trajectory data. The code solves the 2-D compressible reactive Navier-Stokes equations, using a second-order accurate spatial discretization, an explicit RK4 time integration scheme, and a second-order semi-implicit midpoint scheme for scalars. Forebody stagnation properties are measured, and the impact of high temperature gas effects is demonstrated. The results of this study will help establish design requirements for future planetary entry probes.

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

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

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

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

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

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

The Key Features Venture Capitalists Focus on for the Most Promising Investment
Zhuoya Li
Mentor: Michael Ewens

Venture capital is believed to greatly contribute to the strength of the world economy by promoting the development of innovative start-ups, but little is known about what are the key features VC focus on when filtering which companies to invest in. My project aims to compare the difference between VC and nonVC financed companies to conclude what kind of companies are most likely to receive VC financing. I used a dataset of 5000 companies that have already gone public with both VC and nonVC included. After gaining more data on companies from API, we can apply the OLS method to gain insight into the difference between VC and others. The project found that VCs have certain high preferences against types of industries, size, region, revenue growth, innovation capability, and early employees' background of companies. The project also constructs a prediction model to calculate the likelihood of young start-ups being financed by the VC in the future.

Integration of Cell-free DNA Features in Machine Learning to Improve Detection of Peripheral Nerve Sheath Tumors
Sarah Liaw
Mentors: Aadel Chaudhuri, Jeff Szymanski, and David Van Valen

The leading cause of mortality for 8-15% of patients with neurofibromatosis type 1 (NF1) is the development of malignant peripheral nerve sheath tumor (MPNST). Additionally, the transformation of the benign precursor, plexiform neurofibroma (PN), to MPNST is hard to diagnose with current detection techniques (tissue biopsy and imaging) due to tissue heterogeneity. Here, we propose a computational approach based on the multi-institutional study by the Aadel Chaudhuri Lab and the National Cancer institute, which used fragment size analysis and ultra-low-pass whole genome sequencing of plasma cell-free DNA to distinguish between PN and MPNST, to classify the disease stage for patients with NF1. Using fragment size as an algorithmic feature, this project aims to improve on the machine learning model and employ dimensionality reduction to mitigate overfitting and reduce the complexity of the model due to the large volumes of DELFI and ichor data despite the small dataset. Upon completion, the classification of the model will aid in the early detection of MPNST, and cell free DNA based monitoring of PN burden, improving the prognosis for patients.

Uncovering Neuronal Heterogeneity in the ENS of the Basal Vertebrate, *Petromyzon marinus*
Jason Lin
Mentors: Marianne Bronner and Brittany Edens

The neural crest (NC) is a multipotent cell population from which diverse cell types, including the neurons of the enteric nervous system (ENS), arise[1,2]. Basal vertebrates like lamprey lack vagal crest, yet still develop a functional ENS, raising intriguing questions about evolution of this system. We found by immunofluorescence assays that lamprey intestine presents diverse neuronal subtypes. To completely characterize this heterogeneity, we are developing a protocol for antibody-based live-cell selection of neurons in larval lamprey intestines, from which we will perform single-cell RNA sequencing (scRNA-seq). We have validated the cell-surface marker Gt1b, which is selectively expressed by neurons, as a candidate for cell selection. Ongoing experiments are addressing compatibility of the Gt1b antibody with MACS (magnetic-associated cell sorting). Results of this experiment, in conjunction with published datasets, will allow us to construct an evolutionary trajectory of ENS development, and reveal the ancient function of NC cells in this process.

The Development of a Near-Fault Ground Motion Models for Southwest Iceland
Yi Lin
Mentor: Benedikt Halldorsson

Iceland's location on the Mid-Atlantic Ridge makes it prone to an abundance of seismic and volcanic activity. The densely populated area of Reykjavik, the capital of Iceland located in the vicinity of the South Iceland seismic zone and the Reykjanes Peninsula Oblique Rift (SISZ-RPOR) is especially vulnerable to the earthquakes, and in order to reduce the risk following an earthquake, PSHA is carried out. The Icelandic PSHAs are done with the considerations of the identification of earthquake seismic sources, seismic activity rates, and creation of Ground Motion Models (GMMs). Previous GMMs used in PSHAs of Iceland didn't make a distinction between data in the near-fault and far-fault stations, especially since forward-directivity ground motions from an earthquake exhibit high peak ground velocities (PGV) which are structurally devastating in near-fault sites. Capturing the characteristics of the directivity effects in the strong ground motion recording across the SISZ-RPOR is thus a crucial step in creating an effective near-fault GMM since its findings can be used to building codes that can withstand high PGV values. The near-fault GMMs thus can be used with confidence for a reliable PSHA and will mitigate the earthquake risk in Iceland.

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

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

** Note: italicized = unconfirmed/untested

Character Tables of Small Mathieu Groups
Joey Litvin
Mentor: Anna Szumowicz

Mathieu Groups are groups which act sharply n-transitive on a set, *S*, number of objects depending on the Mathieu Group. A group acts n-transitively on a set if for any choice of distinct a_1, a_2,...a_n in S and distinct b_1,b_2,...b_n in S, there exists g in G such that g*a_i = b_i for all 1≤ i ≤ n. We compute the character table for small Mathieu groups. Specifically the Mathieu Groups M_9,M_{10},and M_{11}. The Mathieu Group M_9 is sharply 2-transitive on 9 objects, M_{10} is sharply 3-transitive on 10 objects, M_{11} is sharply 4-transitive on 11 objects, and M_{12} is sharply 5-transitive on 1 objects.

Developing Motor Control for Biomimetic Autonomous Underwater Vehicles
Joy Liu
Mentors: Morteza Gharib and Meredith Hooper

There is significant interest in the development and deployment of Autonomous Underwater Vehicles (AUVs) for underwater exploration and maintenance, as they remove the need for sustained human interaction and grant much improved accessibility and cost efficiency compared to human-operated alternatives. Of central importance in the design of AUVs is a powerful and flexible propulsion system with biologically-inspired propulsion being a foremost choice owing to its excellent efficiency and maneuverability. We present a working prototype of a biomimetic fish robot with a fin-based propulsion system, greatly improved from its predecessor due to the inclusion of a more powerful redesigned propulsion setup with an embedded harmonic drive which allows the robot to potentially operate underwater for the first time. We detail the innovations in the design and assembly of the vehicle, the characterization of its performance and its optimal fin trajectories, and potential future improvements and applications.

Super-Resolution Microscopy Quantifies the Spatiotemporal Organisation of Transcription Factors
William Liu
Mentors: Shasha Chong and Shawn Yoshida

EWS::FLI1 is an oncogenic fusion transcription factor (TF) that causes Ewing's sarcoma, a devastating paediatric bone cancer with no known molecular therapies. Recent studies have shown that EWS:FLI1 forms local high-concentration hubs of relevant transcriptional machinery at specific gene loci through interactions between intrinsically disordered low-complexity domains (LCDs) and that transcriptional activity is tuned to a narrow optimum of hub size. However, due to their size being smaller than the diffraction limit of conventional light microscopes, little is known about the physical properties of these hubs and their link to oncogenesis. Here, we used single-cell super-resolution microscopy in conjunction with a new quantitative analysis pipeline to characterise EWS::FLI1 hubs. We calculate their diameter, volume, concentration, and show that most hubs are elliptical rather than circular. We compare the spatiotemporal organisation of EWS::FLI1 to FLI1, the related proto-oncogenic TF. Thus, our unbiased, quantitative framework will facilitate the further study of the spatiotemporal organisation of transcription factors, and more broadly, reveal how the strength and dynamics of LCD-LCD interactions mediate transcriptional activity by modulating hub size.

Observing the Magnetic Order Switching of Calcium Ruthenate Under Laser Manipulation Through Magneto-optic Kerr Effect
Yincheng Liu
Mentors: David Hsieh and Xinwei Li

Magnetic order manipulation with laser pulses has great technological potential in fields such as high-speed spintronics. Calcium ruthenate is a strongly correlated magnetic material that possesses a rich phase diagram and is susceptible to laser manipulation. In this work, we report photo-induced magnetic order switching in calcium ruthenate. By performing fluence-dependent and temperature-dependent magneto-optical Kerr effect (MOKE) measurements, we demonstrate that this switching is due to the formation of a meta-stable state occurring above a critical fluence. We further mapped out the temporal dynamics of the generation and the decay of this meta-stable state by measuring its on-off characteristics with shutter-based stroboscopic MOKE experiments. This work provides an example of how meta-stable states of correlated systems can be used to achieve magnetization control with light, providing insights for future technological applications.

Learning Dissipative Dynamics in Chaotic Systems
Miguel Liu-Schiaffini
Mentors: Anima Anandkumar and Zongyi Li

Chaotic systems are notoriously challenging to predict because of their sensitivity to perturbations and errors due to time stepping. Despite this unpredictable behavior, for many dissipative systems the statistics of the long term trajectories are governed by an invariant measure supported on a set, known as the global attractor; for many problems this set is finite dimensional, even if the state space is infinite dimensional. For Markovian systems, the statistical properties of long-term trajectories are uniquely determined by the solution operator that maps the evolution of the system over arbitrary positive time increments. In this work, we propose a machine learning framework to learn the underlying solution operator for dissipative chaotic systems, showing that the resulting learned operator accurately captures short-time trajectories and long-time statistical behavior. Using this framework, we are able to predict various statistics of the invariant measure for the turbulent Kolmogorov Flow dynamics with Reynolds numbers up to 5000.

Spin-phonon Coupling in a Series of Ruffled Copper Porphyrins
Nathan Lopez
Mentor: Ryan Hadt

Here we present the effect of geometric distortion, namely ruffling, of a series of copper porphyrins on the principal g-tensor values, ligand field excited state energies, and spin-phonon coupling (SPC) constants. We identify the symmetric stretching and ruffling vibrational modes as transforming as A_1 in the ruffled porphyrin's D_{2d} point group and can couple to spin relaxation. We identified three copper porphyrins of increasing degrees of ruffling: copper octaethyl porphyrin (CuOEP), copper tetraphenyl porphyrin (CuTPP), and copper tetraisopropyl porphyrin (CuTiPP). Experimental analyses of these ruffled porphyrins include continuous wave electron paramagnetic resonance (EPR) and pulsed EPR. We couple experimental analyses with quantum calculations to computationally predict the effect of ruffling on various quantum chemical parameters. With a greater degree of ruffling, we predict a decrease in $g_{\perp}$ with a concomitant increase in $g_{\parallel}$. Furthermore, we predict a decrease in transition energy from d_{xy} to $d_{x^2-y^2}$ with a simultaneous increase in transition energies from d_{z^2}, d_{xz}, and d_{yz} to $d_{x^2-y^2}$. Finally, we calculate the magnitude of SPC constants for all the coupling vibrational modes, and we find an increase in coupling between the ruffling vibrational mode as a function of the degree of static distortion.

Analytic Continued Fractions for Multivariate Regression Models
Mabel Lu
Mentors: Pablo Moscato and Michelle Effros

Mathematical models for describing two-body interacting potentials have been notoriously difficult to obtain from experimental data and there is a current lack of an algorithmic solution that is simple and effective as well as problem-independent. For instance, in the Thompson Problem the potential between a pair of electrons is known, but the minimum configurations of a set of electrons spread out across the surface of a sphere is not. In the case of noble gases, like Argon, the problem is to identify the two-body potential as a function of the distance between the molecules given some experimental data. In using different combinations of truncated analytic continued fractions (CF) to model these problems, one is of particular interest due to its adaptability, which follows the form of the first CF multiplied by e to the power of the other CF. To develop an algorithm to fit a function of that model, we explored common trends that reduce both complexity and error, including the use of integer and prime coefficients. We also explore simple manipulation of data variables that serve to simplify the problem. These traits in addition to the model are especially powerful in that they are accurate and computationally advantageous.

Differences in Risk-Taking Behavior in Individuals With Mood Disorders
Lana Lubecke
Mentors: Robb Rutledge, Ralph Adolphs, and Gloria Feng

Mood disorders are prevalent in the U.S. adult population and studying the underlying neurological mechanisms can help develop and improve treatment options. Computational models can aid in this via computational phenotyping. By fitting prospect theory and happiness models to the data collected from participants who played a risky-decision-making game, differences in behavior between healthy and affected populations were captured that were consistent with the literature. From the prospect theory model analyses, it was confirmed that people with depressive symptoms were more risk averse in the loss domain than healthy people. From the happiness model analyses, it was confirmed that people with depressive symptoms had a lower baseline happiness level while playing the game. Furthermore, longitudinal analyses will be conducted to determine any correlations between mood disorder symptom severity and differences in risk-taking behaviors across multiple game plays and between different environments.

Autoignition of Phosphate Ester-Based Aviation Hydraulic Fluids
Juan Luchsinger
Mentors: Joseph Shepherd and Conor Martin

Tributyl phosphate (TBP), a phosphate ester, is the primary component of aviation hydraulic fluid. The nature of phosphate ester autoignition is difficult to predict, as the phosphate component exhibits fire-resistant properties but the hydrocarbon component is highly flammable. The ASTM E659 test method was conducted on a range of temperatures and fluid concentrations to characterize the thermal autoignition of aviation hydraulic fluids—Skydrol PE5, Skydrol LD4, Mobil HyJet V—by observing the temperature change and luminosity of each reaction. Analysis of the Skydrol PE5 ASTM E659 tests demonstrates how richer mixtures can generate ignition below the reported autoignition temperature. Additionally, computational modeling of the reactions was carried out through MATLAB and Cantera to identify the products of TBP combustion. With respect to the global equivalence ratio (GER), two products—phosphoric acid and metaphosphoric acid—share an inverse relationship, with maximum metaphosphoric acid production occurring at a GER of 1.

Power Grid Digital Twin for Sustainability and Infrastructure Improvement
Enoch Luk
Mentors: Steven Low and Lucien Werner

Recent advances in renewable energy and its increased adoption, especially at Caltech, are adding pressure to the distribution grid and threatening its power quality. In order to prepare the power grid for fluctuations and increasing load, we must coordinate and optimize the nodes in the power system to form a smart grid. In order to visualize and interpret the results of network calculations, we are building a software interface that provides information about the state of the grid. This interface is a dashboard that queries live data from meters around campus and displays metrics such as kilowatt usage, meter outages, and voltage imbalance. It can be immediately applied to identify under-metered areas and buildings with voltage imbalance, which can damage equipment and incurs penalty fees. We are applying machine learning methods to determine correlations between different electrical readings and overall voltage imbalance. This will help Caltech achieve long-term goals, such as replacing power from the gas plant with renewable resources and reaching net zero emissions.

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

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

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

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

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

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

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

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

Predicting Private Companies' Success Using Web Archives
Georgia Malueg
Mentor: Michael Ewens

Currently, data on private firms is limited to expensive, incomplete datasets that only include the company's financing rounds. Furthermore, most startups fail but do not report if and when it occurs. This project aims to fill in the gaps between private companies' financing rounds, identify key signals of startup failure, and classify the private company as growing, failing, acquired, or out of business. The resulting dataset will be made publicly available as a free noncommercial use database of private companies. The dataset was collected using Common Crawl's free web archives to obtain data on the company's website changes over time, including changes in the company's product, hiring, and team pages every year from 2014 to 2022. Moreover, Common Crawl's web archives provide petabytes of data collected since 2011 and allows affordable access to historical website data. Analysis on the connection between the web scraped variables such as the emergence of a product page and startup characteristics will be completed in the coming weeks to determine key signals of startup failure and identify failed startups.

Repeated Patterns in Arbitrary Colorings
Michael N. Manta
Mentor: David Conlon

For fixed natural numbers n and k and subgraph H, we study the fewest numbers of colors $g_k(n, H)$ such that an edge-coloring of K_n does not contain k vertex-disjoint color isomorphic copies of the same subgraph H. We also study the function $g_k^*(n, H)$, which considers the same question without the vertex-disjoint condition. Both functions are closely related to a problem posed by Conlon and Tyomkyn. Using the Local Lemma, we show that $g_k(n, H) = O(\min\{n, n^{(kv - 2)/(k-1)e}\})$ for $v = |V(H)|$ and $e = |E(H)|$. With the upper bound, we show that $g_k(n, H) = \Theta(n)$ for forests. We present lower bounds of $g_k(n, C_{2t}) = \Omega(n^{1 - 1/t})$, $g_k(n, C_{2t+1}) = \Omega(n^{1/2})$, and $g_k(n, K_t) = \Omega(n^{1/(t-1)})$ for fixed t. We also prove that $g_k^*(n, H) = \Omega(n^{v/e})$ and a general lower bound for $g_k(n, H)$.

Modeling Water Flow in Plants
Emma Markowski
Mentors: Tapio Schneider and Katherine Deck

In order to characterize the effects of climate change, mathematical models are used to represent the surface and its time evolution. One important component of these land surface models (LSMs) is the vegetation on Earth, which mediates energy, carbon, and water fluxes between the Earth's surface and atmosphere. CliMA's LSM currently has a plant hydraulics model that can simulate the uptake of water from the soil into a plant using a representation with a single stem and leaf compartment. The calculation of the change in relative water content is hard coded for these compartments, where the time derivative of the relative water content is proportional to the flux of water into the compartment - the flux of water out of it. With a larger number of compartments, one could get results closer to what real life would yield. My project is to have the plant hydraulics model be able to calculate the relative water content for an arbitrary number of compartments, as well as to streamline the interface to be more consistent with other CliMA LSM components. By changing the plant hydraulic model's domain, roots model struct, and utilizing loops, thehydraulics model should be able to produce more accurate data.

Direct Atomic Resolution of Surface Reconstruction of $SrTiO_3$

Katherine Marquis
Mentors: David C. Bell and Julia Kornfield

$SrTiO_3$ is a standard model for oxides with a perovskite structure, as it contains a 3:1 ratio of oxygen to strontium that forms a packed lattice with titanium in octahedral interstitial sites. Oxide surfaces are technologically significant in catalysis and thin film growth. Thus, it is important that the surface structure and composition of $SrTiO_3$ is understood under varying experimental conditions. Heating a sample of $SrTiO_3$ to 950°C forms atomic terraces, and the surface adopts either a configuration of Ti and O termination with a ratio of 1:2 or an arrangement with Sr and O termination with a ratio of 1:1 [1]. Scanning transmission electron microscopy (STEM) can be used to determine the surface composition of the sample. STEM imaging shows the surface of $SrTiO_3$ heated to 950°C has stoichiometry similar to TiO_2.

Reference:

[1] N. Erdman, L.D. Marks, Surf. Sci. 526 (2003) 107–114.

Modeling Thermal Properties in the Continuum Simulation of AP/HTPB Burn

Patrick Martinez
Mentors: Brandon Runnels and Dan Meiron

Ammonium perchlorate in a hydroxyl-terminated polybutadiene binder is a commonly used solid composite propellant with a complex burn scheme. As such, a robust computational model is needed to simulate the solid phase, gas phase, and interactions between the two in order to improve safety and reduce the need for physical testing. The work uses a multi-phase-field model, or a diffuse interface, to track material and reaction properties with improved computational efficiency. Importantly, the self-sustained deflagration reaction has a cyclical dependency between the high heat flux of the gas phase and the mass flux coming from the deflagrating solid phase. We capture this connection through an adapted heat transport model which is verified with experimental data. Current work is done with simplified two-dimensional models but future working will be scaled to complex three-dimensional models.

Effects of Elemental Substitution on Cuprous Oxide Crystallinity

Russell Martinez
Mentors: Nathan S. Lewis and Sean Byrne

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

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

Warm, Competent, Unequal: The Current State of Hiring Discrimination

Beatrice Maule
Mentors: Colin Camerer and Marcos Gallo

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

Fourier Continuation for Exact Derivative Computation in Physics-Informed Neural Operators
Haydn Maust
Mentor: Anima Anandkumar

The physics-informed neural operator (PINO) is a machine learning architecture that has shown promising empirical results for learning partial differential equations. One key application of learning methods for PDEs is identifying candidates for blowup in fluid equations such as the Euler equations. However, for these candidates to be useful for theoretical work, the blowup candidate must have a guarantee of high accuracy. Learning methods that use the finite difference method to compute derivatives have limited accuracy, so the exact gradient method (computing derivatives via Fourier transforms) is preferable. However, the exact gradient method can only be applied to periodic functions. We present an architecture that leverages Fourier continuation (FC) to apply the exact gradient method to PINO for nonperiodic functions. Using Fourier continuation in this way presents ill-conditioning problems; as a result, the way in which FC is implemented into PINO must be chosen carefully. We present the results of several versions of FC PINO applied to 1D problems to compare their performance. Although the present results are promising, further improvements are required to apply this architecture to outstanding fluid blowup problems.

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

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

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

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

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

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

Quantifying Uncertainty in Reconstructed Interferometric Images for the DSA-2000
Tyrone McNichols
Mentors: Katherine Bouman and Oscar Leong

The DSA-2000 is a powerful upcoming radio interferometer that plans to use a feed-forward convolutional neural network called POLISH to reconstruct images from observed data. However, this process is ill-posed, meaning that there are several possible reconstructions that match the data. Moreover, these different reconstructions can have drastically different scientific interpretations, establishing a need for a measure of reliability in images. Here, we combine POLISH with the principles of Bayesian learning to allow the network to output a pixel-wise uncertainty estimate in addition to the reconstruction. This uncertainty estimate captures confidence in reconstructions as well as imperfections in the data set and model itself. We demonstrate this model using simulated radio sky data. Our model is able to provide accurate reconstructions and metrics needed to assess the reliability of those outputs.

Designing the Drive System Handoff Module for Lunar Crater Traversal
Aramis Mendoza
Mentor: Soon-Jo Chung

The lunar environment is populated with unexplored terrain, craters with up to 40 degree slopes preventing current robotic systems from successfully examining their promising unknown properties. LATTICE (Lunar Architecture for Tree Traversal In-Service of Cabled Exploration) was designed to expel these unknowns with an efficient, ever-expanding robotic system transforming the well-known cable car into lunar infrastructure. The LATTICE drive team have been designing an elevator drill system for an earth scale demonstration which will plant the stakes containing cable for the robotic shuttle to traverse. A stake handoff system was necessary to drive these stakes. The handoff system, in the form of a linear rail, was designed to hold 2 meter stakes, weighing 15 kg, close enough so that they can be drilled, but firm enough so that the stakes do not slip. The handoff was developed as a passive mechanism which releases as the drive system is driven away.

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

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

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

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

Developing the GALACTICUS Dark Matter and Galaxy Formation Code

Ellen Min
Mentors: Ethan Nadler, Andrew Benson, and Philip Hopkins

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

Stochastic Local Search in Surface Chemical Reaction Networks to Solve 3-SAT Problems

Mohini Misra
Mentors: Erik Winfree and Salvador Buse

Chemical reactions drive biological phenomena at a molecular level. To study the sophisticated functionality that is thus enabled in molecular environments, the scientific community has developed models of computation to understand and engineer such systems. Chemical Reaction Networks (CRN) are one such model of computation, which have been studied extensively in well-mixed environments. Chemical reactions are inherently stochastic, so CRNs are modeled to be as well, allowing us to exploit randomness in algorithms we create. This is particularly useful for solving Constraint Satisfaction Problems (CSP) with Stochastic Local Search (SLS). In well-mixed environments, a CRN for the 3-SAT CSP has been previously developed. However, this CRN must scale up the number of species and reactions with the size of the problem. Here we show that such scaling isn't necessary if we solve 3-SAT using a surface CRN, where reactions can be localized and thus reused in different contexts. First we present a simple surface CRN (31 reactions, 11 species) which only resolves constraint conflicts, and second we present a more complex surface CRN which resolves constraint conflicts more efficiently by harnessing directionality and bias. This work has implications for how CSPs are approached in biological phenomena that depend on geometry and location, such as self-assembly and self-healing.

Determination of the Cellular Origin of cfDNA Using Methylation

Prashanth Mohan
Mentors: Aadel Chaudhuri, Nick, Semenkovich, and Judith Campbell

Plasma contains circulating fragments of DNA, known as cell-free DNA (cfDNA), that can be elevated or altered in states of disease and injury. In this project, we attempt to utilize methylation (the addition of a methyl group to certain cytosine base pairs used for regulating gene expression) to determine the cellular origin of a given cfDNA fragment. The ability to precisely identify where a given cfDNA molecule derives from would allow us to gain a deeper understanding of the state of a patient's illnesses and degree of organ damage. Existing research in the field has focused on aggregating methylation data to create a score that can be used to find the origin of the cfDNA fragment, and also focus on identifying high-level cell types. In this project, we attempt to use individual methylation site data to classify more niche cell types as well as high-level ones. To cut down the size of the millions of methylation sites obtained during sequencing, we targeted our analysis around biologically significant promoter sites, and found differentially methylated regions reduce potentially noisy methylation sites. We are now applying an ML model with a transformer-based tabular framework to connect the processed data to its corresponding cell type. If this work is successful, we should be able to sequence the cfDNA obtained in a blood sample from an individual patient, and precisely identify where fragments of cfDNA derive from.

Analysis of Quantum Systems With Large Bond Dimension Using Matchgate MERA

Noah Moran
Mentors: John Preskill and Alexander Jahn

Matchgate MERA (Multiscale Entanglement Renormalization Ansatz) is a variational method to study the ground states of quantum systems. Matchgate MERA replaces the isometries and disentanglers of MERA with matchgates. The use of matchgates replaces tensor contractions with Grassmann integration. The Grassmann integration makes the computational cost of contracting over the tensor networks quadratic, which is several orders of magnitude less costly than MERA. This allows for analysis of the Ising model with large bond dimension and more sites. Since it not known to what extent matchgate MERA can accurately model Hamiltonians, a perturbation may be added to the matchgates to accommodate for more Hamiltonians.

Structural, Biochemical, and Evolutionary Linkage of Kapα:NLS Binding Interaction
Anna Mortari
Mentors: André Hoelz 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. The nuclear import factor karyopherin-α binds the nuclear localization signal (NLS) of proteins, allowing large proteins to move across the NPC. To investigate karyopherin-α:NLS binding and see if it is conserved within humans, karyopherin-α and NLS peptides were recombinantly overexpressed in *E. coli*, purified individually to high homogeneity using a series of chromatographic steps, and mixed prior to vapor diffusion crystallization experiments consisting of over 600 different conditions, resulting in either phase separation, precipitation, or protein crystals. Future work includes performing affinity assays to validate the binding interaction of karyopherin-α to the wildtype and mutant NLSs, as well as using the diffraction data and phases obtained by molecular replacement with previously determined karyopherin-α homologs to resolve structures of karyopherin-α:NLS complexes. The karyopherin-α:NLS structure will elucidate the molecular basis for the karyopherin-α interaction with NLS sequences.

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

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

Genetically Engineering a Chemically "Stealth" *Dalotia coriaria* Beetle
Veronica Muller
Mentors: Joseph Parker and Hannah Ryon

Many rove beetle species in the subfamily of Aleocharinae have convergently evolved myrmecophily, a close social relationship with ants. These species often exploit chemical tools such as insignificance or mimicry in order to integrate into the ant colony and access the safety and resources it provides. *Dalotia coriaria* beetles embody the evolutionary starting point from which myrmecophilous lineages evolved, but *Dalotia* themselves are free-living. *Dalotia* possess a significant cuticular chemical profile and secrete noxious benzoquinones when confronted by hostile ants. In this project, we determine if chemical insignificance is sufficient for a free-living beetle like *Dalotia* to gain access to an ant colony nest. This is investigated by genetically engineering *Dalotia* beetles to inhibit all chemical signal production, and then by performing extensive behavioral analysis on these engineered beetles with *Ooceraea biroi* ants. We will use CRISPR/Cas9 gene editing to knockout enzymes that produce cuticular hydrocarbons and/or benzoquinones, and then observe the behavior of these mutated lines in the presence of ants. By testing the effects of targeted knockouts on behavior patterns, we elucidate possible origins and evolutionary pathways for the development of inter-species symbiosis, and yield novel insights into the extent of behavioral plasticity within a species.

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

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

Simulating the Dynamical Evolution of Giant Planet Resonant Chains
Vighnesh Nagpal
Mentor: Konstantin Batygin

Models of planet formation predict inward migration and the subsequent capture of planets into mean-motion resonances, orbital configurations in which the period ratios between planets are approximated by nearby integers. However, the observational exoplanet sample shows that most planetary systems do not contain such resonant chains—leading to proposals such as the "breaking the chains" scenario, in which the onset of chaotic dynamical instabilities after the dissipation of the disk can disrupt resonant chains and lead to varied planetary system architectures. In this work, we use the hybrid symplectic integrator MERCURIUS to simulate the long-term dynamical evolution of two giant planet systems (with masses drawn from a distribution informed by the observational sample) that are initially in a resonant configuration. We study how different masses, eccentricity, and semimajor axis damping strengths impact the process of resonant capture and the subsequent long-term orbital configurations of systems containing two giant planets. Upcoming work will involve the extension of these simulations to systems with a larger number of giant planets and detailed comparison of the results with properties of the observational sample such as the period ratio distribution in order to derive constraints on the initial resonant configurations of planetary systems.

Class Numbers of Real Cyclotomic Fields, Principal Ideals, and Regular Primes
Kenji Nakagawa
Mentor: Alex Dunn

The real cyclotomic class number problem has been studied historically through the Weber conjecture as well as through the $\mathbb{Z}_p$-extensions of Iwasawa theory. Recent work has attempted to prove the conjecture that the $\mathbb{Z}_p$-extensions all have class number one, or at least for small examples, however, the process of establishing a sufficiently small upper bound for the class number to conclude its exact value has been limited by proving some prime ideals are principal. We provide a proof for some known results as well as develop a theorem that gives conditions for when prime ideals are principal. These theorems avoid explicit computation which lend itself to potentially more efficiency. Furthermore, we will investigate when these theorem's conditions are satisfied as well as a possible generalization of Siegel's conjecture for regular primes.

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

Since the Higgs boson was discovered in 2012 at the Large Hadron Collider, there have been substantial efforts on probing the nature of the Higgs potential. Studying Di-Higgs production, which is sensitive to various parameters of the Higgs potential, provides an excellent avenue to accomplish this. We seek to investigate Di-Higgs production by searching for the decay to four bottom quarks. Event selections and reconstructions for a fully resolved jet state have been performed on simulated data. This allowed the training of a multivariate (MVA) discriminator for the different Di-Higgs production modes which increases the resolution of the analysis. We have started the process of implementing a data-driven method for background modelling, which we can then use to train a MVA discriminant to distinguish between signal and background. In the future, we intend to implement our analysis on real data and further strengthen the statistics on Di-Higgs production.

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

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

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

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

Accelerating Astronomical Classification Models Using Edge TPU Hardware
Randy Ngo
Mentors: Matthew Graham and Ashish Mahabal

The Zwicky Transient Facility (ZTF) is a robotic optical survey that aims to register astronomical events by observing the night sky. In the past, multiple deep-learning models have been developed to read through ZTF data streams and highlight points of interest. By using tensor processing units (TPUs) developed by Google under the Coral brand, these models have been able to run significantly quicker than on traditional computer processors. This was done through converting the existing software models into simpler quantized versions compatible with the TensorFlow Lite library. The flexibility and ease of use of edge TPUs allows for machine learning models to be developed with a lower barrier of entry on a local machine.

Fabricating Titania Lattices Using Hydrogel Infusion Additive Manufacturing
Miguel Nocum
Mentors: Julia Greer and Akash Dhawan

Titania (TiO_2) is a frequently employed material in biomedical devices because of its mechanical properties and biocompatibility. Current utility of titania in biomedical devices is restricted by limitations in fabricating structures with complicated microscale features. Additive manufacturing (AM) is useful to create parts with complex features; however, current ceramic AM techniques are limited by resolution. The Greer Group has developed a novel hydrogel infusion additive manufacturing (HIAM) technique to fabricate metal and ceramic parts from a polymer skeleton. We aim to utilize this process to develop titania octet lattice structures. The calcination temperature of the process was adjusted to isolate a single phase of titania, and the concentration of the metal salt solution and swelling time were both varied to attempt to control the physical properties of the titanium dioxide lattices, namely beam hollowness and porosity. Controlled airflow during calcination was particularly important to maintain structural integrity and avoid excessive amorphous carbon in the final product. We confirmed titania phases and carbon using powder X-Ray Diffraction. Scanning electron microscopy showed two sets of grain sizes implying multiple mechanisms by which grain growth occurred during the ceramic formation. This result is important as it may provide an avenue by which to fabricate hollow structures and should be studied closer.

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

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

Subgrid Modeling for Large Eddy Simulations of Premixed Combustion
Max Oberg
Mentors: Guillaume Blanquart and Matthew Yao

Being able to model hydrogen combustion is important to understand a wide range of physical phenomena from the destruction of stars, to engineering applications as in understanding hydrogen's use as an alternative fuel source. However, thermo-diffusive instabilities in hydrogen combustion require physical models in Large Eddy Simulations (LES) to account for them. The goal of this project was to assess critically current models for the variance (cv) of the progress variable in hydrogen combustion and propose a new model based on these findings. Using Matlab, and Direct Numerical Simulation (DNS) data by a former graduate-student, the data was filtered and analyzed. Currently, it appears that present models using just cv are not enough to fully represent hydrogen combustion. New models will likely need to be developed that will also take the mixture fraction and the variance of the mixture fraction into account.

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

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

Defining a New Class of AGN: The "Low Frequency Peaked" Sources
Sandra O'Neill
Mentors: Anthony C. Readhead and Gregg Hallinan

Interplanetary scintillation (ips), the radio analogue to the twinkling of stars, yields a technique for identifying source sizes when they are smaller than the diffraction limit. We combine archival ips data 81.5 MHz with recent LWA data from 20-88 MHz to study 1789 jetted-AGN sources. The LWA data allows us to construct source spectra, from which we can find spectral index values and identify which sources are turning over. If a source is not turning over, we determine an upper limit to the turnover frequency. For those which are turning over and are either close to or in equipartition, we compute the equipartition brightness temperature, equipartition angular size, magnetic field, and magnetic field to particle energy density ratio. From here, we go on to define a new class of AGN not yet thoroughly examined in the literature: the "low-frequency peaked" sources.

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

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

Classification of Private Highly Innovative Firms
Alejandro Ortega Grisso
Mentor: Michael Ewens

Young private companies or innovative companies are by nature doing new things and so it's challenging to categorize them. Current analysis of private firms, which is already limited, does not account for how a company is innovating and evolving. We are interested in finding and categorizing private high growth firms which could have potential to open new markets. We summarized existing literature and scraped company websites for information via Diffbot and merged with other data sources like LinkedIn. We performed a text analysis which ranked young

private companies on how common their word language usage was. Using employee data as a metric for growth, we found that companies with more uncommon word usage tend to grow more quickly. This suggests that those companies target new high growth areas of their industry with a potential to create new markets.

Unifying Proofs of Definable Dichotomies
Noah D. Ortiz
Mentor: Zoltán Vidnyánszky

There is a recurrent, yet not formally unified, argument in the literature of definable combinatorics about when it is possible to build a definable homomorphism from one graph G to another graph H. By generalising to definable models with finite-arity relations and introducing a ``weak projective limit'', we establish sufficient conditions for the disjunction that, either H can be covered by countably many sets of a certain form, or there is a continuous model morphism from G to H. Kechris+Solecki+Todorcevic (1999) established a minimal definable graph $\mathbb{G}_0$ with uncountable Borel chromatic number. Lecomte (2009) and Miller (2011) presented generalisations to hypergraphs and classical arguments of $\mathbb{G}_0$. Carroy+Miller+Schrittesser+Vidnyánszky (2021) established a minimal definable graph of Borel chromatic number at least three with a similarly structured proof. Despite having remarkable similarities, these proofs have not been unified due to technical differences in each. Our statement covers these results in at least the finite-arity cases. By weakening from continuous to Borel, we anticipate that the statement can be generalised to relations of infinite arity.

Ab-Inito Physical Characterization and Rapid Engineering Development of LATTICE: The Lunar Architecture for Tree Traversal In-service-of Cabled Exploration
Lucas Pabarcius
Mentor: Soon-Jo Chung

Traditional wheeled locomotion systems struggle to climb slopes greater than 20° and are unable to independently return samples from lunar regions of interest such as habitation-enabling, icy permanently shadowed polar craters. To enable a diverse range of future robotic activities within lunar craters, the Caltech NASA Big Idea Challenge team has developed LATTICE, a lightweight, rapidly deploying, long-lived robotic infrastructure. Utilizing a novel cabled locomotion modality, LATTICE provides a scalable framework for transportation of power, information, and mass on the Moon. As team lead, I have conducted a first principles characterization of LATTICE to identify its mass-optimal deployed configuration and delivered value alongside design and engineering work on an Earth-scale demonstrator implementation, described herein.

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

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

Developing Genome Editing Tools to Study Isoform Usage and Non-Coding RNAs
Katherine Pan
Mentors: Alexei Aravin and Peiwei Chen

Transposable elements (TEs) are mobile genetic elements that can act as harmful mutagens through replicative transposition in the host genome. The primary regulatory pathway that keeps TEs in check is the piRNA pathway, where small non-coding RNAs called piRNAs guide the PIWI-family proteins to identify and silence TEs. Without the piRNA pathway, TEs wreak havoc, resulting in animal infertility. One key player of the piRNA pathway is a PIWI protein called Aubergine (Aub), which has two putative isoforms in the *D. melanogaster* genome. While Aub has been studied extensively in the last two decades, nearly all studies have looked at the longer isoform and overlooked the fact that there is another shorter isoform. In this study, we have developed genome editing tools to determine the localization and functionality of both the long Aub isoform as well as the uncharacterized short isoform of Aub. We generated flies that only express the short Aub isoform at the endogenous locus with a N-terminal GFP using CRISPR-Cas9 editing. We also created flies with a N-terminal mCherry at the start codon of the long isoform to visualize the localization of the long Aub isoform. These two edited flies will allow us to compare the two isoforms side by side *in vivo.* Since a bona fide loss-of-function allele for *aub* is unavailable, we have also completely deleted the *aub* gene. In addition, we further applied our genome editing techniques to precisely delete small RNA producing loci to gain further insight into the factors regulating fertility and transposon mobilization. Together, these genome editing tools allowed us to functionally modify genes in a isoform-specific manner and to precisely delete genomic loci encoding either protein-coding genes or non-coding RNAs for functional studies.

MATLAB-based Systemic Detection and Analysis of Spatiotemporal Neuronal Activity Patterns
Rucheng Pan
Mentors: Mikhail Shapiro and Ernesto Criado-Hidalgo

In current research practices, spike sorting is utilized for the analysis of calcium imaging data in order to isolate the signals of individual cells and quantitative representation of their activity patterns. However, oftentimes, this method is done manually as computational tools supporting automated processing and quantitative analyses of their imaging data are often unavailable. This results in considerable consumption of considerable time and human labor. Therefore, this creates the need for an automated processing and quantitative analysis of calcium imaging data for large-scale neurophysiological studies. The application breaks down the imaging data into individual cells, subsequently allowing us to detect calcium spike trains of specific cells. Our application includes several computational algorithms, including a circular Hough transformation (CHT) to detect all circular elements (cells), and a k-nearest neighbor algorithm to ensure no two detected points are pointing at the same cell. Preliminary results demonstrate that our methods not only automates time-consuming, labor-intensive tasks in the analysis of data but quantifying action potentials. Going forward, further analysis of the data may allow us to visualize the quantification of neuronal responses to chemical stimuli as well as visualizing and mapping of spatiotemporal patterns in the mechanical neuronal firing activity of a large network.

Ab-initio Approach to Electronic Noise and AC Mobility in n-Type Silicon
Juhi Parikh
Mentors: Austin Minnich and Benjamin Hatanpaa

Hot electron transport in semiconductors is an area of fundamental interest especially when it comes to miniaturization of devices. The properties of carriers change significantly at such high electric fields. An ab-initio approach to analyzing these properties considering electronic transitions caused by electron-phonon interactions among other causes can help verify results that can be observed experimentally. We use the electron band structure and the scattering rates of carriers calculated using ab-initio methods to examine electronic noise and other transport properties for n-type Silicon. We especially focus on two-phonon scattering of carriers at these fields so as to determine if it has a considerable impact on the observables. We thus try to gain insight into the processes that play an important role in determining the electronic noise and transport properties and try expanding the scope of ab-initio methods to predict these in various semiconductor materials.

Automated Active Learning for Zwicky Transient Facility Data
Saagar Parikh
Mentors: Ashish Mahabal and Michael Coughlin

Active learning is the process of prioritising the data that needs to be labelled in order to have the highest effect on training a supervised model. Since the Zwicky Transient Facility (ZTF) data has a large number of objects having numerous features, it is crucial to leverage active learning and selectively label the most impactful objects from the data. We create a robust active learning framework with automation in selecting the data points to be labelled. We form certain categories consisting of objects that either have some ambiguity in the class scores or are misclassifications. To further bring down the number of objects, we apply filters and eliminate the bogus ones. Thus by ranking these objects, we can select the required number of objects and send them to highly skilled, trained professionals for relabelling. This active learning framework hence significantly reduces human efforts and improves model performance.

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

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

Data-Efficient, Motion-Robust Accelerated MR Reconstruction for Clinical Pediatric Imaging
Deepro Pasha
Mentors: Shreyas Vasanawala, Mikhail Shapiro, and Arjun Desai

Deep neural networks have shown promise for improved image quality and faster inference for magnetic resonance image (MRI) reconstruction. However, current methods rely on large extents of fully-sampled (i.e. labeled) training data and are sensitive to distribution shifts. Recently, VORTEX, a semi-supervised MRI reconstruction framework, demonstrated that under-sampled (i.e. unlabeled), artifact-corrupted scans can be used to train DL models that are robust to acquisition-related perturbations, such as patient motion. In this work, we extend VORTEX to accommodate two-dimensional roto-translational motion frequently observed among pediatric patients. We demonstrate that both augmentation-based supervised and VORTEX methods trained with naïve motion models are equally sensitive to more roto-translational motion perturbations. However, by using our proposed roto-translational motion models during training, VORTEX models can generalize better to multi-dimensional motion artifacts.

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

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

Utilizing Chemotactic Bubble-Based Microrobots for Blood-Brain Barrier Penetration
Payal Patel
Mentors: Wei Gao and Songsong Tang

While it is responsible for protecting one of the body's most delicate regions, the blood-brain barrier (BBB) prevents many therapeutic agents from reaching their intended targets in the brain. Recently, however, 3D-printed and organically-derived microrobots have become popular candidates for delivering drugs because of their ability to navigate through hard-to-reach places like tissues and organs. The most prominent microrobotic systems rely on external acoustic and/or magnetic fields for locomotion, but such systems are limited by specific frequency ranges and field orientations. Here, we propose the development of chemotactic, bubble-based microrobots that are actuated by the chemical breakdown of glucose. Through in-vitro models of the BBB using transwell assays, we saw that the microbubbles, when functionalized with glucose oxidase and catalase from bovine liver, can actively diffuse towards higher concentrations of glucose, making them ideal candidates for future in-vivo studies regarding BBB penetration in mice. Moreover, we performed in-vitro assessments with bEnd.3 endothelial cells to gauge microbubble cytotoxicity and cellular uptake of the microbubbles. With our experimental conclusions and observations on the flexibility of bubble modification, we expect to be able to use these microbubbles as carriers to transport therapeutic compounds across the BBB.

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

Polymer mechanochemistry is field of research where mechanical force, transduced by polymer chains, causes predictable chemical transformations in force-sensitive molecules known as mechanophores. Mechanophores have been developed that generate color, switch electrical conductivity, and release small molecules under applied stress. Prior work in the Robb group identified a mechanophore design capable of mechanically triggered small molecule release via a retro-Diels-Alder reaction revealing a furfuryl carbonate that decomposes to release covalently-bound small molecules in a polar protic solvent. However, this platform has only been proved successful in solution-phase experiments using ultrasound and it has yet to be demonstrated in solid state materials. In our current work, we investigate mechanically triggered release of fluorogenic, odorous, and reactive small molecules in bulk polymeric materials using various modes of mechanical activation. Mechanically triggered release in bulk polymeric materials is promising for potential applications in drug delivery, mechanical lithography, and self-healing materials.

Monitoring Ultraluminous X-Ray Sources (ULXs) Using Chandra

Gauri Patti
Mentor: Hannah Earnshaw

Ultraluminous X-Ray Pulsars (ULXPs) often demonstrate long-term variability and may exhibit a bimodal flux distribution which can be caused by the onset of propeller effect. Previous studies required a large amount of data and focused on a small number of sources. We monitored long term variability of ULX-rich galaxies: M51, NGC 253 and NGC 4485-4490 in order to identify methods which do not require a large amount of data and study the ULX population as a whole. The ULX populations of these galaxies appear to have different variability behaviors. Sources exhibiting different variability behaviors were examined using spectral analysis by studying their photon index. NGC 4485-4490 ULX 3 exhibited soft spectra and is persistent over time, which we suggest could possibly be due to observing the accretion disk from a higher inclination angle. The slightly variable source NGC 253 ULX 2 exhibits a significant downward relation between luminosity and photon index with a correlation coefficient of -0.726 and p value of 0.017. We plan to model the sources with physically motivated thermal models such as diskpbb. To understand these we intend to further study hardness ratios of the whole ULX population using BEHR as this method can be used even for very low-count data.

Robust Quantum Control of Solid-State Ytterbium Qubits

Elijah Paul
Mentors: Andrei Faraon, Andrei Ruskuc, and Chun-Ju Wu

Robust quantum control is crucial to realizing any form of quantum technology. For microwave spin-transitions and optical readout transitions in qubits, this requires detailed understanding of noise sources, and electromagnetic pulses designed to combat these errors. We investigate improvement to previous high-fidelity single-qubit gates in $^{171}Yb^{3+}$ doped into an yttrium orthovanadate crystal, along with simultaneous control of two detuned qubits with a single control field through use of composite pulses. We further demonstrate accurate simulations of the quantum system, and show the applicability of the GRAPE algorithm to this system. We also investigate the use of these techniques applied to optical readout transitions, where high-fidelity control is necessary to achieve long-range entanglement and large quantum networks. This is done through a free space optical setup utilizing a double-pass acousto-optic modulator (AOM), which is designed to test the ability to generate arbitrary pulses.

Information Theoretic Trade-offs in Creating Disentangled Representations

Eric Paul
Mentor: Juan Pablo Vigneaux

Techniques in AI such as β-VAE have shown the benefits of creating disentangled representations of data. It turns out that the use of variational disentanglement algorithms is useful even in the absence of independent generative factors. When the generative factors are dependent, we experimentally see that there is a trade-off between the two goals of creating a disentangled representation: capturing one of the generative factors and being independent of the other generative factors. In our project we reformulated the idea of disentangled representations with information theoretic terms and studied the experimentally found trade-off. We looked simple cases and found three general regimes depending on how prioritized the goal of being independent of other factors was. We then proved under certain regimes how the optimal construction is a function of the generative factors. A better understanding of the trade-off that occurs provides for a better understanding of the best disentangled representations that can be achieved and thus has implications for the potential of AI's that depend on such representations.

Using Stochastic Surface Chemistry to Solve the k-Coloring Constraint Satisfaction Problem

Jean-Sebastien Paul
Mentors: Erik Winfree and Salvador Buse

Well-mixed stochastic Chemical Reaction Networks (CRNs) have been shown able to exploit their inherent stochasticity to solve hard NP-Complete constraint satisfaction problems. Seeing how the inherent randomness of low-level chemistry can be used to form efficient stochastic local search algorithms, one intuitively asks how this might apply to surface CRNs- an equally stochastic, yet spatially restricted counterpart to stochastic CRNs.

In this vein we explore the graph k-Coloring problem. By treating chemical reactions as a means to identify violations of defined constraints, we are able to randomly resolve vertex coloring conflicts until a valid solution is found- a defined equilibrium. Harnessing the surface CRN's spatial constraints, we achieve a surface CRN (DirectColoringCRN) with 7 species and 24 reactions that can solve any solvable planar 3-coloring problem. We are also able to construct a surface CRN with 15 species and 72 reactions that implements biased local search to improve performance in the 3-coloring case (RejectWaveColoringCRN). Finally we are able to create a larger CRN that uses directional propagation of information (in addition to local search bias) to effectively solve k-coloring in all arbitrary solvable graphs (RejectSignalColoringCRN); that architecture provides a promising springboard for the implementation of a surface CRN neural network.

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

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

Measuring Terahertz Radiation in Laboratory Simulations of Astrophysical Plasma Jets With Field-Effect Transistors
Joshua Pawlak
Mentor: Paul Bellan

Experiments simulating astrophysical plasma jets at Caltech have densities of 10^{21} to 10^{22} m^{-3}, so the electron plasma frequency falls in the low terahertz regime. Because the upper hybrid frequency is dominated by the electron plasma frequency in this experiment, a strong terahertz radiation emission is expected from electromagnetic wave excitation at the upper hybrid resonance layer. However, measurement of this radiation is challenging because of the "terahertz gap" in detection technology, such that there is a dearth of suitable detectors.

Field-effect transistors (FETs) have been shown to develop an internal plasma wave resonance when illuminated by terahertz electromagnetic radiation. Nonlinearity associated with this resonance produces a small tunable DC response which can be used to produce a relatively simple detector of terahertz radiation. We are constructing such a device from a commercially available FET and will attempt measurement of plasma radiation in this frequency regime from the jet experiment.

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

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

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

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

Development of a Controlled Humidity System to Understand the Water-Membrane Interactions in Polyamide Reverse Osmosis Membranes
Claire Perhach
Mentors: Michael Toney, Emma Antonio, and Konstantinos Giapis

Reverse osmosis (RO) for water desalination is an increasingly important technology for enabling global fresh water access. To improve polyamide (PA) membranes for RO, it is important to better understand the water-membrane interactions. Fourier transform infrared (FTIR) and x-ray photoelectron spectroscopy (XPS) are used to observe PA membrane structure as they are hydrated and dehydrated to understand these molecular interactions between water and the PA. A device was developed that controls the hydration of the membrane and its surrounding environment by altering the ratio of dry nitrogen to water saturated nitrogen under flowing conditions. This project aims to fine-tune the device and observe changes in the membrane at different humidity conditions.

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

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

Clouds in Climate Models
Khanh Pham
Mentors: Tapio Schneider and Anna Jaruga

One of the most important innovations has been our ability to model the climate of the Earth. The CliMA group has been working on developing an earth system model that can learn from data. Modeling the Earth system is a very complex problem and requires many parameterizations, for example parameterization of processes leading to the formation of clouds and precipitation (the cloud microphycics). The goal of my project is to find which of the parameterized cloud microphysics processes has the greatest effect on numerical simulations. I study this by varying the intensity of individual cloud microphysics processes and measuring their impact on the final cloud and precipitation fields for different cloud regimes (stratocumulus, shallow and deep convection). In my simulations I use a numerical model that is a prototype of the future CliMA Earth system model. In my presentation I'm going to show that the parameterization of rain formation has the biggest impact on the simulations. Afterwards, I'm going to show the effects of calibrating that process in order to fine tune the model.

Realizing a Scalable Quantum Network: Strain-tuning Silicon Vacancy Color Centers in Diamonds
Phuong Pham
Mentors: Marko Loncar, Daniel Assumpcao, and Maria Spiropulu

The feasibility of a global quantum communication network has been limited by the lack of a stable, scalable quantum bit (qubit) platform with long quantum coherence times. The negatively charged silicon-vacancy (SiV) color center in diamond has gained attention as a promising mean of generating entangled qubits due to its exceptional spin coherence and spectrally stable emission. However, SiV centers are sensitive to thermal decoherence due the high susceptibility of SiV's energy level to strain. Previous experiments have found that the strain of the SiV centers can be temporarily controlled with a nano-electro-mechanical system to increase the spin coherence without altering the temperature of the environment. Here, we introduced a permanent strain in the embedded SiV color centers through depositing a high stress thin film of silicon nitride onto the diamond devices. The SiV devices showed a large shift in the photoluminescence spectrum, indicating a large shift in their energy levels and therefore, a corresponding increase in their coherence times.

Analysis of Instabilities in Simulation of Rotating Detonation Engine
Luke Phillipps
Mentors: Guillaume Blanquart and Alexandra Baumgart

The standard gas turbine engine has been the dominant engine type in both commercial and military use, but a new engine type, the Rotating Detonation Engine (RDE), is theorized to be much more efficient because of its ability to steadily create a detonation wave rather than a pressure-cycle. The gas turbine engine has been thoroughly modeled and studied computationally, and the RDE needs similar care before it can fully come to fruition. However, because of unconventional traits associated with how the RDE works, it can be difficult to create a realistic detonation wave model. The current model is sufficient to depict the detonation, but needs improvement in order to become a realistic model. Several different iterations of the detonation wave have been tested, in which characteristics of the simulation such as inlet and outflow conditions were changed. Upon review, it was found that the current detonation model had an issue at the boundary condition, in which data that should have been going past the boundary was being reflected back into the domain, creating disturbances in the overall wave shape. Additionally, analysis of the detonation in both one and two dimensions over long timescales showed a breakdown in the overall form of the detonation wave.

2.2.2 Bicycle Fragment Development for the Synthesis of Cochlearenine
Tessa Pierce
Mentors: Sarah Reisman and Raymond Turro

Diterpene alkaloids have been produced by the Reisman group in the past (2021), and consist of an electrophilic epoxyketone and a nucleophilic 2.2.2 bicycle fragment. The overall goal of my SURF project is the development of a selective and efficient reaction sequence to synthesize the diterpene alkaloid, Cochlearenine, in quantities sufficient for analysis or biological studies. To accomplish this, the two fragments of the diterpene alkaloid must be produced. The focus of my project has been the production of a 2.2.2 bicycle fragment for use in this reaction. The current route for synthesizing the enantioenriched bicycle fragment has approximately 10 steps. This series of transformations forms several stereocenters present in the final natural product. The goal of this project is to find which sequence of reactions maximizes the yield of the desired 2.2.2 fragment.

Phase Field Modeling of Ductile Fracture in Additively Manufactured Metals
Kyle Piper
Mentors: Vinamra Agrawal and Chiara Daraio

Metal additive manufacturing is a rapidly growing field. Especially within the aerospace industry, metal additive manufacturing provides significant cost and lead time reductions, lower-weight final products, and consolidation of components. The additive manufacturing process can lead to voids in the test parts, and it is critical to understand how these voids can lead to crack growth and material failure. Our objective is to improve computational crack analysis tools to accurately model crack growth and material failure in ductile materials. This is done using a phase-field energy model of the part, where it is assumed a crack forms when the energy required to create the crack is lower than the energy of intermolecular bonds holding the material together. In order to implement the model for ductile fracture, we first compute the plastic strain and hardening of the material, before combining them with the previous brittle fracture energy equation, to develop a model describing the failure of a ductile material.

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

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

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

Abstract withheld from publication at mentor's request.

Electron Beam Injection Method for Determining Plasma Frequency and Electron Density
Geoffrey Pomraning
Mentor: Paul Bellan

A method for the direct measurement of plasma frequency from a detected electron beam in the Caltech ice dusty plasma experiment [2] is being investigated. Adapting a method of Shirakawa [1], an electron beam will be generated from an emissive tungsten filament and injected into a weakly (10^{-6}) ionized plasma with cold (190 K) neutrals. This beam should generate electron plasma waves excited by the two-stream instability. The waves would then be detected by a separate receiving probe in the plasma. This method overcomes several limitations of the conventional Langmuir probe method (e.g., thin-film deposition, uncertain calibration), and removes the dependence on plasma ionic composition for computing electron density. Results from measurements are discussed.

Minimizing *E. coli* With REXER/GENESIS
Cristian M. Ponce
Mentor: Kaihang Wang

By parsing through the genome and removing these non-essential genes, work towards the creation of an organism that encodes exclusively for traits necessary for survival is made possible. Genes can be classified as essential, non-essential, quasi-essential, or as combinatorial lethals. Essential genes are necessary for the survival of the organism- if they are removed from the genome, the organism will die. Non-essential genes can be removed without cell death. Quasi-essential genes can also be removed without leading to organism death, but encodes for critical functions that ensure proper development. Combinatorial lethals are the problematic set of genes, as they encode for the same function as other genes. Therefore, they appear to exist as non-essential genomes, as the removal of a single gene will not lead to organism death, but removal of all genes that encode for the shared function will result in organism death. Removal of non-essential genes results in the creation of minimal genomes. The most successful minimization effort was able to create a minimal genome of just 2.98 kb, a reduction of ~35 percent. This project originally aimed to create a minimal genome that will represent a 60-70 percent, but has been rescoped to minimize a quarter of the genome by utilizing REXER/GENESIS, a technique for full-genome engineering through piecewise replacement of the genome. The minimization of a quarter of the genome will demonstrate the ability of REXER/GENESIS (originally optimized for insertions, not deletions) to be used as a powerful tool for genome minimization. Plasmids for the minimization are assembled in yeast, purified and transformed into *E. coli*, and then utilized for minimization experiments using REXER. While issues such as slowed growth time and the risk of mutations in constructed plasmids face the project, the project team seeks to utilize extensive troubleshooting, ~12 colonies per construct, and the reimplementation of quasi-essential genes into the genome to mitigate the impact of these issues.

Analysis of Respiratory Transitions in AMZ Bacterial Communities
Chris Pope
Mentors: Victoria Orphan and Yamini Yangir

Despite the extreme conditions and low oxygen content of the deep ocean's anoxic marine zones (AMZs), communities of bacteria within these zones are still able to maintain some level of aerobic energy production. This is thought to be achieved via an equilibrium between portions of said community respiring aerobically and others doing so anaerobically. To study how these microbes adapt to the varying conditions in AMZs and how the community transitions its energy production mechanisms to adapt from oxygenated to anoxic conditions, a community of *marinobacter* (a common AMZ inhabitant) was inoculated inside of a chemostat. While the temperature, pressure, pH, and amount of nutrients were kept constant, the oxygen concentration in the microbial environment was varied (20%, 10%, 5%, 2%, 1%, and 0% oxygen concentrations) and at each level the community's response was studied by taking samples for transcriptomics and conducting RT-PCR assays, while studies on cell viability were carried out (via flow cytometry and optical density measurements). These results will help lead to a greater understanding of the effects of a changing ocean on microbes, and possibly have astrobiological implications in learning how bacterial communities adapt to low and varying oxygen concentrations in their environment.

Using Radio Transients From VLASS to Search for Binary Neutron Star Mergers
Evan Portnoi
Mentors: Gregg Hallinan and Casey Law

In recent years, advances in instrumentation and computing have allowed or an explosion in astronomical data available, such as sky surveys that image of 80% of the sky at once. This allows for the easy discovery of transients, where a signal becomes significantly brighter or dimmer over time. Hopefully, one of these transients will the collision between a system of two neutron stars, which has never been found before. This can be accomplished by first finding the host galaxy for each transient and using the characteristics of those galaxies to determine the best candidates. Follow-up observations can provide enough information to create light curves which can be compared to the theoretical light curves. Assuming they share enough characteristics, it would be the first recorded discovery of a binary neutron star merger.

Computational Neuroethology Approaches to Probe Complex Social Behaviors Between Species
Aditee Prabhutendolkar
Mentors: Joseph Parker and Julian Wagner

Social behaviors between multiple interacting species occur across the animal kingdom, but are challenging to robustly, quantitatively study. Rove beetle symbionts engage in a diverse set of behaviors with various ant species, providing an insect model system to study social behaviors and a test case for machine vision approaches to analyze them quantitatively. One way in which rove beetles parasitize ants is through grooming—a beetle scrapes nestmate recognition pheromones off an ant's body and rubs them on itself, which allows the beetle to integrate into ant colonies. Classifying the behaviors of the symbiotic rove beetle and ant is important to understand how such tactics evolved and are regulated at a sensory level. Behavioral recordings are often extensive (millions of frames), and we aim to use computational neuroethology techniques to streamline behavioral classification. Here we train a convolutional neural network (CNN) to precisely categorize the behaviors of the beetle as it interacts with the ant. Using a supervised deep learning model with six behavioral categories, we find that CNNs are highly accurate and efficient in classifying beetle behaviors. Our success illustrates the power of relatively simple modern machine vision approaches to provide robust quantitative analysis of social interactions.

Geospatial Analysis of the Amargosa River Using High-Resolution Digital Topography
Sarah Preston
Mentors: Michael Lamb and Madison Douglas

Single-channel meandering rivers exert high shear stresses on their banks, so they require a high degree of bank cohesion. This is typically provided by plants; however, there is evidence of meandering rivers on Mars and on Earth prior to the evolution of land plants. Today, there are meandering rivers in arid regions, including the Amargosa River, an ephemeral, unvegetated river in Death Valley. In this work, I use high-resolution LIDAR topography data, existing MATLAB toolboxes and new, purpose-written MATLAB functions to extract information about the channel morphology in order to compare the Amargosa River to vegetated, perennial rivers to determine whether it is similar in morphology. To do this, we compute the Shields stress and particle Reynolds number to determine whether the Amargosa River obeys the power-law relationship between the Shields stress and particle Reynolds number that is characteristic of vegetated, perennial single-channel meanders. I will present an analysis of the morphology and characteristics of the Amargosa River in comparison to other single-channel meanders.

Developing the Cable-Traversing Robot of an Innovative Lunar Infrastructure System
Kemal Pulungan
Mentor: Soon-Jo Chung

In the coming decade, NASA and other spacefaring agencies are interested in establishing a permanent human presence on the moon. The need to carry cargo over the surface of the moon for long distances arises. Such cargo includes water from permanently shaded regions (PSRs) in craters, important to reducing dependency on regularly-launched supplies from the Earth.

To access these PSRs requires traversing steep slopes and rough terrain, which traditional wheeled vehicles cannot go through. A Caltech student team has been developing the Lunar Architecture for Tree Traversal In Service of Cabled Exploration (LATTICE). It robotically places stakes in the ground, through which cables are strung, allowing a shuttle robot to travel and carry cargo. The shuttle robot needs to tension the cable with forces as high as 4 kN and travel up slopes as steep as 30 degrees. An Earth-based prototype was built and tested to demonstrate this system.

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

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

Vision-Based Relative Navigation of Formation Flying Spacecraft Using Convolutional Neural Network Based Object Detection
Isabelle Ragheb
Mentors: Soon-Jo Chung and Kai Matsuka

Real-time velocity and position estimations of an uncooperative spacecraft in planetary orbit with a spacecraft swarm is paramount to the success of close-proximity operations eg. autonomous rendezvous, satellite formation, on-orbit servicing, etc. In this paper, a novel real-time ROS2 implementation of YOLOv5 in parallel with a Kalman

Filter is used to estimate the trajectory of an uncooperative spacecraft in planetary orbit. First, we create realistic, diverse scenes of spacecraft in Earth-bound orbits by utilizing Blender software, spacecraft CADs, and spacecraft images scraped from the internet. These scenes are used to generate custom training, testing, and validation datasets. Then, we train YOLOv5 on our custom datasets, resulting in a novelly-trained model of YOLOv5, optimized for detecting spacecraft in planetary orbit. Finally, we introduce a ROS2-YOLOv5 pipeline to estimate the velocity and position of an uncooperative spacecraft during close-proximity operations in planetary orbit. This pipeline implements a ROS2-YOLOv5 wrapper and custom ROS2 nodes to apply a Kalman filter, estimating the detected spacecraft's velocity and position. Based on preliminary results, we expect that our ROS2-YOLOv5 pipeline will be capable of persistently detecting an uncooperative target spacecraft in planetary orbit over multiple frames and reliably estimating the target spacecraft's velocity and position in real-time.

Discrimination Metrics, Coalition Games and Its Influence on the Impoverished
Kavya Rajagopalan
Mentors: Colin Camerer and Marcos Gallo

In America and throughout the world, wealth inequality is a significant contributing factor in dictating how people behave. Individuals are described as making a sequence of decisions and bargains in order to reduce the strain of their daily demands in a process similar to that of an economic decision: Allocating limited resources such as energy, time, emotions, and goods (Goode, 1960) in different ways. The particular set of bargains we seek to focus on are related to coalition games: a type of competitive collaborative task between 3 or more individuals in which rewards are distributed depending on how members of a coalition game view their partner's contributions. The research this summer intends to investigate the role that discriminatory biases across social classes have in the distribution of rewards in these coalition games. Note that current literature suggests that perceptions are determined by a two-dimensional factor analysis across 'Warmth and Competence' variables. We expect that in our experimental process, we will observe participants who view one another as high in 'Competence,' to collaborate positively with one another. However, we only expect that distribution of reward resources to be positively correlated to high Warmth. These results in conjunction with the results of a meta-analysis on Warmth and Competence ratings across the poor and rich, should ideally provide significant information as to how discriminatory biases exists within distinct demographic groups.

Analyzing Satellite Properties of Milky Way Mass Galaxies in Dissipative Self-Interacting Dark Matter Simulations
Eitan Rapaport
Mentors: Phil Hopkins and Xuejian Shen

The current ΛCDM cosmological model encounters issues at small scales, particularly concerning the quantity of dwarf and satellite galaxies, properties of central regions of dark-matter dominated galaxies (Cusp-Core problem), and mismatch in the central density of observed luminous satellites and subhaloes in simulations (Too-Big-To-Fail). Many alternatives to the CDM paradigm have been proposed to explain the discrepancies, one of which is Self-Interacting Dark Matter (SIDM). Dissipative dark matter (dSIDM) is a version of SIDM which introduces inelastic collisions, as opposed to the elastic collision model of regular SIDM. These inelastic collisions show promise for producing the compact dwarf galaxies that are missing from the predicted standard CDM model.

The simulations to observe dSIDM properties are produced in the Feedback In Realistic Environments (FIRE), a high-resolution cosmological simulation of galaxy formation. We explore the satellite properties of Milky way mass galaxies in existing dSIDM simulations to compare them to CDM simulations and real-world observations. These include the radial distribution of satellites, the existence of satellite planes, and the evolution of satellites in constant cross-section and velocity-dependent dSIDM models. The analysis of these satellite properties is an important step in either falsifying the dSIDM models or proving their merit.

Injection-Induced Earthquakes
Kyle Reese
Mentors: Jean-Philippe Avouac and KJ Im

Induced earthquakes have recently become a crucial concern in geothermal energy development and CO2 sequestration. Previous studies reveal that underground waste water injections and extractions induce earthquakes through poro-thermo-elastic stress change. Many previous studies use a simplified geometry to investigate the phenomenon with the modern, rate-and-state friction law. However, this project aims to develop a pressure module in an existing 3D fault simulation and investigate the effects of injections on distributed faults. We simulated injections in fault zones to observe how the faults react to changes in pressure. To determine the effects of continued injection on seismicity, we focused specifically on fault velocity, normal effective stress, pressure, and displacement. Within these simulations, we find that faults rupture multiple times and eventually stabilize as normal stress decreases. Our simulator can accommodate pre-existing fault networks at actual injection sites which enables us to better understand how injections alter these key variables and their concerning long-term effects. This is significant as we can apply this knowledge to optimize future injection locations or create alternate methods of waste water disposal that have less detrimental repercussions with continued use.

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

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

First Direct Comparison Between Resolved and Sub-Grid Star Cluster Formation in Simulations
Darren Rhodes
Mentors: Mike Grudic and Philip Hopkins

Individual stars normally cannot be simulated in Galaxy simulations. These simulations need to use "sub-grid" prescriptions to determine star formation, while controlling important factors such as initial conditions, numerics, gas microphysics, feedback, etc. . However, these methods have not been tested nor validated with a resolved star formation model. We compare simulations of giant molecular clouds (GMC) at high resolution ($\Delta m = 10^{-3} M\odot$) with STARFORGE and low resolution (1 to $10^3 M\odot$) with FIRE-3 using the GIZMO code. We find that the low-resolution GMCs form stars much earlier but, by the end of the simulation, will produce a star formation efficiency comparable to high-resolution runs within a factor of 2. We also perform a detailed comparison of star cluster properties and stellar feedback efficiency. We discuss some key corrections to current prescriptions that should increase the fidelity of galaxy simulations on GMC scales.

Designing the Receiving Ground Station for Space Solar Power Transmission
Raha Riazati
Mentors: Ali Hajimiri and Austin Fikes

An exciting new method of harvesting renewable energy presents itself in space solar power, whereby solar radiation is collected in space, unrestricted by daylight hours, and wirelessly beamed to Earth. Caltech's Space Solar Power Project seeks to accomplish just that and will demonstrate proof-of-concept on a launched payload soon. My project is to design, build, and test the ground station that will receive the low-power signal transmitted from the payload to Earth. This includes selecting a high-gain antenna to receive the signal, designing and constructing a heterodyne receiver that will amplify and digitize the signal for processing and detection by a spectrum analyzer, configuring a tracking device (telescope mount) on which to mount the antenna and track the payload across the sky, and building the mechanical interface between the antenna and mount. All components have been designed, manufactured, and assembled. Testing of the apparatus, however, remains: a test of the tracking capability by strapping a camera to the mount and attempting to photographically track ISS and a test of the receiving capability with a point-to-point transmission of a signal from Mount Wilson to the lab. Upon successful completion of testing, the ground station will be ready for the November launch.

Autoencoders for Simultaneously Optimizing One- and Two-dimensional Embeddings of High-dimensional Single-cell Data
Philippa Richter
Mentors: Peng Yin, Xiaokang Lun, and Lulu Qian

Visualizing and interpreting high-dimensional data is necessary in a multitude of research contexts, particularly in the analysis of single-cell data. Typically, this challenge is addressed by applying dimensionality-reduction techniques to embed data to two-dimensional space, allowing it to be plotted on a Cartesian plane. However, doing so results in axes which are essentially meaningless. If, instead, cellular features are partitioned into groups (e.g. separating protein and RNA transcript data), and each group is reduced to a single dimension, then each axis of the Cartesian coordinate system represents a distinct set of cellular features. Faithfully embedding partitioned features requires simultaneously optimizing embeddings in both one and two-dimensional space, which cannot be done using traditional dimensionality-reduction techniques. Here, we propose a new type of autoencoder architecture which is capable of this simultaneous optimization. Preliminary results show that this architecture can reliably produce high-quality one-dimensional embeddings, comparable to those produced using traditional dimensionality reduction techniques, which also form meaningful clusters in two-dimensional space.

Analyzing Emotion in Political Ad Videos Using Novel Neural Model
Patrick Rim
Mentor: R. Michael Alvarez

Political ad videos are employed by campaigns to influence a voter's preference in an upcoming election. Candidates often employ one of two general strategies in their political ads to increase the voter turnout of their party. They can invoke positive emotions, such as enthusiasm, about their campaign to "motivate participation and activate existing loyalties." Otherwise, they can incite negative emotions, such as fear, about the opponent's campaign in an attempt to "stimulate vigilance and increase reliance on contemporary evaluations." Thus, an interesting question arises: What is the emotional content of a party's political ad videos and how does it affect elections? We use the 2020 U.S. presidential election as a case study and the Google Transparency Report as our source of ad videos. We present a novel three-stream neural model to analyze each frame of the ad videos. First, the image is passed through a Faster R-CNN network that identifies each object in the image with a bounding box. Each bounding box is passed through a ViT-BERT transformer model that outputs a feature vector representing an embedding of each bounding box. Then, the entire image is passed through the same ViT-BERT transformer. These feature vectors are then averaged using the area of each box/image as a weight. Finally, the entire image is passed through a ResNet-101 model. The feature vector from the ResNet-101 model is concatenated with the average feature vector of the ViT-BERT model and is passed through a fully connected layer that produces the final classification of an image. The results for each frame in a given ad video are aggregated to obtain the final results for the video as a whole.

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

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

Structural Identification of Cytoplasmic Filament Trimer (CFT) Within the Nuclear Pore Complex
Asha Rollins
Mentors: André Hoelz and Songhao Zhao

The nuclear pore complex (NPC) is a critical protein megastructure found within the nuclear envelope that entirely regulates all nucleocytoplasmic transport. Its intricate 110 MDa structure is composed of proteins termed nucleoporins. The NPC cytoplasmic face is tied to mutations which cause cancer and other genetic diseases. A key component of this region is the cytoplasmic filament trimer (CFT), formed by nucleoporins Nup82, Nup159, and Nsp1. The CFT serves as a hub for the heterohexameric cytoplasmic filament nup complex (CFNC), and is anchored to the pore's symmetric-core by Nup37 and Nup145C assembly sensors. In this project, we aim to solve the structure of the CFT trimer by crystallization in complex with Nup37 and various Fab antibodies. To complete this work, necessary proteins were expressed and purified through a series of chromatography columns. We conducted extensive screening over 1500 conditions and were able to obtain a potential initial crystal hit. Future steps for this work include crystal refinement, x-ray diffraction data collection, and structure solution.

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

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

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

Abstract withheld from publication at mentor's request.

Refining the Process of Using DNA Tags for Commercial Use
Sagan Russ
Mentors: Jeff Nivala, Jiaming Li, Yuan-Jyue Chen, and Justin Bois

DNA-based molecular tagging, a process that involves the labeling of objects using strands of synthetic DNA, has many practical applications. DNA tagging is a solution for scenarios in which physical objects require identification but cannot be easily tagged using standard barcodes, or when an extra layer of security is required. Examples of practical labeling uses include agricultural products and luxury goods. In recent years, the University of Washington's Molecular Information Systems Lab (MISL) has been working on a secure and accurate system using DNA tag solutions — which are applied to objects — and paper tickets used to report the results. The goals of the project have shifted towards reducing the cost of the tagging procedure and increasing the accuracy of the results. This paper explores some of the methods used to achieve these goals using experimental wet lab and image processing techniques.

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

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

Energy Absorption in Nano-Architected Composites
Yahriel Salinas-Reyes
Mentors: Julia Greer and Kevin Nakahara

Energy absorption and impact resilience are crucial in a number of real-world applications from crashworthiness testing to protection from traumatic head injury in sports & ballistic impact in the battlefield. These challenges are often addressed by the application of composite materials. Recent work in the Greer Group has focused on dynamic testing and improving energy dissipation through structural hierarchy. Incorporating architecture with nano-scale features into composite systems may achieve previously inaccessible regions in the material property space. In pursuit of this objective, we formulated nanocomposites comprised of a stiff SU-8 (4-5 GPa) nano-architected matrix and various compliant infill materials (polydimethylsiloxane, polyacrylic acid gel, 2k-Epoxy, 635-Epoxy). Difficulties with instrumentation limited the extent of experimentation; the resolution of which became a predominant focus of this work. Despite this, constituent materials were independently characterized using dynamic mechanical analysis (DMA) under compression at a fixed strain rate of 1E-3 s-1 . Our interpenetrated composites were evaluated for their compressive stiffness and energy absorption, which was calculated by integrating the area under the force-displacement hysteresis curve. Variation in the mechanical response of different infill materials showed that the unique combination of nano-architected lattices, developed by the Greer Group, and compliant resins demonstrated behavior deviating from the rule of mixtures expectations.

Investigating the Mechanical Behavior of Anisotropic Structured Materials Using Digital Image Correlation
Perry Samimy
Mentors: Chiara Daraio and Jagannadh Boddapati

In the past, mechanical behavior of materials was often characterized through uniaxial testing of isotropic samples whose material properties are direction independent. Anisotropic materials, by contrast, have complex asymmetric internal geometries that lead to direction dependent properties. This anisotropy can cause a material to experience shear even when under a purely uniaxial load, a phenomenon called shear-normal coupling. Although this behavior can be observed in nature, advancements in software and fabrication have greatly expanded the design space of these materials. This project explores the effects of shear-normal coupling by studying the variations in mechanical response upon altering both material and geometry. Sources of fabrication error as well as the effects of boundary conditions are also investigated. Acrylic and a two-phase material (DM8530 and Tango Black) are considered, each with five geometries. Four of the geometries are asymmetric and exhibit shear-normal coupling. The fifth is a symmetric control geometry that does not. After cleaning the samples and applying a layer of speckled paint via airbrush, a uniaxial tension test is conducted. Throughout the test, a load cell collects force measurements, and a camera captures images of sample deformation. Digital image correlation is then used to generate full-field displacement contours from the images. As anticipated, the symmetric geometry yielded a load ratio of 0% in both materials. Using the first asymmetric geometry, however, Acrylic and two-phase samples experienced a shear force to axial force ratio of 14% and 17% respectively. This difference could be due to the linear behavior of acrylic compared to the viscoelastic response of the two-phase material. Interestingly, both values differ from the simulated ratio of 25%. The remaining three geometries also resulted in force ratios that differ from finite element simulations. Further DIC analysis is being conducted to determine the source of this discrepancy.

Computational Analysis of Random Utility Model With Missing Information
Alec Sandroni
Mentors: Kota Saito and Yi Xin

Falmagne (1978) proved the necessary and sufficient conditions for a complete system of choice probabilities to be induced by rankings. Similar results for the case of incomplete choice probability information contain many redundant conditions. The space of random utility models allows a representation as a polytope, which may be obtained computationally for small numbers of alternatives. For some special cases of incomplete choice probability information, studying the geometry of such polytopes may illuminate these redundant conditions and provide intuition for removing them. Using the five alternative case as a model, we compute the pertinent geometric properties to identify redundancies.

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

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

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

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

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

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

Correlated Delayed Self-Heterodyne Measurement of Linewidth for an Optical Parametric Oscillator
Louise Schul
Mentors: Alireza Marandi, Luis Costa, Luis Ledezma, and Arkadev Roy

An optical parametric oscillator (OPO) is a light source that uses an optical resonator and optical nonlinearity to convert an input wave into two output waves of lower frequency. This project involves measuring the linewidth of a 2μm OPO using the correlated delayed self-heterodyne method. An interferometer was constructed in which one path introduces a 700MHz frequency shift (using an intensity modulator) and the other path introduces a delay via a 20m fiber. The two paths are combined to form a beat signal at the frequency of the shift. Since the delay was expected to be much shorter than the coherence time of the OPO, the phase noise of each path of the interferometer was correlated, and thus additional signal processing was required to obtain the linewidth of the OPO from the beat signal. A 1μm laser was first used to validate the method and demonstrate that linewidths as narrow as 1kHz can be measured.

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

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

Robustness in Bacterial Dosage Control
Aditi Seetharaman
Mentor: Richard Murray

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

Probing Eukaryotic Origins Through Binding of Motor Proteins to OdinTubulin
Samuel Senzon
Mentors: Matthew Thomson, Alec Lourenco, and David Larios Colorado

The cytoskeleton is the essential machinery underlying eukaryotic cell division, cell movement, and intracellular transport. In eukaryotes, the cytoskeleton is composed of filaments which bind to and are walked on by motor proteins, yet bacteria contain filaments but lack motors. The evolution of the cytoskeleton remains a major mystery in understanding the emergence of eukaryotic life. Odinarchaeaota is a member of Asgard archaea, the closest known prokaryotic relatives to eukaryotes. Through computational predictions, we hypothesized that existing eukaryotic motor proteins are capable of binding to OdinTubulin, tubulin found in Odinarchaeaota. In this project, we set out to test this hypothesis experimentally by purifying OdinTubulin, polymerizing OdinTubulin, and testing its binding to motor proteins. Work this summer has focused on testing this protocol, specifically debugging various expression complications.

A Reactive Controller Enables Robotic in-Mouth Bite Transfer
Lorenzo Shaikewitz
Mentors: Dorsa Sadigh, Aaron Ames, and Suneel Belkhale

Assistance during eating is essential for those with severe mobility issues or eating risks. However, dependance on traditional human caregivers is linked to malnutrition, weight loss, and low self-esteem. For those who require eating assistance, a semi-autonomous robotic platform can provide independence and a healthier lifestyle. We demonstrate an essential capability of this platform: transfer of a bite-sized chunk of food from a utensil directly to the inside of a person's mouth. Our system uses a reactive controller to accommodate the user's motions throughout the transfer, allowing full reactivity until bite detection then reducing reactivity in the direction of exit. Additionally, it reduces user discomfort with a dexterous wrist-like end effector capable of small, unimposing movements. Although full results have not been obtained, early trials using a denture mouth model suggest this approach can safely enter the mouth and transfer food.

Time Complexity Inference via Static Analysis of Abstract Syntax Trees
Yakov Shalunov
Mentor: Adam Blank

Asymptotic time complexity describes how the runtime of an algorithm scales with the size of its input and it is a key component of practical and theoretical algorithm design. We approach the problem of determining the time complexity of actual code through static analysis. While similar tools exist for some functional languages, as far as we are aware, no such tools exist for the Python programing language. Though the Halting Problem implies that the general case is impossible, we observe that the ability to loop forever is a bug for pure functions and thus limit our algorithm to a carefully chosen subset of Python which is not Turing complete. The complexity decider traverses the abstract syntax tree and computes expressions as symbolic functions of the inputs while keeping track of the total work done. In order to resolve recursion and loops, symbolic recurrence relations are used.

The primary motivation for this complexity decider is as an instructional tool to be used in a new course offered at Caltech to bridge the gap between practical, implementation-based classes and theoretical proof-based class by having students first write code and then prove its correctness and complexity already knowing it works.

Multiwavelength Characterization of the High-Mass X-Ray Binary Population of M33
Cheyanne Shariat
Mentors: Fiona Harrison and Margaret Lazzarini

High-mass X-ray binaries (HMXBs) are systems containing a compact object–neutron star or black hole–that accretes mass from its massive stellar companion ($>8\ M_{\odot}$), which then forms an accretion disk that emits X-ray radiation due to its high temperature (~10e6 K). In this study, we present 48 HMXB candidates selected from point-source optical counterparts from the PHATTER survey that were spatially coincident with Chandra X-ray regions in M33. We use the Bayesian Extinction and Stellar Tool (BEAST) to perform spectral energy distribution fitting to infer properties of the companion star. From the best-fit luminosity, effective temperature, and radius, we classify the spectral type for 20/48 companion-star candidates, identifying 6 O-Type and 14 B-Type stars; another 8 candidates fit to one or more spectral types within 1σ error. We also compare our Chandra X-ray data to new observations of the same sources one decade apart; by comparing old luminosities and hardness ratios in the 0.35-8.0 keV band to the new observations, we can identify variable sources within this time frame, possibly suggesting an evolution in their accretion states. Examining HMXBs will help constrain future binary population synthesis models, giving insight into the rich physics that these complex systems exhibit.

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

The habitability of early Mars was likely majorly impacted by nitrogen, which has undergone significant loss to space in the past 4 Ga after the shutoff of Mars' global magnetic field. ^{15}N, due to its heavier weight, escapes Mars at a different rate than ^{14}N and can be used as a constraint for ^{14}N's escape (Fox et al., 1993, Kurokawa et al., 2018). Before the transition from ancient Mars (likely warm and wet) to a modern, cold, dry Mars, nitrates were deposited on the surface and record the nitrogen fractionation imparted by planetary processes at the time of their formation. Processes influenced by the loss of Mars' magnetic field, including photochemistry, are responsible for the loss of the atmospheric nitrogen reservoir to space. Nitrogen escapes primarily through photochemical loss. High-energy photons from the sun collide with ambient chemicals in the atmosphere, splitting them and transferring enough energy to reach escape velocity. In a warm, wet early Mars climate, lightning may have split N_2 in the lower atmosphere, allowing atomic N to bond with other ambient species, forming NO_X. Nitrogen oxides (NO_X) may have implications for the origin of life by acting as a high-potential electron acceptor and source of fixed nitrogen for protometabolisms (Ducluzeau et al., 2009, Nitschke & Russell, 2013). This NO_X reacts with HO_X in the atmosphere to form HNO_X, which dissolves and precipitates out in rain. Eventually, the water component of HNO_X

evaporates, leaving NO_X deposits on the surface (Adams et al., 2021a). Meanwhile, nitrate depositions could still form in a cold and dry climate by relying on SEP events for nitrogen fixation and ice particles for precipitation (Adams et al., 2021b). We use the Caltech/NASA JPL 1D photochemical model, KINETICS, to conduct simulations of early Mars in the Nochian epoch with various initial conditions and a primordial $^{15}N/^{14}N$ ratio of 1/270 Knowledge of the amount of nitrates and nitriles in Mars' early history will help put future astrobiological investigations in the context of Mars' atmospheric evolution and potential habitability.

Multi-agent Online Convex Chasing With Untrusted Machine-Learned Advice

Junxuan Shen
Mentors: Adam Wierman and Nicolas Christianson

We study the problem of k-chasing of convex functions in a leaning-augmented setting, where multiple decision makers must make decisions each round they receive a request, to minimize the sum of the convex hitting cost and the cost of switching decisions between the rounds. Unlike the traditional online algorithms, we assume that the k decision makers have access to some machine-learned predictions with untrusted quality. We design a novel memoryless algorithm for the 2-chasing problem on R, and prove that, it exploits the ML predictions when they are accurate, while also guaranteeing performance compare to the offline optimal decisions even when the ML predictions are poor. Our competitive ratios are error-dependent, which is a function of some parameters that is adjustable by the users, depending on their confidence level of the ML predictions.

Developing A Photometric Alert Stream for ZTF's Lower Variance Transients

Cason Shepard
Mentors: Matthew Graham and Niharika Sravan

The Zwicky Transient Facility (ZTF) is a new optical time-domain survey that uses the Palomar 48 inch Schmidt telescope. ZTF's main goal has been to detect and map changes in the brightness of transients to learn about their physical properties. Development of an alternate photometric alert stream algorithm will be critical in the function of LIGO O4, as one of the main targets of monitoring during this new LIGO run will be Active Galactic Nuclei (AGN) in the error volume of a LIGO source. This algorithm utilizes the SQL query pipeline of the Infrared Processing and Analysis Center (IPAC) to detect which sources from the specified catalog of sources have been observed in a given night. Photometric data of corresponding identified sources are then pulled from IPAC using ztfquery and astropy packages. This algorithm uses a cluster-based query system that helps increase database query efficiency and reduce runtime.

Mathematical Modeling of Biosensors

Kaushal Shyamsundar
Mentors: Axel Scherer and Changsoon Choi

Immobilized Enzyme Layers are an important component of biosensors, a classic example of which are Continuous Glucose Monitors. In order to improve the performance of these devices it is necessary to better understand the reaction-diffusion dynamics of the products generated in these layers. To that end we provide an analysis of the transient response of these types of layers when assuming an ideal electrochemical sensor, as well as provide conditions under which the biosensor can be thought of as having an ideal electrochemical sensor.

GA Ansatz Optimization on a QAE for HEP Anomaly Detection

Thomas Sievert
Mentors: Maria Spiropulu, Jean-Roch Vlimant, S. Davis, and N. Lauk

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

Capacitance Measurements on Multilayer Tungsten Diselenide Graphene Heterostructures
Siu Chi Wang
Mentors: Stevan Nadj-Perge and Zhang Yiran

Recent works have shown that the proximity effect between tungsten diselenide (WSe_2) and graphene enhances the spin-orbit coupling (SOC) in the graphene layer. It is found that such induced SOC affects the properties of graphene. This project aims at performing capacitance measurements on WSe_2-Graphene devices. Since the capacitance is associated with the compressibility of states, it is sensitive to the density of states. Capacitance measurements enable probing of certain band structure properties such as band gap openings. It is expected that such measurements facilitates our understanding of the effects of the proximity interactions between WSe_2 and graphene on the graphene properties, which in turn may be useful for engineering highly tunable nanodevices.

Functions of Sex Specific Cell Types in Social Behaviours
Sam Small
Mentors: David Anderson and Mengyu Liu

To obtain a greater understanding of innate social behaviours, such as aggression and those present in mating in humans, it is imperative that we investigate the neural circuits that control these in a mammalian brain. After it was discovered that stimulating the lateral hypothalamus in cats evokes aggressive behaviour, researchers looked at other species and found similar results. This is how the role of the ventrolateral area of the ventromedial hypothalamus (VMHvl) in mice was discovered. Every animal which reproduces sexually exhibits behavioural differences based on gender. This is most clear during displays of aggression, during mating, and parental care. These behaviours are known to be innate and require zero prior experience or training, meaning the development of the neural circuits that control them is a result of genomic differences. We used techniques such as fiber photometry and optogenetics to analyse the activity of sex specific cell types in the VMHvl, as well as fluorescent imaging to observe the projections of these cells. Our projects seek to aid in the understanding of the roles of these sex specific cell types.

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

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

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

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

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

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

Optimizing Sulfonamide-based Electrolyte in Li-ion Batteries for Full Cell Stability
Leah Soldner
Mentors: Yang Shao-Horn, Daniel Wang, Yirui Zhang, and Harry Gray

Lithium-ion batteries are quickly becoming the technology of choice in a wide range of energy storage applications. As Li-ion battery costs decrease, energy density and thus driving range remains a roadblock for mass-market vehicle electrification. A novel electrolyte called N,N-dimethyltrifluoromethane-sulfonamide (DMTMSA), developed by Professor Shao-Horn, was found to provide exceptional interfacial stability in $Li||Ni_xMn_yCo_{1-x-y}O_2$ half-cells. This research was extended to Li-ion batteries to understand the effect of DMTMSA in full cells and to optimize the battery stability via electrolyte additives (commonly used for LP57) such as vinylene carbonate (VC), fluoroethylene carbonate (FEC), triphenyl phosphate (TPP), and ethylene sulfate (DTD). Cyclic voltammetry was used to examine the reduction potentials of DMTMSA and additives to understand the formation of the solid electrolyte interphase (SEI) better, which is crucial to a stable battery and healthy cycle life. Ionic conductivity tests were run to see how DMTMSA compared to the commercial electrolyte LP57 and to determine which additives would increase ionic conductivity the most. Cycling tests will be conducted to examine the effects the optimized electrolyte combinations have on full cell stability and coulombic efficiency. Finally, post-mortem electron microscopy will be used to better understand the structural and chemical degradation of the electrode.

Towards On-demand Strong $\chi(2)$ Nonlinearity in Nanophotonic Waveguides
Jennifer Solgaard
Mentors: Alireza Marandi, Ryoto Sekine, and Gordon Li

Periodically poled thin film lithium niobate (TFLN) has emerged as a promising platform for ultrafast quantum and classical information processing, due to its strong and instantaneous second order ((2)) nonlinearity. This nonlinearity is enabled in ridge waveguides by a process called quasi-phase matching (QPM) where the phase mismatch between the different interacting wavelengths is compensated. However, reliably producing phase-matched waveguides remains a challenge. By systematically investigating poling parameters and conducting numerical simulations, we optimized our pre-waveguide etched poling recipe. To further eliminate the uncertainty in waveguide dimensions from poling period calculations, we applied a similar approach to optimizing poling of TFLN chips with pre-etched waveguides, achieving poling halfway through the depth of the waveguides, a significant improvement over previous attempts. Finally, we characterized the waveguides on a TFLN chip to identify where our current models for predicting optimal poling period for QPM differ from experimental results.

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

Critical to the development of optical molecular reporters such as GFP and GCaMP have been high-throughput measurement devices capable of assaying 10^3 - 10^8 unique mutants per experiment. Recently, acoustic molecular reporters--in the form of gas vesicles (GVs)--have been developed, but there are no high-throughput screening methods to aid in their engineering. The goal of this project is to develop an acoustic 96-well plate reader that would enable rapid measurement of 10^3 unique GV constructs in bacterial or mammalian cells using any of the custom imaging pulse sequences developed by the Shapiro lab. A lot of the software and hardware had already been developed over the years in the Shapiro Lab on MATLAB. However, it is a bit scattered and not easily usable, especially for those without a coding background. Using MATLAB's App Designer, Graphical User Interfaces (GUIs) are being developed to allow for easy data acquisition, processing, and visualization.

Dirac Magnetic Monopole Search and Rock Magnetism Investigation of Asteroid Ryugu Sample
Michael Sowell
Mentor: Joseph Kirschvink

Hayabusa-2 returned pristine material from asteroid 162173 Ryugu. Magnetic investigations can return novel information about the history and origins of asteroid Ryugu, which in turn could return vital information about the formation of the early Solar System and universe. Dirac magnetic monopoles may have been trapped in the pre-solar nebula, from which they could only currently be found in smaller planetary bodies, such as comets and asteroids. By passing asteroid material through a SQUID moment magnetometer, a theoretical Dirac magnetic monopole would return an increase in measured flux by a value of $2\Phi_0$, in which Φ_0 is the magnetic flux quantum. The moment measured by SQUID moment magnetometers can be related via a surface integral into measured flux. These experiments were done on a sample of Ryugu using SQUID moment magnetometers at the University of Tokyo and Kochi University. While the measured difference in magnetic flux was statistically significant ($t = 7.70$), it was far less than $2\Phi_0$. This experiment should be repeated using the magnetometers at Caltech, where confounding variables can better be addressed. At Caltech, rock magnetism investigations could derive the magnetic history of Ryugu.

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

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

ADAPT-QAOA With a Classically Inspired Warm Start
Vishvesha Sridhar
Mentors: Sophia Economou, Mohammed Mirhosseini, Yanzhu Chen, and Sam Barron

ADAPT-QAOA is a promising quantum algorithm to find solutions to the MaxCut problem on NISQ devices. In this project, we studied initializing this algorithm with a state derived from a classical approximation of the solution. Simulations were used to examine the effect of this change on small regular graphs. We present analyses of the performance of the warm start algorithm and compare it with the standard ADAPT-QAOA. These simulations have shown that the warm start produces a solution closer to the ground state than the standard algorithm at lower circuit depths. Future work will include further simulations of the algorithms on larger graphs along with more analysis of the behavior of the two algorithms at low circuit depths.

Counting n-Arcs in Projective Planes Over Finite Fields
Andrei Staicu
Mentors: Ronno Das and Elena Mantovan

Given a collection of points in the plane, classifying which subsets are collinear is a natural problem and is related to classical geometric constructions. We consider collections of points in a projective plane over a finite field such that no 3 are collinear. This is a finite set and its size is both combinatorially interesting and has deeper topological consequences. We count the number of such collections classified by the algebraic symmetries of the finite field. Variations of this problem have been considered by Glynn, Bergvall, Das, O'Connor et al. We obtain new counts for 7 points over fields of characteristic 2 and give an approach for 8 points. These new counts are governed by the existence and classification of configurations of points called the Fano plane and the Möbius-Kantor configuration.

Intercellular Protein Transfer
Margaret Sui
Mentors: Michael Elowitz and Shiyu Xia

Intercellular protein transfer sends therapeutic circuits from sender cells to target diseased cells. Secretion sequences cause the tagged protein to be secreted from sender cells, while cell-penetrating peptides enable the protein to penetrate into receiver cells. We wanted to determine whether this system could be used to transfer cell death-inducing circuits into the receiver cells with minimal killing of the sender cells, by separately transferring circuits components that only induce cell death together. With sufficiently high receiver efficiency, most of the target receiver cells will receive all necessary circuit components to induce cell death. Target cells can be cancer cells or senescent cells, and coupling the system to specific markers indicative of cancer or senescence allows for cell type detection and conditional cell death activation.

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

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

Computer Vision Techniques for Grevy's Zebra Re-Identification From Camera Trap Images
Avirath Sundaresan
Mentors: Pietro Perona and Sara Beery

The Grevy's zebra is an endangered zebra species native to Kenya and southern Ethiopia that has been the target of sustained conservation efforts in recent years. Accurately monitoring Grevy's zebra populations is essential for ecologists to evaluate these ongoing efforts. Camera traps are a cost-effective and non-invasive method to obtain robust population estimates, in particular with the use of computer vision techniques for re-identification (re-ID) of individual animals across images. In this research, we evaluate the effectiveness of Wildbook's Local Clusters and their Alternatives algorithm, an existing re-ID method previously used only for high-quality human-captured images, on Grevy's zebra images from a camera trap network at the Mpala Research Center in Kenya. In addition, we investigate approaches to improve zebra re-ID by incorporating temporal and social network information (e.g. camera location, time of image capture) into the clustering algorithm.

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

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

Private Company Outcome Prediction
Brea Swartwood
Mentor: Michael Ewens

Due to limited regulations guiding the accessibility of private capital market data, there is a lack of structured data for researchers to reliably track the birth, venture capital (VC) financing, and potential death of entrepreneurial firms [1]. To fill this gap without using costly resources such as commercial databases, this project aims to merge LinkedIn and OpenCorporates data concerning startups founded from 2002 to 2017. After the creation of this dataset, analysis will be done to study the full lifecycle of startups. Startup lifecycle includes growth, development, market-entry, financings, merges, and failures. Ultimately, a model predicting the failure of startups can be generated from the OpenCorporates matches to startups originally selected in LinkedIn. Preliminary results indicate that utilizing the list of filing dates allows the construction of the model to predict startup failure.

Reference
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Modelling Galaxy Evolution With Gas Temperature-Stellar Mass Distribution Feedback
Riley Tam
Mentors: Charles Steinhardt and Stanislav G. Djorgovski

Galaxies exist in a myriad of shapes, sizes, colours, and environments but we observe that they follow a common evolutionary history. This uniformity implies that a feedback mechanism, which is not well modelled or understood, ties together the parameters that affect galactic star formation. Recently, a relationship has been found observationally between two such parameters: temperature in star-forming clouds and stellar Initial Mass Function (IMF), which describes the mass distribution of stars at formation. The resulting model has led to several new predictions such as inside out galaxy growth and compact, hot galaxies at high redshifts. Previous simulations which assume galaxies are monolithic cannot explore such radial variations. Here, we employ GIDGET, a one-dimensional radius dependent galaxy evolution model, incorporate into it a temperature-dependent IMF and compare its results to observations.

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

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

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

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

Generation of Greenberger-Horne-Zeilinger (GHZ) States of Time-Bin Encoded Photonic Qubits for Quantum Networks
Nassim Tavakoli
Mentors: Maria Spiropulu, Samantha Davis, Raju Valivarthi, and Nikolai Lauk

Quantum entanglement is a vital resource for quantum information applications such as quantum computation, communication, and metrology, which hold promise for computational speedups, information-theoretic secure communications, and enhanced sensing capabilities. This project will focus on GHZ states, which consist of three entangled particles. We aim to generate GHZ states of time-bin qubits using fiber-coupled components, bulk nonlinearities, and state-of-the-art superconducting nanowire single photon detectors (SNSPDs). Entangled photons can be generated by spontaneous parametric down-conversion and post-selection with continuous-wave pump light. These "flying qubits" transfer information encoded through the time bin technique, which is based on their time-of arrival. This demonstration will be an important step towards real-world quantum networks as a more efficient way of generating the necessary states for quantum teleportation.

Exploring a Mapping Between Deep Learning and Renormalization Group Flow in the Ising Model
Kaden Taylor
Mentors: Joseph Lykken and Maria Spiropulu

Renormalization group flows are a technique essential in statistical physics and quantum field theory, which considers scale-invariant properties of physical theories and how such a theory's parameters change with this scaling. Deep learning is a powerful technique in computation that uses multi-layered neural networks to solve a myriad of complicated problems. Previous research suggests the possibility that unsupervised deep learning is actually a form of renormalization group flows, with some critics disagreeing. We seek to examine this connection on a more rigorous basis for the simple example of Kadanoff block renormalization of the 1D and 2D nearest-neighbor Ising models. For the 1D Ising model, we successfully used Adams optimization on a correlation length loss function to learn the group flow; yielding results consistent with the analytical model for infinite N. We also attempted it on a free energy loss function, but the learning was under-constrained. For the 2D Ising model, we successfully generated Ising model samples using the Wolff algorithm, and performed the group flow using a quasi-deterministic method, validating these results by calculating the critical exponent v. These results can now be more rigorously compared to deep learning analyses of the Ising model.

Quantum State Generation via Variational Circuit and Its Application in Quantum Metrology
Yi Teng
Mentors: Maria Spiropulu, Samantha Davis, Volkan Gurses, and Jean-Roch Vlimant

The generation of quantum states, including Fock, GKP and N00N states, is of immense importance in various applications of quantum information processing. Designing a quantum circuit for target state generation with near term hardware is challenging, however, quantum machine learning can be exploited to obtain optimal parameters once the circuit architecture ansatz is devised. We used Adam optimizer in Strawberryfields to train two classes of variational circuit, one with non-gaussian cubic phase gates, the other with photon number resolution detectors (PNRs). Both circuits give fidelity higher than 0.99 for all target states, but the depths of circuit that achieve this fidelity varies: The circuit with non-gaussian state requires 20 layers for N00N and 30 layers for GKP, whereas that with PNRs only needs 5 layers for both states. After state generation, the two-mode N00N state is then used to perform single phase estimation with an error lower than 3 percent, and the signal-to-noise phase profile matches the theoretical prediction. The potential of simultaneous multiphase estimation using multimode N00N state is also explored, with the goal to yield additional advantages to Heisenberg limit. This work lays the foundation for on-chip implementation of state generation and quantum metrology.

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

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

Experimental Observation of Measurement-Induced Phase Transitions Using Linear Cross-Entropy
Jonathan Thio
Mentors: Austin Minnich and Shi-Ning Sun

Qubits subject to random quantum circuits with projective measurements occurring at random points on the circuit show phase transitions depending on the rate at which the measurements occur. Previous work has observed these phase transitions experimentally by determining the entanglement entropy between different groupings of qubits. However, this approach is computationally limited because of the underlying exponential scaling due to the required quantum state tomography and sampling of the probability distribution. Recently, it was proposed that the phase transition may also be observed by calculating the linear cross-entropy between pairs of random quantum circuits. This new protocol removes the underlying exponential scaling, allowing for experiments to probe larger system sizes. We optimized and implemented this protocol on current quantum hardware. Our simulations show that our implementation may be able to observe the phase transition for larger system size than have been achieved before.

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

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

Non-invasively Actuating Mechanochemistry Inside Body for Localized Drug Release
Laurent Andrea Torres Sauceda
Mentors: Mikhail Shapiro and Yuxing Yao

Abstract withheld from publication at mentor's request.

Stability for the Second Non-Trivial Neumann Eigenvalue of the Laplacian
Justin Toyota
Mentor: Mikhail Karpukhin

Stability for the first non-trivial Neumann eigenvalue of the Laplacian was proved for general finite-measure open in Euclidean space by Brasco and Pratelli. In this case, the shape that maximizes the first eigenvalue is the ball. It was later shown by Bucur and Henrot that the second eigenvalue is maximized among bounded open sets by the union of two disjoint balls of equal volume. In this paper, we build off this proof using rearrangement techniques found in the proof of stability for the first eigenvalue (as described by Brasco and De Philippis) to prove a stability result for the second eigenvalue.

Probing Tensor Gauge Theory Stability With Monte Carlo
Kayton Truong
Mentors: Xie Chen and Kevin Slagle

From Maxwell's equations of electromagnetism to the Standard Model, gauge theories are successful in explaining the dynamics of elementary particles. Such theories encompass a gauge field that transforms under local symmetries. Spin liquids, which are phases of matter in which there is an emergent gauge theory, can arise in systems like antiferromagnetic triangular lattices of Ising spins.

A new kind of electromagnetism called symmetric tensor gauge theory was recently theoretically predicted. This theory assumes an additional constraint that the electric dipole moment is conserved in addition to electric charge. Conservation of electric dipole moment requires that isolated charges are immobile, while dipoles can be fully mobile. These isolated charges are called fractons (because they are "fractions" of mobile particles) and are the focus of this project.

Using computer simulations, we investigate whether symmetric tensor gauge theory can be realized in a condensed matter system. In 2016, Rasmussen et al. argued that tensor gauge theory is stable in 3+1 spacetime dimensions because quantum fluctuations do not lead to confinement in the gauge theory. However, there are some significant logical leaps in their arguments, which motivates us to check its conclusion using computer simulations.

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

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

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

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

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

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

Wavelet-based CNNs for Zwicky Transient Facility Light Curve Classification
Sanjay Venkitesh
Mentors: Ashish Mahabal and Alberto Krone-Martins

Wavelets are a powerful tool for the time-frequency analysis of signals and can be effectively integrated with Convolutional Neural Networks (CNNs) as down-sampling layers. Using wavelet-based filters for down sampling can facilitate improved feature extraction and higher noise robustness. We propose a new method for classifying objects observed by the Zwicky Transient Facility (ZTF) by directly using the light curves of transient objects. In this work, we implement recurrence analysis to transform light curves into two-dimensional images. The recurrence plots obtained from the light curves are then directly used as inputs to the CNN. However, as ZTF light curves are unevenly sampled, the light curves are first interpolated and sampled evenly through analysis of the Lomb-Scargle periodogram. Thus, the performance of different wavelet-based CNN architectures trained on recurrence plots was compared.

Gut-Brain Circuits in Huntington's Disease
Sophia Vera
Mentor: Ali Khoshnan

The aim of this project was to observe the role of the gut microbiome on the number of enteroendocrine cells in *Drosophila melanogas*ter models of Huntington's Disease. Huntington's disease is an inherited neurodegenerative disorder caused by a polyglutamine expansion in the huntingtin gene, which causes insoluble aggregates to form. These aggregates are associated with degeneration in the nervous system but are also present in the digestive tract. The gut-brain axis, or the network which links microbiota of the gut to the enteric nervous system may be linked to the body's response to mutant huntingtin. Specifically, enteroendocrine cells play a role in metabolic homeostasis and intestinal immune response. This project sought to measure the relationship between the composition of intestinal microbiota in the midgut (specifically Lactobacillus and E. Coli), Htt aggregates, and the enteroendocrine cells in *Drosophila melanogaster* models. Since HD Drosophila models do not readily form aggregates, it was necessary to cross the transgenic samples with pan-midgut specific Gal4 drivers. The methodology used was antibody staining and qRT-PCR, and results were inconclusive due to technical difficulties.

Making Electrochemical Water Treatment Technology Economical by Setting the Parameters Dynamically: A Machine Learning Approach
Vignesh Vinayagam Kala
Mentors: Michael R. Hoffmann and Heng Dong

Electrochemical oxidation (EO) is a promising technique for decentralized wastewater treatment, owing to its modular design, high efficiency, and ease of automation and transportation. Despite the high efficiency, small footprint and easy operation of electrochemical reactors, the large-scale application of EO technology has been often limited by its cost. One of the major components of the cost of EO systems is the energy consumption. Generally, the treatment performance for EO systems increases with its energy consumption. For decentralized systems, the small waste volume leads to large water quality variation. To ensure effluent quality, conventional EO systems have to apply a large constant power, which leads to substantial energy waste when the influent has a low waste load. Therefore, the operation parameters of EO systems need to adjust to the influent quality to produce satisfactory effluent quality at the minimum energy cost. This necessitates the modeling of the "optimal" operation parameters with respect to the influent water quality. ML has been demonstrated to be a powerful tool for modeling highly non-linear systems like wastewater. Previous studies have successfully used ML to predict the doses of oxidants and coagulants in the drinking water treatment process. However, it has rarely been applied to electrochemical systems yet. Our motive for this project is to minimize the power requirements of an EO system by modeling the operation parameters to influent wastewater quality using machine learning models.

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

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

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

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

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

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

Mechanism of Translesion Synthesis Past an HMCES DNA-Protein Cross-Link
Bryan Wang
Mentor: Daniel R. Semlow

Interstrand crosslinks are formed between two complementary DNA strands. Failure to repair ICL repairs can cause lasting damage due to its effects of causing under-replication of DNA and formation of double strand breaks (DSB). One repair mechanism is the NEIL3 pathway in which CMG helicase stalls at the ICL and recruits DNA repair factors such as NEIL3 to cleave one of the two N-glycosyl bonds that form the cross-link. This results in an AP site to be produced which is then bypassed by REV1-Polζ translesion synthesis (TLS) polymerase. To fix this, HMCES prevents ssDNA AP site cleavage by rapidly cross-linking to ssDNA AP sites encountered during replication. The cysteine in HMCES binds to the AP site which was simulated using a HMCES peptide. We will further explore the removal of this peptide. Moreover, we performed a SPRTN depletion and proteasome inhibition to confirm the insertion of dG across the AP site and whether or not the proteolysis influences TLS. We saw that with the removal of SPRTN the dG insertion across the AP site increases, and that the proteasome has no influence on TLS. Therefore, it is evident that the HMCES-DPC formed during ICL repair directs the insertion of dG opposite the DPC.

Constraining Models of M31's Last Significant Merger Using Its System of Stellar Streams
Sylvia Wang
Mentors: Ivanna Escala, Ana Bonaca, and Philip Hopkins

Galaxy mergers play a significant role in the hierarchical assembly of large galaxies such as M31 or the Milky Way. M31 has a system of tidal shells which is thought to have originated from the same merger event that created a giant stream of stars extending south of M31. We use Python-based galactic and gravitational dynamics code Gala to model the formation of M31's tidal stream and shell system. A composite potential with a disk, bulge, and halo component is used to model M31 and a Plummer potential is used to model the satellite galaxy involved in the merger. By varying parameters involved in the simulation, such as the mass of the satellite galaxy or M31, we can produce models with different tidal debris patterns after the disruption of the satellite progenitor. We will constrain these models by making statistical comparisons to the observations made in M31's tidal streams and shells.

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

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

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

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

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

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

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

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

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

Testing and Development of Stake Design for a Modular Lunar Traversal System
Brooklyn Williams
Mentor: Soon-Jo Chung

On the surface of the moon, there exist large craters that never receive sunlight. The extreme conditions in these permanently shaded regions would potentially allow them to host significant amounts of volatile material. However, the slopes of these craters and the extreme temperatures has prevented NASA or any other agency from collecting material from these regions.

In order to gain access to these unexplored lunar environments, a team of Caltech students has developed the Lunar Architecture for Tree Traversal In Service of Cabled Exploration, also known as LATTICE. This system features a lead rover that is capable of planting multiple stakes connected by cables in the lunar regolith. This stake and cable structure allows for the traversal of shuttle robots and their cargo into and out of the permanently shaded regions. Prototypes of these stakes were designed and tested to allow for a full system demonstration in an Earth environment.

Heterogeneity of MexT Expression in Chronic Wound Isolates of *Pseudomonas aeruginosa*
Grace Wilson
Mentors: Stephen P. Diggle, Kathleen O'Connor, and Dianne Newman

Pseudomonas aeruginosa (P. aeruginosa) is an opportunistic bacterial pathogen that causes serious infections in chronic wounds. Several of *P. aeruginosa*'s virulence factors are controlled by multiple complex quorum sensing (QS) networks. QS is a chemical communication system that is active at high densities and highly variable between bacteria strains with complex regulation. MexT, the transcriptional regulator of the MexEF-OprN efflux pump, plays an important role in regulating QS in *P. aeruginosa.* However, the exact mechanism in which MexT interacts with QS is unknown. To further explore this area, we evaluated the dynamics of MexT expression in *P. aeruginosa* from the chronic wounds of human patients. We conjugated *P. aeruginosa* with a pMexE-lux fusion plasmid into the CTX site of the genome and then measured the lux signal in a plate reader over 16 hours. We tested the construct in well-defined laboratory strains and chronic wound isolates. We found that the expression of MexT varies between

P. aeruginosa chronic wound isolates, peaks during log phase growth, and decreases once cells enter stationary phase. This data suggests that MexT gene regulation is density-dependent.

A Verified WebAssembly Compiler

June Woodward
Mentors: Deian Stefan and Richard Murray

WebAssembly (also known as Wasm) is commonly used to run untrusted code both safely and efficiently; its original use-case was the Web, but it has also been found useful for sandboxing third-party libraries within programs and for content-delivery networks to isolate programs from different clients. However, there currently exists a sharp tradeoff between security and performance when executing untrusted Wasm code. This has contributed to multiple vulnerabilities in systems that use WebAssembly and potentially discouraged its usage elsewhere. For secure approaches to be more widely adopted, they must be more efficient; this motivates the creation of a verified compiler. We present a compiler from Coq to C, using the WasmCert and CompCert formalizations of these languages, and verify that this compiler preserves operational semantics and produces securely sandboxed programs.

Targeted Mutagenesis of Endogenous Loci Using TRACE

George Wythes
Mentors: Fei Chen and Kaihang Wang

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

Special Families of Faithful Metacyclic and Dicyclic Galois Covers of the Projective Line

Brian Yang
Mentor: Elena Mantovan

The study of special subvarieties of the Torelli locus has long been of great interest. We present a criterion for a dimension 0 subvariety of the Torelli locus, arising from a G-Galois cover of $\mathbb{P}^1$ branched at 3 points, to be special. We develop methods to compute the complex multiplication field and type of Jacobian varieties arising from these covers. Then, we apply the formula of Shimura and Taniyama to compute the Newton polygons of these Jacobians. As an application, we consider the cases where G lies in the following two families of non-abelian finite groups: faithful metacyclic groups and dicyclic groups. We find that the Newton polygons arising from dicyclic covers are particularly well-characterized.

Hunting for Kilonovae With ZTF and SkyPortal

Leo Yang
Mentors: Mansi Kasliwal and Robert Stein

Binary neutron star mergers release large amounts of energy through gravitational waves, and a subsequent kilonova releases electromagnetic radiation. Only one kilonova has ever been observed, making it a key topic of study. The electromagnetic radiation released from kilonovae are detected by observatories such as the Zwicky Transient Facility (ZTF), an optical telescope at Mt. Palomar, CA. This project focuses on how data from ZTF is managed and further analyzed to study kilonovae. This is done by improving SkyPortal, the main data platform of the ZTF collaboration. This platform lets astronomers manage, analyze, and collaborate on astronomical data. Improvements to Skyportal include finding associated classifications for transients saved in the database based on the time of their original detection and tracking follow-up observations reported by other observatories using NASA's Gamma-Ray Coordinates Network. Automation by the means of SkyPortal will reduce the latency in scientific analysis and will lead to more efficient studies on kilonovae during LIGO/Virgo/KAGRA's O4 observing run.

Improving Rain Formation in Climate Models

Lynn Yang
Mentors: Tapio Schneider and Anna Jaruga

The goal at the Climate Modeling Alliance (CliMA) is to develop and improve methods in climate modeling via data assimilation and machine learning. There are still great uncertainties in the state-of-the-art models regarding clouds and precipitation. The current model used at CliMA underestimates the rain specific humidity across various cloud regimes. The main objective of my project is to implement new rain formation functions into the CloudMicrophysics.jl library and to improve rain formation models through function calibration and machine learning. The currently used rain formation function in this library is a simple equation with a relaxation term and a Heaviside step function. A variety of new precipitation functions have been implemented into the CloudMicrophysics.jl library. It has been observed that the precipitation statistics changed for different cloud regimes like stratocumulus, shallow convection, and deep convection which are numerically simulated with CliMA code. The parameters have been calibrated for the new rain formation functions using high resolution data and machine learning.

Investigating the Effect of Surface Material on Time Resolution of the Barrel Timing Layer Sensor Modules for the MIP Timing Detector
Zhe Yang
Mentors: Maria Spiropulu and Anthony LaTorre

To sufficiently disentangle the multiple tracks from all primary interactions at the HL-LHC, the CMS experiment will be upgraded to include the Minimum Ionizing Particle Timing Detector (MTD). The fundamental unit of the Barrel Timing Layer of the MTD is composed of a 57 mm long and 3mm thick LYSO:Ce scintillator crystal with silicon photomultipliers (SiPMs) attached to each end. We used a Geant4 simulation of the LYSO:Ce crystal to determine the impact of the surface material properties of the LYSO:Ce crystals on the overall time resolution. The timing resolution and photon paths are compared for various implementations of diffuse and specular reflectors. Preliminary results show that for scintillation light from high energy muons, the majority of the first photons that reach the SiPMs reflect off the surface material. Thus, altering the reflector properties can significantly impact detector timing. We find that specular reflectors outperform diffuse reflectors at low photon detection thresholds, while diffuse reflections start to show better time resolution at higher thresholds.

Distributionally Robust Offline Learning With Limited Online Exploration for Contextual Bandits
Zhouhao Yang
Mentor: Anima Anandkumar

In offline policy optimization, the goal is to find a policy that achieves the maximum value function, with only access to a pre-collected dataset by some unknown behavior policy. In this paper, we study policy gradient methods, where we maintain an estimate of a target policy and update it via policy gradient. The estimation of the gradient based on the offline dataset could be inaccurate due to the distribution shift between the target and behavior policies. To address this issue, we propose to estimate the policy gradient based on a reward distribution which is learned to account for the worst possible data collecting policy that could render the offline dataset. This pessimistic estimation of the reward distribution is robust to the distributional shift between the target and behavior policies. We conduct experiments on real-world datasets under various scenarios of distributional shift to compare our proposed algorithm with baseline methods in offline contextual bandits, which demonstrates the effectiveness and robustness of the proposed algorithm. We also propose a variant of our algorithm to further improve the performance with additional newly collected data when limited online interaction is allowed.

Probing Metastable Helium in a Cryogenic Buffer Gas Cell With a Homemade External Cavity Laser
Zitian Ye
Mentors: Nicholas Hutzler, Yi Zeng, and Yuiki Takahashi

Cold molecules are an important resource for studying fundamental physics, quantum simulation, quantum computing, and ultracold chemistry. However, the internal complexities of molecules render laser cooling, a technique commonly used to cool and trap atoms, extremely difficult. Cryogenic buffer gas cooling is useful as a starting point for laser cooling, and works by introducing the hot species of interest into a cell containing a cold, inert buffer gas such as helium at a temperature of a few Kelvin. However, there has never been a direct probe of the dynamics of the helium buffer gas atoms inside the cryogenic cell. In this project, we build an external cavity laser with a broadband gain module in the Littröw configuration to probe metastable helium atoms. We characterize the metastable helium in a closed cryogenic buffer gas cell by its lifetime and its Doppler broadening. We also observe the fine structure in the $2^3P_{0,1,2}$ states. Our work furthers our understanding of the helium buffer gas atoms in the cryogenic cell, and opens up new pathways for diagnostics and optimizations for buffer gas sources.

Designing Electrostatic Transducer With Heuristic Algorithm
Yue Yu
Mentors: Mohammad Mirhosseini and Han Zhao

Phonon at gigahertz frequency is one of the most promising platforms for quantum transduction between microwave photons and optical photons. However, the predominant platform for electro-mechanical coupling, polycrystalline piezoelectricity material, requires complicated hybrid integration and significantly limits the phonon lifetime to sub-microseconds. To address this major obstacle, the Mirhosseini Lab develops electrostatic transducer with metal-on-silicon structure and demonstrates its long photon lifetime compared with piezoelectrical transducer.

Despite its novel design, electrostatic transducer still has room for improvements, especially in the mechanical displacement of nanobeam breathing mode. In order to obtain 5 GHz vibration, the nanobeam consists of several cells with elliptical hole. However, finding the geometry that supports strong and uniform collective vibration between cells is a multi-parameters optimization task and has no trivial solution. My primary research objective is searching for the optimal geometry with heuristic algorithm. The simulation result shows that through optimization, we can double the electromechanical coupling strength, which will lead to stronger electromechanical cooperativity between microwave photon and phonon and facilitate the further quantum transduction experiment.

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

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

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

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

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

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

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

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

Gene Expression Analysis for YAP/Hippo Pathway Proteins Involved in Alzheimer's Disease
Claire Zhang
Mentors: Barbara Wold, John Allman, Long Cai, and Libera Berghella

Alzheimer's disease (AD) is the leading neurodegenerative disease in the elderly population. YAP1 is a phosphorylation-deactivated oncoprotein that functions as a downstream transcriptional regulator in the Yes-Associated Protein (YAP1)/Hippo pathway, which is heavily involved in cell proliferation, regeneration, and apoptosis. After migrating into the nucleus, YAP1 binds to TEAD2 to form transcriptional regulatory complexes that bind to DNA, trigger transcription, and turn on corresponding genes. YAP1 and its ortholog TAZ/WWTR1 have been discovered to be highly upregulated in AD brains. Other major indicators of AD are hyperphosphorylated tau neurofibrillary tangles and beta-amyloid (Aβ) plaques. Immunohistochemistry and spatial genomic methods such as seq-FISH enable an understanding of the regulatory mechanisms and pathological features of AD and potential relationships between its indicators. This specific project aims to use immunofluorescence to confirm and uncover coexpression patterns of upregulated genes—with particular focus on YAP/Hippo pathway proteins—in AD, and observe correlations with specific cell types, tau tangles, and Aβ plaques. The following antibodies are used: anti-AT8 stains tau neurofibrillary tangles; anti-Aβ stains Aβ plaques; anti-TOX1/4 and anti-CTIP2 are nuclear stains; anti-YAP1/TAZ stains for YAP1/TAZ protein (nuclear, cytoplasmic, and in vasculature); PECAM stains endothelial (vascular) cells; IBA stains microglia.

Implementing Seesaw Logic Gates in Synthetic Cells
Heyi Alina Zhang
Mentors: Richard Murray and Manisha Kapasiawala

Synthetic biology at its core involves either designing or creating new genetically encoded pathways and systems for useful purposes, such as detection of molecular signatures or environmental modeling and remediation. During the previous few years, the Murray lab has been able to develop and improve an *in vitro* transcription-translation (TX-TL) system using *E. coli* extract. This system can express gene circuits with the simple addition of DNA encoding the circuits into a test tube. TX-TL prototyping has allowed the Murray Lab to implement regulatory circuits, in addition to decision-making logic. However, while they have used TX-TL to implement gene circuits, they have not yet put DNA circuits in artificial cells (vesicles that encapsulate TX-TL machinery). While gene circuits act at the protein level, with many parts that take advantage of cell machinery to encode RNAs and proteins, DNA strand displacement circuits simply act on DNA strands. Because DNA behaves much more predictably than proteins, they have an advantage over normal gene circuits because they are easier to manipulate. In addition, gene circuits are much more susceptible to crosstalk than DNA circuits, so using DNA circuits could make it much simpler to implement complex decision-making capabilities. Thus, I use previously studied see-saw gates that would be a part of a TX-TL system that can work in artificial cells, where the *in vivo* implementation is replaced with an artificial cell implementation using giant unilamellar vesicles (GUVs), which are model systems for the cell membrane because of their size and physical properties that are like ones that belong to living cells.

Testing the Feasibility of Tri-Higgs Production at LHC
Hongyu Zhang
Mentors: Maria Spiropulu and Si Xie

While the groundbreaking discovery of the Higgs Boson in 2012 at the Large Hadron Collider (LHC) filled in the last piece of the puzzle for the Standard Model. Though the study continues, the full set of Higgs boson production modes at the LHC and the associated mechanisms are yet to be measured. Di-Higgs and tri-Higgs production especially allow us to inspect the parameters of Higgs self-coupling and the shape of the Higgs potential. Such processes are rare, so, we use Monte Carlo simulation to generate particle collision events to study kinematic features of di-Higgs and tri-Higgs production. These properties allow us to infer the production rate of di-Higgs and tri-Higgs at LHC, which allows us to constrain the Higgs coupling parameters, giving us the shape of the Higgs potential. We have measured the production rate of three boosted Higgs and two boosted Higgs. We are currently looking into the kinematic properties of these Higgs production modes and will further constrain the Higgs self-coupling parameters in the future.

High-Fidelity Spacecraft Dynamics Simulation in ROS2 Using Basilisk
Leo Zhang
Mentor: Soon-Jo Chung

Over the recent years, the technology for close-proximity formation flying spacecraft has advanced significantly by applying modern robotics algorithms (such as computer vision and motion planning). Open-source and modular middleware ROS/ROS2 played a large role in this advancement, but its application to autonomy in space has been limited. Thus, Caltech has planned a cubesat technology demonstration mission called CASTOR to demonstrate swarm autonomy in Earth orbit using ROS2. However, currently, there is no software compatible with ROS/ROS2 that simulates high fidelity dynamics of spacecraft in planetary orbits. This project aims to integrate the open-source spacecraft simulation software, Basilisk, along with ROS2.

While both ROS2 and Basilisk are capable of simulating dynamics and real-time software in a modular fashion, they have separate software infrastructure and their own messaging protocols between modules. To bridge this gap, we developed a new interface Basilisk module that also publishes and subscribes to ROS2 messages such that other ROS2 algorithms can interact with dynamics simulated in Basilisk in real-time. The work was validated by implementing attitude and translation controllers in ROS2 and validated with the dynamics in Basilisk in a closed-loop fashion for an along-track formation keeping example.

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

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

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

Within eukaryotic cells, massive ~110-MDa transport complexes called nuclear pore complexes (NPCs) facilitate the transport of macromolecules across the nuclear envelope. Protein constituents of the NPC, called nucleoporins (nups), are essential in the assembly of the mitotic spindle during cell division. Mutations in nups can cause erroneous spindle morphology, leading to defects in the biogenesis of various human tissues and resulting in uncurable congenital diseases such as achalasia, Addison disease, and alacrima autosomal disorder, collectively symptoms of triple A syndrome. The disease mechanisms of Triple A syndrome have remained elusive, with no clear correlation between mutations and disease phenotype.

We will use pull-down biochemical assays to identify the binding partners of nups implicated in Triple A syndrome. We will solve high-resolution crystal structures to inform our biochemical analysis of mutations associated with Triple A syndrome. Our findings will facilitate development of targeted therapies for those suffering from Triple A syndrome.

Global Convergence With Local Information in Networked Entropy-Regularized Multi-Agent Reinforcement Learning
Yizhou Zhang
Mentor: Adam Wierman

Our research studies multi-agent reinforcement learning (MARL) under the setting that the agents are on a network and the state transition probability is determined only by the neighboring states and local action. The goal of these agents is to maximize the global discounted reward, which is the sum of local rewards that can only be observed locally by the agents, using only the information provided by its nearby agents. We introduced entropy regularization method to our problem and proved that under entropy regularization there is a small bounded suboptimality gap between our decentralized policy class and the centralized policy class which contains the optimal global policy. We also proposed a decentralized policy iteration algorithm which converges to a policy with bounded error to the optimal global policy. Possible further research may contain applying this algorithm to complex real-world environments, proving convergence rate bound and analyzing sample complexity of our algorithm.

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

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

Investigating the Effect of the Hantzsch Ester on the Photoinduced Hydrogenation of Nitrogen to Ammonia
Luke Zhou
Mentors: Jonas C. Peters and Emily Boyd

Sustainable methods for the conversion of nitrogen gas into ammonia are in high demand, as the Haber-Bosch process, which industrially produces ammonia, expends large amounts of energy. Recently, the Peters group has reported a fully reduced Hantzsch ester as a photoreductant capable of donating an H_2 equivalent to N_2 to form NH_3 in the presence of a molecular molybdenum precatalyst and under blue light irradiation at ambient temperatures and pressures. We investigate the influence of the structure of the Hantzsch ester on its function in the reduction of N_2 to NH_3 through the synthesis of diethyl 4-isopropyl-2,6-dimethyl-1,4-dihydropyridine-3,5-dicarboxylate ($^{iPr}HEH_2$), a Hantzsch ester with a bulky isopropyl group. Here, we present the results of attempted photodriven N_2 reduction with $^{iPr}HEH_2$ and discuss the effects of the isopropyl substituent on N_2 reduction pathways as well as on photoinduced Hantzsch ester decomposition through the analysis of both fixed-nitrogen and organic products.

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

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

Manufacturing 3-D Lithium-Ion Batteries With Interpenetrating Lattice Electrodes
Nathan Zou
Mentor: Julia Greer and Yingjin Wang

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

Subtropical Relative Humidity in the CMIP6 Ensemble
Isabella Zuniga
Mentors: Tapio Schneider and Clare Singer

The dryness of the subtropical atmosphere is a key regulator of global climate, acting as the "radiator fins" (efficient, large OLR) which keep the tropics from entering a local runaway greenhouse state (Pierrehumbert, 1995). We show a preliminary analysis of subtropical relative humidity across the CMIP6 models including the zonal means and RH maps (latitude vs. longitude) for 1x, 2x, and 4x CO_2 in ten year intervals. Across the ensemble, predictions of relative humidity are robust and show an expansion and slight drying of the dry, subsiding subtropical region in the 1\% year increasing CO_2 experiments, agreeing well with previous work (Sherwood, 2010). We discuss variations between models in their representation of pre-industrial RH distributions as well as their response to climate change through plot analysis.

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

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

Measuring TKID Responsivity With Photon Shot Noise
Elizabeth Berzin (Jet Propulsion Laboratory, California Institute of Technology)
Mentors: Jamie Bock and Bryan Steinbach

Thermal Kinetic Inductance Detectors (TKIDs) are cryogenic bolometers that measure incident power through resonant frequency shifts in a superconducting micro-resonator. Currently, TKIDs are designed with external circuitry used to bias a resistive heater to simulate optical loading for calibration measurements. This additional circuitry defeats much of the multiplexing benefit introduced by TKIDs. Here, we explore a method of measuring TKID responsivity with photon shot noise, with the goal of removing the need for the existing heaters. Similar to the process by which CCD cameras calibrate gain by exploiting the Poisson statistics of photon counts, we use the power proportionality of photon NEP to estimate responsivity. We demonstrate through modeling and experimental results that this method is sensitive to systematic errors, such as chip heating and direct quasiparticle production, and discuss strategies for mitigating these effects. We also compare our measurements to models of NEF, quasiparticle lifetime, and frequency shift.

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

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

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

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

Developing a Mosaic Nanoparticle Capable of Eliciting Cross-Reactive Immune Responses Targeting a Broad Range of Merbecoviruses

Sergio Zafra Butron Jr.
Mentors: Pamela Bjorkman and Alexander Cohen

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

Prototype of an Autonomous Tracked Vehicle for Inspection of Vertical Steel Surfaces

Lydia Calderon-Aceituno
Mentor: Joel Burdick

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

Carbon Export in Drake Passage: Observations From Ocean Autonomous Platforms

Taylor Cason
Mentors: Andrew Thompson, Lily Dove, and Mar Flexas

The ocean plays a vital role in the climate system due to its ability to uptake and store carbon present in the atmosphere, making it of great interest to study as anthropogenic atmospheric CO_2 increases. The Southern Ocean is unique due to the presence of the Antarctic Circumpolar Current (ACC), which exerts a large influence on the world's carbon cycling. Within the Southern Ocean, a region known as Drake Passage is observed to understand the impact of air-sea exchange, a critical process for carbon uptake and storage.

We are interested in understanding ventilation of surface waters in Drake Passage. Using glider and altimetry data collected from Drake Passage, we identify patterns and anomalies in temperature, salinity, chlorophyll fluorescence, and dissolved oxygen. Preliminary results have found two frontal structures that show an increase in mixed layer depth, temperature, and salinity and a decrease in dissolved oxygen. These horizontal gradients imply the presence of strong jets that facilitate ACC transport and catalyze the generation of eddies and filaments that enhance exchange between deep and surface oceans. Further quantifying these vertical and horizontal gradients will contribute to illustrating the impact of submesoscale dynamics on carbon and nutrient distribution throughout the global ocean.

Production of Sugar Precursors on Early Mars

Rachel Caulfield
Mentor: Yuk Yung

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

C-quester: CO_2 Mitigation System

Luana Dos Santos
Mentors: Michael Hoffmann and Clement Cid

The United States emits over three gigatons of Carbon Dioxide(CO_2) annually, substantially contributing to global warming[1]. The goal of the research is to be extracting CO_2 and other effluents from different point source emitters. Other techniques have used K_2CO_3 as their primary absorption product but we are aiming to use $CaCO_3$ since initial testing showed a higher absorption rate. $CaCO_3$ is a greener absorbent than other available technology, it also costs less per ton of CO_2 sequestered. The system will be utilized for industrial use where temperature, humidity and pressure will be monitored and controlled. While the final model incorporates these variables, the prototype has a humidifier and monitors flow rate. A small scale reactor design was used to determine what conditions, and absorbent product worked best for this system. The CO_2 absorption was tested with various products: $CaCO_3$, K_2CO_3, and Na_2CO_3. Data was collected by running CO_2 through a reactor filled with an absorbent product, using Gas Chromatography and Mass Spectrometry to track absorption of CO_2. Results show a large difference in absorption between the two primary products K_2CO_3 and $CaCO_3$. The latter has a higher rate and shows promise for future application.

PTZ Induced Whole-Brain Neuronal Activity Changes of Wild-Type Zebrafish and ASD-risk Gene Mutants

Emily Echevarria Perez
Mentors: David Prober and Jin Xu

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

Redesigning Adeno-Associated Virus Serotype 9 to Efficiently Deliver CRISPR/Cas9 Proteins

Ayoola Fadonougbo
Mentors: Viviana Gradinaru and Tim Miles

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

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

$Li_5B_7S_{13}$ as a Solid-State Lithium-Ion Electrolyte

Dawn Ford
Mentors: Kimberly See and Kim Pham

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

and $Li_2B_2S_5$. The current work has allowed our group to understand the thermodynamics of this phase space and the conditions required to synthesize materials in the Li-B-S phase space. Future work will build upon these results to obtain the pure phase $Li_5B_7S_{13}$.

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

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

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

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

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

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

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

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

Finding the Optimal Unitary to Saturate the Imperfect Quantum Fisher Information
Nickholas Gutierrez
Mentors: John Preskill and Tuvia Gefen

The imperfect quantum Fisher information (QFI) is a generalization of the QFI that quantifies the optimal sensitivity of a quantum sensor in the realistic case of noisy measurements. Therefore, for a given quantum metrology scheme, it is of utmost importance to determine the optimal control unitary to apply before the measurement to saturate the imperfect QFI. Previously, there has been work done in trying to obtain the optimal unitary analytically. However, no analytical method for finding the optimal unitary has been found for states that are non-pure. Also, there is no explicit expression for the imperfect QFI for non-pure states and very little is known about it. In this work we utilize numerical methods to obtain the optimal unitary in a variety of special cases. We use numerical optimization algorithms to find parameters for the construction of the optimal unitary. Finding these optimal unitaries allows us to evaluate the imperfect QFI for non-pure states and may help us understand the behavior of this quantity with various different states.

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

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

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

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

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

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

Using Cavity Ring-Down Spectroscopy to Measure Methane and Deuterated Products From Nitrogenase HCN Assays
Kyla Hudson
Mentors: Mitchio Okumura, Termeh Bashiri, Douglas Ober, and Siobhán MacArdle

Nitrogenase is an essential enzyme that could have the potential to replace the environmentally harmful Haber-Bosch process. Nitrogenase can reduce many biological molecules including HCN to methane. Studying the isotopologue preferences of the products of HCN reduction assays can provide insight into the mechanism of the nitrogenase enzyme. To achieve this goal, HCN assays were prepared in either 100% H_2O or 50% D_2O, and the gas from the headspace was sampled and analyzed using Cavity Ring-Down Spectroscopy (CRDS). Using the spectral lines from the HITRAN database, CH_4 peaks were identified and analyzed. The CH_3D, CH_2D_2, CHD_3, and CD_4 peaks are being identified and quantified as well. Future work includes analyzing the kinetic isotope effect of the HCN reduction mechanism by nitrogenase. This work proves that CRDS is a more sensitive method for methane isotopologue analysis for nitrogenase assays and provides informative mechanistic details about nitrogenase.

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

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

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

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

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

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

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

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

Elucidating Structure-Property Relationships in Metal/Semiconductor Materials for Solar-Driven Carbon Dioxide Conversion

César A. Lasalde-Ramírez
Mentors: Harry Atwater and Aisulu Aitbekova

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

Parcel-Level Disaster Recovery in the Florida Panhandle: An Analysis of Hurricane Michael

Kushnerniva Laurent
Mentors: R. Michael Alvarez and Danny Ebanks

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

Characterizing Translational Processes of Organisms Across Domains by Polysome Profiling

Alejandra Leal
Mentors: Victoria Orphan and Rodney Tollerson II

For our cells to function correctly, it is critical that the genetic information is translated accurately to proteins. Because cellular functions can be regulated at the level of translation, characterizing this process may allow one to observe regulation of gene function that would normally be obscure. We aim to understand if translational processes under different metabolisms and domains of life are conserved. To answer this question, we focus on an intercellular structure where protein synthesis occurs, the ribosome. The model system for this study includes *Escherichia coli* (fast-growing bacteria), *Geobacter metallireducens* (slow-growing bacteria), *Methanosarcina acetivorans* (slow-growing archaea), and *Methanocaldococcus jannaschii* (fast-growing archaea). These organisms have been successfully grown in pure cultures, and their cell lysates have passed through a sucrose density gradient that allowed us to collect the ribosomes. Results from polysome profiling will be used to perform a comparative analysis of translation in organisms of different domains of life.

Constructing Stabilized Occluded-Open HIV-Env Proteins as a New Research Model and Potential Immunogen

Nathaniel Liendo
Mentors: Pamela Bjorkman and Andrew DeLaitsch

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Works Cited:

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

Rapid Synthetic Image Generation Using Neural Radiance Fields for Vision-based Formation Flying Spacecraft

Christine Ohenzuwa
Mentors: Soon-Jo Chung and Kai Matsuka

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

A Paradigm for the Study of Escape and Reward Computation Under Threat

Noah Okada
Mentor: Dean Mobbs

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

Prediction of Lift for Airfoil at Low Reynolds Number

Brandon Paez
Mentors: Jane Bae and Di Zhou

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

Exploring the Abiotic–Biotic Gap: A Novel Technique to Measure the Isotopic Composition of Acetate and its Implications for Astrobiology

Juliann Panehal
Mentors: Alex Sessions and Elliott Mueller

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

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

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

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

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

Learning From Hints
Marilyn Recarte
Mentors: Yaser Abu-Mostafa and Dominic Yurk

Despite its widespread applications, image classification tasks remain challenging given a limited dataset. In our study, we experimented with neural networks using duplicate examples as hints to gain insight into the predicted outcome through logical reasoning, mimicking the human behavior of deductive reasoning. The use of duplicate examples provides an alternative means of representing certain types of hints, recognized as invariance hints, since they expand the existing training dataset. The invariance hints used were scaling, shift, and rotation. From hints, we learned the properties of the target function independent of the training examples. We examined whether one can design meaningful or meaningless hints when using duplicate examples, upon which reasoning can be based to explain the predicted outcomes. Therefore, different sets of duplicates can be designed to explain the predicted results without compromising the credibility of the performances. Using three benchmark datasets, we demonstrated our method's results by documenting the target and hint performance. Further research implications suggest that a network may not give a correct response to the output for an input stimulus that has not been previously trained. Additionally, understanding what the relationship between the target and the hint performance indicates as the network is sensitive to errors.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Quantitative Analysis of *Pseudomonas aeruginosa* Growth in Agar Block Biofilm Assays (ABBAs) to Assess Antibiotic Resistance and Tolerance

Gia Han Vuong
Mentors: Dianne K. Newman and Avi I. Flamholz

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

Integration of Ultra High Vacuum Cryostat in Ultrafast XUV Spectroscopy for Charge-carrier Dynamics Analysis

Audrey Washington
Mentors: Scott Cushing, Jocelyn Mendes, and Jonathan Michelsen

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

Inhibition of Gram-Positive MraY Through Protein and Antibacterial Small Molecule Inhibitors

India Wesley-Cardwell
Mentors: William M. Clemons and Anna Orta

Antimicrobial Resistance (AMR) is an increasing issue around the world according to the CDC. AMR occurs when the targeted pathogen is resistant to antibiotics making the infection harder to treat. This increases the need for better antibiotics. Researchers in the Clemons lab have identified a need for phage antibacterial therapeutics. Protein and small molecule interactions can be utilized to innovate better treatments that can combat AMR. Phage therapeutics aim to inhibit potential drug-resistant mutations in bacteria such as *Bacillus subtilis* and *E. coli.* The lytic phages escape from the host cell wall using proteins known as holins, which are cytoplasmic membrane proteins that form large oligomers that form a pore in the lipid bilayer. The cytoplasm will leak and release endolysins which are muryalytic enzymes that degrade the peptidoglycan layer. The amurin is the protein that encodes for gene E produced by the phiX174, referred to as protein E. Overexpression of protein E causes bacterial cell lysis. MraY is essential in all bacteria making it a focal point for antibiotic development. There are currently no clinical inhibitors of MraY. Therefore, our research will further prove that phage therapeutics via peptidoglycan inhibition can be useful in antimicrobial interactions. The Clemons lab has generated an *E. coli* strain where the genomic MraY gene has been replaced by a *B. subtilis* MraY (*Bs*MraY). This means that this *E. coli* strain will be resistant to protein E, as protein E is specific to *E. coli* MraY (*Ec*MraY). Using an E library to expose this *Bs*MraY to an array of protein E mutants would allow for the selection of protein E mutants that inhibit *Bs*MraY.

Allosteric Leak Reduction in Catalytic Strand-Displacement Circuits

Spencer H. Winter
Mentors: Lulu Qian and Samuel Davidson

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

Malnutrition and Nutrient Context for Peri-implantation Embryo Development

Peyton Yee
Mentor: Magdalena Zernicka-Goetz

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

An Ingestible Bioelectronic Capsule for Continuous Monitoring of the Gastrointestinal Tract

Rinni Bhansali
Mentors: Wei Gao, Jihong Min, and Juliane Sempionatto

The gastrointestinal (GI) tract contains a host of information about nearly all complex bodily systems. However, though it is an optimal target for continuous, non-invasive disease diagnosis and health monitoring, the environment is difficult to reach. Hence, we are developing an ingestible capsule small enough to pass through the GI tract, yet powerful enough to continuously measure its conditions and communicate the data in real time over bluetooth. We first design and integrate electrochemical sensors for pH, to localize the capsule, and lactate, an indicator of health in the gut microbiome. Finally, we evaluate the performance of the entire integrated device, with the sensors, PCB, bluetooth module, and power source. Specifically, we evaluate the capsule's longevity, its ability to perform bluetooth communication through the human body (independent of orientation), and finally demonstrate the capsule's abilities in a simulated, in vitro representation of the GI tract.

Early Language Development in Children With Agenesis of the Corpus Callosum as Compared to Children at High- and Low-Likelihood for ASD

Ella Bohlman
Mentors: *Ralph Adolphs, Lynn Paul, and Jasmin Turner*

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

Predicted Three-Dimensional Structure of TAS2R50 Including Associated G-Protein and Agonists

David Clancy
Mentors: William Goddard III and Soo-Kyung Kim

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

Love to Fight: Studying the Role of the "Love Hormone" Oxytocin in Mediating Aggression Neural Circuitry

Bryan Dong
Mentors: David J. Anderson and Amit Vinograd

Previous studies on the neurobiology of aggression have indicated that the hypothalamus is a key structure in the regulation of aggressive behavior [1, 2], with aggression-specific neural ensembles identified in ventrolateral ventromedial hypothalamus (VMHvl) [3, 4]. While it was shown that estrogen receptor 1-expressing (Esr1+) neurons in VMHvl are necessary and sufficient to drive aggression [5], the mechanisms by which different neurochemicals affect Esr1+ neurons, and consecutively the formation and modulation of aggressive behaviors have yet to be fully characterized.

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

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

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LFP Dynamics of Recovery After Perturbation of a Premotor Circuit

Jordan Feldman
Mentors: Carlos Lois and Zsofia Torok

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

Analyzing Biological Processes of F_1-ATPase to Create Enhanced Probability Distribution Equations to Determine Chemical States

David Enzo Florendo
Mentors: Sándor Volkán-Kacsó and Rudolph A. Marcus

F_1-ATPase, the minimal component of the enzyme which produces ATP molecules, serves as a biological rotary motor, rotating unidirectionally counterclockwise in rotational steps of 40° and 80°. A nanoprobe is elastically attached to the probe to analyze the length of each dwell and transition state of the enzyme, with each species of

F_1 possessing varying lengths for each of these states. At a microscopic level, there are many variables which lead to inconsistency such as angular tilt, Brownian motion, and uneven surfaces, so numerous algorithms are being developed to mitigate this, since the behavior of the enzyme should be repeatedly chemically consistent. The goal is to reduce the effect of external variables on the enzyme in order to create a more accurate representation of the chemical behavior of ATP synthase. Further research will include implementing these correctional algorithms on new sets of data which seek to further reveal the behavioral patterns of F_1-ATPase in order to understand, control, and potentially manipulate its behavior in the future.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

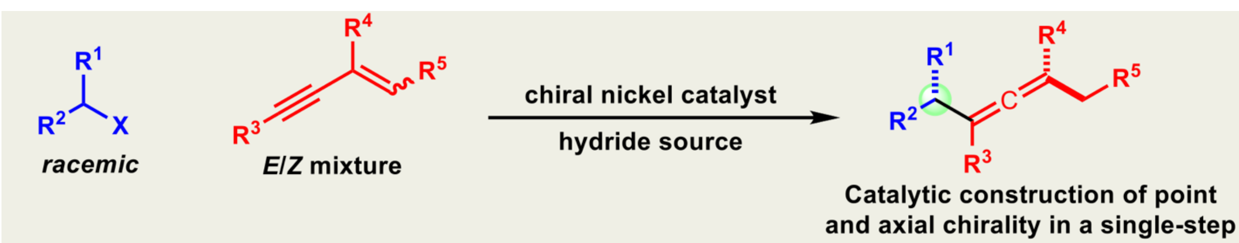
Delayed sleep phase syndrome (DSPS) is the most common circadian rhythm disruption among sleep-wake disorders. DSPS is the product of the atypical molecular regulation of specific proteins and their interactions found in mammals, resulting in delayed sleep cycles of up to several hours. The interactions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

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

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

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

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



Optical Contact Bonding for Mitigating Clamping Losses in Silicon Resonators

Ojo Akinwale
Mentors: Aaron Markowitz, Rana Adhikari, and Shruti Maliakal

This experiment aims to improve the quality factor of silicon resonators in order to mitigate the thermal noise present in the mirrors and suspension systems in the LIGO Michelson Interferometer. The oscillation of the cantilever is analyzed and used to calculate the mechanical quality factor through the exponential decay of the oscillations in the ringdown method. The clamping losses and thermoelastic sources of loss are studied to understand the intrinsic factors affecting the quality factor. The design of the clamp will use optically contacted layers silicon in order to reduce the acoustic waves radiating away from the resonator into the substrate, which will achieve the effect of improving the quality factor of the cantilever.

Synergies With WINTER, ZTF, and LIGO for Kilonova Discovery

Faith Bergin
Mentor: Shreya Anand

During LIGO's fourth observing run (O4), we expect to discover more gravitational wave (GW) events than ever before, including binary neutron star (BNS) and neutron star black hole (NSBH) mergers that produce electromagnetically bright kilonovae. The Zwicky Transient Facility (ZTF) has thus far performed extensive follow-up in the optical regime during LIGO's third observing run, O3. During O4, the Wide-Field Transient Explorer (WINTER), designed specifically for gravitational wave follow-up, will join the campaign in the near-infrared Y, J, and short-H bands. We investigate the potential of combining the resources of both WINTER and ZTF to create an observing strategy suited for joint gravitational wave and electromagnetic discoveries. We use the Nuclear and Multi-Messenger Astrophysics (NMMA) Bayesian Python pipeline to simulate WINTER's observations of kilonovae with different Target of Opportunity (ToO) triggering criteria and observing setups. We draw from a simulated population of LIGO observations and radiative transfer kilonova models. This study begins to assess kilonova parameter recovery with WINTER. In the future, we hope to simulate the the combined WINTER/ZTF observing system to determine the most effective follow-up strategy for a given LIGO gravitational wave alert and integrate it into the campaign starting in O4.

Implementation of an Inpainting Filter to Mitigate the Effect of Glitches on Gravitational-Wave Parameter Estimation

Viviana A. Cáceres Barbosa
Mentor: Derek Davis

Recovering accurate distributions for the source parameters of gravitational-wave signals is essential to confirm current models of general relativity and understand astrophysical properties of the universe. Glitches in gravitational-wave strain data may cause a bias in parameter estimation analyses that use Bayesian inference. We implement inpainting to address this problem in Bilby, one of various parameter estimation pipelines used for gravitational-wave analyses. Using two different methods to obtain inpainted data, we study how each process affects likelihood evaluation times and Bilby's ability to recover accurate posterior distributions. We will also work towards running different PE analyses using inpainted data with injected signals and studying how often Bilby can recover injected parameter values within a specific confidence interval.

Mode Matching for Triangular Ring Cavity

Peter Carney
Mentors: Shruti Jose Maliakal and Rana X. Adhikari

In upcoming LIGO designs, a Phase Sensitive Optomechanical Amplifier (PSOMA) will be introduced to help mitigate readout losses in the LIGO interferometer. Though only at the tabletop stage, the PSOMA design is experiencing mode mismatch in its triangular ring cavities. The cause of this discrepancy is assumed to be in the mode matching lenses. Methods of analysis are to model the design with a thick lens, and consider lens aberrations. While a thick lens design is more straightforward to construct, considering lens aberrations is no trivial task. In this project, we take a conceptual idea of the cause and effects of lens aberrations, and apply them to Gaussian beams. The results given may provide much better analysis on how optics play a role in not only the PSOMA cavity, but in the LIGO interferometers.

Improved Targeted Sub-threshold Search for Strongly Lensed Gravitational Waves With Sky Location Constraint

Aidan H.Y. Chong
Mentors: Alvin Li, Ryan Magee, Juno C.L. Chan, Cody Messick, and Alan J. Weinstein

Gravitational lensing is an important field in both astrophysics and cosmology as it could provide a large amount of crucial information about our universe unmatched by other phenomena such as the determination of expansion rate of the universe and the distribution of dark matter. Until recently, gravitational lensing had only been applied to the observation of the electromagnetic spectrum. Since the first successful observation of gravitational waves

back in 2015, discussions had started to try to find lensed gravitational wave signals. However, in most cases, the lensed image should be much dimmer than the original signal, which might be buried in the noise as it could not pass the normal detection threshold. Our work would be to improve the existing TESLA searching pipeline to suit our need for lensing searches. We hope to recover originally buried sub-threshold lensed signal from the collected data. Our work would be implemented in the TESLA pipeline for future uses.

Fisher Information Analysis for Emissivity Estimation
Hiya Gada
Mentors: Radhika Bhatt, Rana Adhikari, and Christopher Wipf

We wish to estimate the emissivities of various test mass barrel coating candidates for the Mariner upgrade of the 40m prototype at Caltech. The cooldown of a sample in our test cryostat has a time constant of several days, making it infeasible to run the experiment multiple times to estimate its emissivity. The methodology involves system identification using Fisher Matrix analysis on the cryostat and finding the optimal experimental configuration and input that minimizes uncertainty on the final emissivity estimate. The Fisher Matrix analysis has shown us a relationship between system design parameters and uncertainty in the test mass emissivity. The optimal heat input is determined using power spectrum optimization, which distributes the total power over various signal frequencies. For a first-order system, this method gives an optimal frequency very close to the one obtained while minimizing the uncertainty of the parameter corresponding to the system's pole. The optimal design parameters and input will be implemented in future measurement runs with silicon wafers.

Prototype Mirror Suspension for Cryogenic Interferometers
Juan Gamez
Mentors: Koji Aria and Rana Adhikari

Gravitational wave astronomy has been a rapid growing field, we use interferometers to detect gravitational waves which give us insight into optically hidden events such as black hole mergers. Since the current noise levels of the Advanced LIGO detectors are reaching to the physical limit, they will soon need detector upgrade. For the successful design of such upgrade, the development of the cryogenic suspension is imperative. The goal of my summer research is to build and test a prototype suspension system. In this article, we will be describing the project "LIGO Voyager" and our goal for the summer to help push the advancement of the current aLIGO to LIGO Voyager by creating a prototype suspension system. This prototype will then be tested in air, vacuum, and at cryogenic temperatures specifically looking at the dynamical and cooling performance. Our Test results are feedback to the modification of the suspension design for Mariner and thus increase the feasibility of the Voyager upgrade.

Active Monitoring of the Auxiliary Laser System
Cecilia Hanna
Mentors: Francisco Salces-Carcoba, Anchal Gupta, and Rana Adhikari

The Auxiliary Laser System is used to reduce interferometer locking time, by measuring the difference between the resonance of the cavity and the Pre-Stabilized Laser without locking the cavity to the PSL. Thus we can keep the cavity unlocked while locking the rest of the interferometer to the PSL. The difference between the frequency of the Auxiliary Laser (AUX) and cavity resonance is measured by the Pound-Drever-Hall technique, and minimized by a feedback loop. The gain of this loop is a function of the frequency of the noise entering it. Using a Red Pitaya as a vector network analyzer measuring the AUX laser control loop, we can create an active monitoring system that returns the unity gain frequency (UGF) of the loop, and thus allows us to monitor whether the UGF drifts over time and how frequently recalibration of the loop is necessary.

Methods of Improving Optical Contacting
Jennifer Hritz
Mentors: Rana Adhikari and Koji Arai

This project will attempt to improve the technique of optical contacting, which is the process of bonding polished, flat surfaces using Van der Waals dispersion forces. It will explore the efficacy of different preparation methods for creating a bond. There will be a focus on the use of heat and pressure to increase the strength of the bond between glass slides and silicon wafers. One of the main goals of the project is to find the best temperature for creating a strong bond. The quality of the bond can be assessed by measuring the shear strength, tensile strength, air gap, and mechanical quality. The eventual goal is to make optical contacting strong enough to be a viable method for conjoining pieces of high precision equipment in space, specifically for the LIGO Voyager.

Determining the Feasibility of Matched Filter Searches for Core-Collapse Supernovae
Pavani Jairam
Mentor: Ryan Magee

With the efforts of the Laser Interferometer Gravitational-Wave Observatory (LIGO) collaboration, gravitational waves (GWs) have been successfully detected from black hole mergers, neutron stars, and neutron star-black hole binaries. However, there are other violent phenomena, such as core-collapse supernovae (CCSNe), that are potential candidates for gravitational wave studies. CCSNe are of particular interest because they emit other astrophysical messengers such as neutrinos and electromagnetic rays. I will study the feasibility of using matched filter searches for CCSNe with a phenomenological GW model that aims to be representative of CCSNe waveforms. I will examine the impact of stochasticity on the g-mode dominated emission of CCSNe, determine if the randomness of waveforms is manageable for generating a parameter space, design a template bank of CCSNe gravitational waveforms, and compare a search benchmarked against numerical relativity simulations.

Approximating Simulated Stochastic Gravitational Wave Background BBHs With Broken Splines and Power Laws
Taylor Knapp
Mentors: Arianna Renzini and Patrick Meyers

The Stochastic Gravitational Wave Background (SGWB) is the combination of assumed isotropic, stationary, unpolarized, and Gaussian sources of gravitational waves. We expect a large contribution of neutron star and black hole binaries to this unresolved signal. Current LIGO detectors are not sensitive enough to the SGWB strain regime but we anticipate future observing runs to have the required visibility for the SGWB. The promise of future detectors registering the SGWB requires the introduction of detection and fitting algorithms to understand future observation results. A Reverse Jump Markov Chain Monte Carlo (RJMCMC) algorithm permits us to probe the fitting parameters for SGWB signals via spline and power law fittings. The versatility of the RJMCMC can be applied to the astrophysical case of recovering the energy density spectra based on injected mass distributions and merger rates for binary black hole mergers (BBHs). Accurately fitting the SGWB profiles and parametrizing profiles via spline and broken power laws will aid in identifying various components of the SGWB in data from upcoming LIGO observing runs.

Analyzing the Effective and Component Spin Distributions of Binary Black Hole Mergers
Zoe Ko
Mentors: Katerina Chatziioannou and Simona Miller

Gravitational wave (GW) observations of binary black hole (BBH) mergers provide measurements of BBH parameters such as mass and spin, which shed light on the evolutionary history of these systems. We explore the distribution of BBH spin on a population level through looking at different spin parametrizations. LIGO data currently provides strong constraints on effective spin, a mass weighted average of component spin projected in the direction of the angular momentum, but component spin is weakly constrained for individual events. Through a Bayesian hierarchical inference approach, we explore whether we can differentiate synthetic populations with the same effective spin distributions but different component spin distributions. We explore these spin distributions for two different population sizes: one comparable to LIGO's third observing run (O3) and one comparable to the predicted population size after the next observing run (O4). This study demonstrates how current models of spin distribution will improve with O4.

Supermassive Black Hole Property Determination via Gravitational Radiation From Eccentrically Orbiting Stellar Mass Black Hole Binaries
Andrew Laeuger
Mentors: Brian Seymour and Yanbei Chen

The gravitational waveform from a compact inspiraling binary, such as a BBH, can indicate the presence of a nearby massive body, such as an SMBH. The waveform is modulated by de Sitter precession of the BBH's inner angular momentum and by the time-dependent Doppler phase shift of the BBH in its orbit. The future generation of space-based GW observatories, focused on the millihertz and decihertz band, is uniquely poised to observe these waveform modulations, as the GW frequency from stellar-mass BBHs remains in this band for the months or years over which these modulation effects accumulate. In this work, we apply the Fisher information matrix to estimate how well a decihertz detector can measure properties of BBH+SMBH hierarchical triples. We consider an eccentric orbit of the BBH about the SMBH, extending previous studies which were limited to circular orbits. We find that the uncertainties in measurements of the SMBH mass and semimajor axis can be improved by a factor of a few when the BBH takes a non-circular orbit, but improvement is not universally guaranteed. Furthermore, the eccentricity and argument of periapsis are very well measured.

Recovering Higher Order Modes in the Ringdown of Binary Black Hole Coalescences
Rachel Mechum
Mentors: Alan Weinstein and Richard Udall

Disturbances in the curvature of spacetime from the coalescence of binary black holes can be probed by the gravitational waves of radiation emitted by these sources and recorded by Advanced LIGO and Virgo. The merger of such objects allows us to test Einstein's theory of general relativity in the regime of strong and highly dynamical gravity - specifically, the newly formed black hole rings down in a series of quasinormal modes, whose frequencies and damping rates are fully predicted by general relativity. We focus on the ringdown of the remnant black hole, implementing ringdown analysis in the time domain. We demonstrate the ability to fit and recover higher order modes of the ringdown within the simulated IMR signal. Possible deviations of the frequencies and damping times of the ringdown may point to new physics beyond general relativity, such as quantum gravity that we are not yet familiar with.

Incorporating a Stepping-Stone Sampling Algorithm Into BayesWave
Seth Moriarty
Mentors: Katerina Chatziioannou and Sophie Hourihane

BayesWave is a library of code used to analyze data from LIGO's gravitational wave detections. BayesWave uses Bayesian statistics to reconstruct signals and determine possible sources. The likelihoods of various models can be compared, such that BayesWave can determine the most likely sizes, locations, and types of sources that could produce a certain detected signal. Currently, BayesWave uses Thermodynamic Integration (TI) to calculate the likelihoods of various models. An alternative method is called Stepping-Stone (SS) sampling. In other fields, SS has been shown to be as accurate as TI while also being less computationally expensive. This project explores the comparison between TI and SS methods when each is applied inside BayesWave, to determine if SS is a viable replacement for TI to be used for analysis of LIGO's fourth detection run in 2023.

Emissivity Engineering for Radiative Cryocooling
Clare Nelle
Mentors: Rana Adhikari, Radhika Bhatt, and Christopher Wipf

The Laser Interferometer Gravitational Wave Observatory (LIGO) will undergo the cryogenic Voyager upgrade to increase detector sensitivity, allowing gravitational wave astronomers to learn more information about astronomical events in the field of multimessenger astrophysics. This upgrade will require efficient cooling of the test mass, in part through high thermal emissivity coatings applied to the barrel surface. Testing the emissivity of various coatings is expensive and time consuming, so it is important to find an optimal experimental design and cryogenic test chamber geometry. We used Markov Chain Monte Carlo (MCMC) analysis to observe how errors within the system propagate and to fit the value of the test mass emissivity to noisy data from the system cooldown. This analysis will be applied to emissivity tests of various high thermal emissivity coatings that potentially can be used in the LIGO Voyager upgrade.

Detecting Non-Power Law Stochastic Gravitational Wave Background
Jandrie Rodriguez
Mentors: Patrick Meyers and Arianna Renzini

The Stochastic Gravitational Wave Background (SGWB) is a consistent signal composed of a combination of many unknown sources. Since the SGWB is continuous, there is information on a much larger scale with the hope of included remnants of the early universe in the background. Current models work well to describe SGWB with current detector sensitivity where SGBW can be described by a simple power-law. However, common theories predict a turnover that will be detected with future detectors' sensitivity; this will lead to inconsistencies if current models are used. Since there is so much we do not know yet of the unknown sources it is pivotal to design a general and generic model to detect a SGWB that does not characterize as a simple power law. We use a new method of the Bayes factor along with \code{westley}, to do generic fitting when describing non-power law models, to detect SGWB. We will use splines and Gaussian processes to define this generic model and test with simulated data.

Characterization and Control of the Auxiliary Laser PZT
Deeksha Sabhari
Mentors: Rana Adhikari, Anchal Gupta, and Francisco Salces Carcoba

Frequency doubled auxiliary (AUX) lasers in the 40m prototype are used as out-of-loop arm cavity length sensors to help bring the interferometer robustly into resonance with the main laser. To do this, each AUX laser is locked to an arm cavity using the Pound-Drever-Hall (PDH) scheme. To achieve the necessary phase modulation for length sensing using PDH, a piezo electric transducer (PZT) mechanical resonance is exploited. While in this case the single PZT mechanical resonance turns out to be useful, they are generally detrimental to active stabilization of the laser frequency, lowering the gain and with it, the control bandwidth. The aim of this project is to accurately measure the open-loop transfer function of the AUX controller, as well as the PZT actuation transfer function for which a simple analytical model might help predict the shape of PZT mechanical resonances. Having identified several spurious PZT resonances, the inverse actuation transfer function can be found and applied to the system using a digital filter, effectively improving the gain of the system. Our work adds a digital aspect to the AUX laser control system that were previously entirely analog.

GW Strain Calibration of LIGO Detectors With High Precision and Low Latency
Naomi Shechter
Mentors: Ethan Payne and Alan Weinstein

The detection of gravitational waves (GW) has opened a new era of astrophysical observation, allowing scientists to view and analyze previously unseen phenomena. This process hinges upon measuring the strain ΔL/L of space over 4 km long baselines, which change by a differential arm (DARM) length on the order of 10^{-20} meters when a GW passes. From this information-rich time series, a wealth of astrophysical information may be deduced. In order to produce a reliable estimate of the strain, the Laser Interferometer Gravitational Wave Observatory (LIGO) detectors must be precisely calibrated. Furthermore, the calibration pipeline must produce an associated calibration uncertainty estimate with which to characterize the strain. While uncertainty estimates can currently be produced with low latency, it takes months to investigate the sources of error and verify the quality of calibration. Producing a high precision, low latency uncertainty estimate and a diagnostic monitoring software is therefore crucial for LIGO's fourth observing run (O4). It is this task that forms the basis of this research project. The uncertainty estimation and monitoring software are to be produced using pyDARM, a python package which implements the DARM control loop model and is currently under development. The software must reliably output uncertainty estimates and a suite of diagnostic plots on the timescale of an hour. It will actively be of use in O4.

Testing Universal Relations Under Non-Parametric Equation-of-State Models
Bubakar Oscar Sy-Garcia
Mentors: Isaac Legred and Katerina Chatziioannou

The equation-of-state (EoS) for the nuclear interactions between particles at very high densities remain a mystery to us. At the moment, our only avenue for exploring the characteristics of matter at these densities is through neutron stars, objects that are extensively studied by LIGO. We aim to test the validity of "Universal Relations", that is, relationships between properties of neutron stars that might hold regardless of the nuclear EoS. We are especially interested in these relationships, as they would be able to tell us more about the nuclear EoS and would further the strength of data gathered by LIGO. To do this, we aim to analyze these relations under many different algorithmically generated EoS models and inspect the variance observed. This is done by generating predictions based on these models through which we are able to evaluate their goodness of fit based on the uncertainty of the models from the prediction.

Exploring LIGO Sensitivity Across Binary Black Hole Parameter Space
Daniela Hikari Yano
Mentors: Alan Weinstein, Richard Udall, and Jacob Golomb

As we look ahead to LIGO, Virgo and KAGRA (LVK)'s next observational run (O4) and future gravitational wave observatories such as Cosmic Explorer, understanding the sensitivity of the detectors network for compact binary coalescences (CBCs) is important to estimating the merger rate density. The parameter space of CBCs is composed of fifteen parameters, which are used to characterize the binary systems. In this work, we explore how the network sensitivity (space-time sensitive hypervolume) changes according to changes in the CBC population parameter space. Using Monte Carlo simulations, we solve the averaged space-time sensitive hypervolume for different parameter configurations, marginalizing over subsets of the parameter space so that we can compare them.

Testing Mass Distribution Estimation of Binary Black Hole Mergers
Jingyi Zhang
Mentors: Alan Weinstein and Jacob Golomb

With ~70 binary black hole merger (BBHs) events detected by the Advanced LIGO and Advanced Virgo Scientific Collaboration, it is possible to infer the overall character of the black hole population in the universe. Specifically, the mass distribution of BBHs provides us with valuable information on stellar evolution and binary formation channel. We here aim to test the current estimation of BBHs population mass distribution based on the third Gravitational-wave Transient Catalog (GWTC-3). The project involves: (1) Examine agreement between the observed data and the fitted mode by conducting goodness-of-fit tests; (2) identifying outliers and examining the impact of non-conventional events with leave-one tests on population parameter estimation; (3) adjusting model to better characterize astrophysical phenomena and describe observed result; (4) compare different theoretical models that may describe the BBHs distribution by fitting observed data to multiple models.

Archiving and Labeling Data for NASA's Planetary Data System
Nisha Balaji
Mentors: Glenn Orton and Tom Momary, Jet Propulsion Laboratory/California Institute of Technology

Over the past 20 years, Dr. Glenn Orton and his team have captured mid-infrared images of Jupiter in order to study the planet's atmosphere and weather patterns. These images provide a vast array of data, including concentration of gasses, distributions of clouds, and ranges of temperatures. As a result of a contractual obligation to NASA, the images must be archived and labeled prior to submission to NASA's Planetary Data System (PDS). Archiving these images will be valuable to advance research of the Jovian atmosphere by allowing the scientific community more streamlined access to high-quality, standardized data from the Juno mission. These thermal images have been organized into various collections in accordance to the instrument used to acquire them and the type of image format. As a part of the archival process, we are completing the labeling of current data and the integration of more recent images into the current dataset.

High Altitude Balloon Flight Termination System for Use in Autonomous Launching System
Geoffrey Basinger, University of Illinois, Urbana-Champaign
Mentor: Virgil Adumitroaie – Jet Propulsion Laboratory/California Institute of Technology

HAB's (High Altitude Balloons) provide a cost effective and relatively simple method of sending scientific payloads into high atmosphere. Following the ideal of maximizing the scientific observation period for balloons, the ultimate goal of this research group is to create an auto-launching system that can autonomously launch and recover balloons along with payloads, without the need for human intervention. A reliable means of terminating balloon flight is paramount in ensuring that the balloon does not glide over restricted airspace or otherwise land in an unrecoverable location. In light of this goal, the team has developed a self-sufficient module, capable of integrating with any HAB system, that detaches payload from balloon for subsequent recovery. This system, dubbed the "Flight Termination Module," houses its own power source, temperature regulation system, microcontroller, and circuitry which allows it to reliably perform in the harsh conditions of the upper atmosphere. This module can terminate flight given any set of conditions provided by its onboard sensors, or wirelessly interface with the main flight computer to be manually activated over radio or satellite communications.

Studying Planet Formation Using Millimeter Observations of a Protoplanetary Disk
Emily Baylock – California Institute of Technology
Mentors: Marion Villenave and Karl Stapelfeldt - Jet Propulsion Laboratory/California Institute of Technology

Protoplanetary disks are a stage in the formation of young stars during which we believe planets also form. Through past research of low inclination disks, we have a good understanding of the structures inside these disks which suggest the presence of planets forming; however, we still do not understand how the dust in the disk grows sufficiently rapidly to form planets, nor the efficiency of the process of forming planets. We study one highly inclined disk, DoAr25, to provide insight into its vertical structure which can help us understand the mechanisms and distribution of dust within the disk. Using a radiative transfer model informed by the surface density profile of the disk along the major axis, we aim to simulate DoAr25, and iteratively improve our simulation by adjusting our surface density profile by the error in the previous model. After producing a precise model along the major axis of the disk, we compare the brightness along the minor axis of the disk with our simulation at various scale heights. We find that for millimeter sized dust around 100au from the central star, our model matches the observations with a scale height up to 2au. By putting an upper limit on the scale height of DoAr25, we aid our understanding of the mechanisms acting inside this disk and the vertical concentration of grains in the midplane.

Computer Vision Techniques for Fixing Missing Data in TRN Reference Maps for Future Lunar Missions
Sravani Boggaram, California Institute of Technology
Mentors: Yang Cheng and Kamak Ebadi, Jet Propulsion Laboratory/California Institute of Technology

Terrain Relative Navigation (TRN) is required for successfully landing a spacecraft near the Lunar South Pole in future missions. TRN requires an accurate map for properly tracking position with respect to the ground. The map data from the Japanese Kaguya satellite has a 7 meter/pixel resolution and has no faults near potential landing sites and is an optimal map choice for TRN; however, it has missing data holes in several other locations. This project focused on fixing these holes by replacing the missing data points with valid data points from another map, data from the Chinese Chang'E spacecraft with a resolution of 20 meters/pixel. The Digital Elevation Models of both datasets were analyzed using geospatial software and Python libraries. The holes were filled using various computer vision techniques including connected component labeling, homography transformations, and image blending. Since existing TRN algorithms tend to fixate on these missing data holes, creating a smooth and functional map is necessary for successful TRN in Lunar missions.

Investigation of Auroral-Related Phenomenon at Jupiter's Poles
Catherine Deng, California Institute of Technology
Mentors: James Sinclair and Glenn Orton, Jet Propulsion Laboratory/California Institute of Technology

Jupiter has the strongest planetary magnetic field in the solar system and a magnetosphere modulated by volcanic output from its moon, Io, which results in extreme examples of space weather. We aim to determine the extent to which the observed variability in Jupiter's heating and chemistry is driven by solar forcing or Jupiter's magnetosphere by quantifying the timescales and magnitude over which temperatures and hydrocarbon abundances (C_2H_2, C_2H_4 and C_2H_6) vary at Jupiter's high latitudes. High resolution TEXES (Texas Echelon Cross Echelle Spectrograph) spectra were recorded on NASA's IRTF (Infrared Telescope Facility) between 2014 and the present day. We use the Non-linear Optimal Estimator for Multivariate Spectral Analysis (NEMESIS) model on those spectra to derive vertical profiles of temperature and hydrocarbon abundances as a function of latitude, longitude, altitude, and time. In addition, images of Jupiter's mid-infrared CH_4 emissions were recorded by MIRSI (Mid-Infrared Spectrometer and Imager) on NASA's IRTF in June 2022. We reduce and calibrate these images to determine the magnitude and morphology of Jupiter's lower stratospheric temperatures. We intend to use TEXES-derived temperature distributions to simulate MIRSI images of Jupiter thereby combining both datasets to improve the temporal sampling."

Monitoring of Satellites and Near-Earth Objects (NEO) Through Synthetic Tracking
Philippe des Boscs
Mentor: Russell Trahan, Jet Propulsion Laboratory / California Institute of Technology

Synthetic Tracking technology aims to enhance the ability to detect faint and fast objects close to the Earth from video sequences taken by cameras looking through telescopes. There are two primary missions for this project. The goal for NASA is to discover Near Earth Asteroids (NEA) that may be of potential danger to the Earth. For the United States Space Force (USSF) the goal is to track known manmade satellites and discover small debris orbiting the Earth which may be a hazard to other spacecrafts. In this project, I have developed a web interface and a central database. The central database gathers information recorded by telescopes across the world every night while the web interface enables easy access to the data and the analysis of various trends through graphs. The central database contains thousands of entries on various matters that can be easily accessed, filtered, sorted, graphed, or even displayed in the case of images. Additionally, the web interface also gives access to historical data markers from past nights as well as images of the respective mount setups of the cameras and telescopes. The web interface will also be used to detect anomalies in the performance of the system and act as the main access point of the data it gathers. Finally, it will report the data submitted by the system to NASA's Micro Planet Center (MPC).

Atmospheric Retrieval Strategies for the JWST Observations of Temperate Exoplanets
Audrey DeVault, Jet Propulsion Laboratory, California Institute of Technology
Mentor: Renyu Hu, Jet Propulsion Laboratory, California Institute of Technology

The James Webb Space Telescope (JWST) is an infrared-optimized space observatory with powerful spectroscopic abilities. It provides a novel source of data to investigate the physical and chemical properties of exoplanets. Temperate sub-Neptunes are a promising class of exoplanets with respect to habitability as some may possess liquid water oceans, depending on their atmospheric properties. A new method of identifying possible liquid water oceans on temperate sub-Neptunes was recently developed by Dr. Renyu Hu et. al. It takes advantage of the mutual exclusivity of the condition to form a liquid water ocean and the condition to achieve thermochemical equilibrium. Using a Bayesian algorithm atmospheric parameters can be retrieved from exoplanetary transmission spectra. These parameters can then be examined for evidence of solution equilibrium, and by extension, liquid water. This method is now being applied to JWST observations. To better understand how sensitive the analysis method is to various atmospheric parameters when using JWST data, we generate simulated JWST spectra with varied parameters and signal-to-noise ratios. We then perform the analysis and compare the retrieved parameters to those used in generating the simulated spectra. In this way, the accuracy of the analysis method on JWST data is probed.

Mid-Infrared Studies of Jupiter: (a) Examining Correlations Between the Morphology of Jupiter's Polar Regions at Various Wavelengths, and (b) Creation of a Reduction Pipeline for MIRSI
James Downs, California Institute of Technology
Mentor: Glenn Orton, Jet Propulsion Laboratory/California Institute of Technology

In support of the Juno mission, we examine potential correlations between the morphology of atmospheric phenomena in Jupiter's polar regions at .889, 2.26, 5.10, 7.80, and 17.65 microns. Data were gathered from the NASA Infrared Telescope Facility's SpeX, Gemini North's Near Infrared Imager (NIRI), and the Juno mission's JunoCam. After performing geometric calibration and merging images to gain full longitudinal coverage, we produced individual and composite polar projections to facilitate visual analysis and comparison between wavelengths. Additionally, we quantitively identified discrete points that constitute a mostly continuous boundary for each pole. Plotting these points independently and overlaid with various wavelengths provides insight into potential correlations including that the near infrared boundary is more circular in the South than the North, at 5.10 µm the boundary is farther away from the pole in the North, and the undulations present in JunoCam images are not visible in 2.26-µm SpeX data.

Additionally, we created a routine to reduce data from the recently refurbished Mid-InfraRed Spectrometer and Imager (MIRSI). This program removes the strong vertical stripes present in raw MIRSI images and is integrated into the Data Reduction Manager - which was made using the Interactive Data Language – for efficient future usage.

A Sensorweb for High-Resolution Flood Monitoring on a Global Scale
Akseli Kangaslahti, University of Michigan - Ann Arbor
Mentors: Steve Chien and Jason Swope, Jet Propulsion Laboratory/California Institute of Technology

Flooding is a recurring problem that poses an expensive and potentially deadly threat to humanity. Thus, an extremely important application of satellite imagery is flood monitoring, which aids in understanding the size, impact, and causes of floods. Due to the sparsity of flooding on earth's surface and the scarcity of pointable, high-resolution assets, previous studies have only used satellite imagery to track floods with either regional scale or low resolution. However, we describe a "sensorweb", or a network of instruments that use information from other sensors in the network to determine their own behavior, to monitor flooding at high resolution on a global scale. To do so, we identify flood events using worldwide low-resolution satellite data then trigger follow-up observations from targetable high-resolution instruments. With this fully automated system, we deliver high-resolution surface water extent products and statistics from flood events around the world. This supplies end users with convenient and precise information and provides a template that can be used for future work in other environmental monitoring with remote sensing.

Vertical Distribution of Pop-up Clouds in Jupiter's Atmosphere From JunoCam Images
Caleb Keaveney, North Carolina State University
Mentors: Glenn Orton and Tom Momary, Jet Propulsion Laboratory

Pop-up clouds are small cumulus-like clouds formed by convection with visible elevation relative to surrounding cloud features in Jupiter's atmosphere. Observed primarily in JunoCam images as bright white puffy or linear clouds, they are common throughout the atmosphere, particularly in mid-to-high latitude folded-filamentary regions. Given their discrete size, appearance, and apparent vertical elevation, pop-up clouds present an excellent opportunity to measure small-scale vertical distribution of high-altitude clouds that past observations and models have failed to resolve. Here, we measure the vertical height of pop-up features based on the shadows they cast on underlying cloud features, as observed with JunoCam. To do so, we use the Integrated Software for Imagers and Spectrometers (ISIS) to measure the length of observed shadows antiparallel to the solar azimuth. These measurements together with incidence and emission angles, the position of the spacecraft, and the orientation of the cloud, are used to estimate the height of the cloud top relative to the underlying cloud deck. Preliminary results suggest heights of less than one Jovian scale height, comparable to clouds in Earth's troposphere, which seldom exceed one scale height above sea level.

Development of a Testbed for Multipath Channel Sounding Experimentation
Garrett Knuf, Jet Propulsion Laboratory, California Institute of Technology
Mentors: Marc Sanchez Net and Kar-Ming Cheung, Jet Propulsion Laboratory, California Institute of Technology

Multipath fading is a phenomenon that occurs when signals reach a receiver via different paths, altering their relative strengths and causing phase shifts. Landed spacecraft on the Moon's South Pole are likely to experience multipath fading effects as a result of Earth subtending low elevation angles in the lunar sky. Characterizing the severity of multipath fading and its impact on link performance is critical to ensuring reliable communications between astronauts and mission operations. Since there is currently no landed spacecraft landed on the lunar South Pole, direct measurements from a real-life operational system cannot be obtained. This project aims to develop a testbed with software-defined radios (SDRs) that can simulate the multipath fading conditions experienced at the lunar south pole. By designing a payload that integrates an embedded SDR with an unmanned aerial vehicle (UAV), the relative positioning and velocity between the payload and a stationary receiver on the ground can be controlled. Furthermore, by appropriately selecting the flight trajectory of the UAV while transmitting data, the desired effects of multipath fading can be achieved.

Reduction and Analysis of Near-Infrared Images of Saturn: Examining Seasonal and Non-Seasonal Variability of Deep Clouds
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Mentors: Glenn Orton and Tom Momary, Jet Propulsion Laboratory

Saturn's atmosphere is composed of chemically distinct layers that influence the planet's thermal radiation. Both seasonal and non-seasonal atmospheric disturbances provide an opportunity for studying the properties of these layers. Ground-based observations of Saturn, which depict thermal emissions from the planet, provide insight into

the deep cloud structure of the atmosphere and these disturbances. Whereas 5.1-micron images primarily showcase thermal radiation, images taken in 1.58 microns entirely show reflected sunlight. However, the raw images give inaccurate and unusable data of the thermal radiance of Saturn. To determine the true thermal radiance, we first reduce and calibrate raw images using the Data Reduction Manager (DRM) code. Next, we use a solar radiative-transfer model to account for the effect of reflected sunlight in the 5.1-micron images using the 1.58-micron images. In doing so, we establish a viable and successful method of compensating for the effect of sunlight when measuring the radiance of planets. Moreover, our results yield new and usable information on the behavior of clouds at and below the 1-bar level of Saturn's atmosphere. This information differentiates atmospheric changes due to seasonal variability and the planet's non-seasonal climate changes.

Characterization of Thin-Film NbTiN Devices: KI-TWPA and SOFTS

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Two thin-film superconducting devices that exploit the nonlinear kinetic inductance of NbTiN are a Kinetic Inductance Traveling Wave Parametric Amplifier (KI- TWPA) and a Superconducting On-Chip Fourier Transform Spectrometer (SOFTS). These devices enable much more precise measurements in millimeter-wave astronomy and observational cosmology. The KI- TWPA is an on-chip broadband parametric amplifier that can achieve quantum-limited sensitivity over wide fractional bandwidths, while being able to amplify signals to the level needed for sensitive astronomical measurements.[1,2] There already exist current commercial amplifiers which are able to amplify signals with sufficient gain for these purposes, but not without adding unwanted noise to the amplified signal. KI- TWPA's have the ability, unlike other amplifiers, to contribute no unwanted noise to the amplified signal, besides that due to quantum fluctuations (making it "quantum-limited").[3] SOFTS is an on-chip broadband spectrometer that can achieve significantly more efficient measurements for various cosmological surveys than current standard spectrometers.[4] It is much more efficient because it achieves interferometry on a mm-scale wafer, as opposed to the conventional meter-scale opto-mechanical device. The construction of kilo-pixel focal planes of the SOFTS device would enable hyperspectral imaging of signals in the microwave band, including signals from the cosmic microwave background, emission from high redshift galaxies, and spectral absorption from interstellar dust. As a student in the SURF-JPL program, my work has involved the characterization of these devices, using measurements taken of the devices informed by theoretical simulations.

New Computational Tools for Visualizing 3-Body Invariant Manifolds

Thomas MacLean - Caltech
Mentors: Martin Lo and Alan Barr - Jet Propulsion Laboratory, California Institute of Technology

New Computational Tools for Visualizing 3-Body Invariant Manifolds Visualization of 3-body invariant manifolds for periodic orbits with Poincare maps and smooth surfaces is useful for representing and designing future mission trajectories. Sparseness of manifold trajectories, computational boundaries, and dimensional problems cause an inability to plot manifolds as surfaces. We present new computational tools to represent the invariant manifolds, which lie in 6-dimensional phase space, as visualizable surfaces. A new smooth, continuous interpolating function in Mathematica efficiently and accurately represents the manifolds, as tested in specific coordinate systems optimizing applications from the visualizations. We also present a solution for efficient densification of sparse manifold trajectories using a curvature method and Poincare map sections to detect trajectory separation in Matlab. Visualization applications are explored.

Acknowledgement:
This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and was sponsored by (name student program) and the National Aeronautics and Space Administration (80NM0018D0004).

Qualification of Adhesive Mixtures and Surface Preparations

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The goal of this project is to pursue safer and less time consuming methods of surface preparation and adhesive mixing to better existing processes. Using ASTM standards D1002 for testing bond strength and E595 for testing outgassing of mixed adhesives results show that using gritblasting and an automatic mixer are viable options for improving the current process for surface preparation and adhesive mixing. The samples prepared using gritblasting save a great deal of time and perform just as well if not better than ones that are hand abraded. As well as samples mixed with the automatic mixer also do better than hand mixed samples when it comes to outgassing. Based on current results with some refinement and more testing data, gritblasting as a method of surface preparation and speed mixing adhesives could be implemented in the future.

If these new tested methods improve outgassing and bonding performance or even save time that could lead to improved optimal performances of spacecraft in the future.

Investigating Markov Chain Monte Carlo Simulations for Cosmological Parameter Fitting

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In order to extract the large-scale cosmological information from upcoming galaxy redshift surveys such as SPHEREx, I utilize Markov Chain Monte Carlo (MCMC) samplers to connect a theory power spectrum model to the measured power spectrum. Constraining cosmological parameters from galaxy redshift surveys allows us to gain a better understanding of the origin of the universe, the evolution of dark energy, and discover new physics. I implement MCMC samplers that utilize the likelihood function to constrain cosmological parameters by numerically approximating the posterior distribution of these parameters and efficiently handling a high dimensional parameter space. We trace the posterior distribution in our parameters with a sequence of samples in our parameter space called the Markov Chain. We utilize an MCMC sampler because we want to understand the shape of our likelihood function and its maximum likelihood. An MCMC sampler assists in finding these cosmological constraints from the properties of our likelihood function. We also conduct numerous evaluation metrics to test the performance of our MCMC samplers with our model. We investigate MCMC samplers such as Metropolis-Hastings, Ensemble Slice Sampling (ESS), and Preconditioned Monte Carlo. We find that ESS can efficiently handle a high dimensional parameter space compared to the Metropolis-Hastings sampler.

Sub-grid Scale Drivers of Pollution Inferred From Model-based Inference and Machine Learning

Eshani Patel, California Institute of Technology
Mentor: Yuliya Marchetti, Jet Propulsion Laboratory

The use of spatial and temporal environmental data from international stations for a machine learning (ML) model is used for the prediction of tropospheric ozone, so that physical scientists can understand the drivers of pollution. The accuracy of the model is determined by studying the error and correlation between the model's output and the measured ozone levels. The feature and permutation importance, extracted from the Random Forest ML model, gives insight on several drivers, such as altitude and population density, and their impacts on the prediction of ozone levels. Additionally, the use of bias data in the ML model gives insight into major bias predictors, and the use of Google Earth Engine images for feature engineering provides greater coverage and the addition of features impacting the prediction of ozone.

Calibration, Validation, and Machine Learning for the Recent NASA/JPL EMIT Mission Using a Network of Ground-based Robotic Measurements of Aerosols and Radiances

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Mentor: David Thompson (Jet Propulsion Laboratory/California Institute of Technology)

In July, 2022, JPL and NASA launched an instrument to the International Space Station. The EMIT mission's purpose is to determine the effect mineral atmospheric dust clouds have on a region's climate. EMIT tracks ground mineralogy and uses Aerosol Optical Depth (AOD - distribution of aerosols) models to determine dust cloud composition. The first task was to determine these models' accuracy by comparing predicted and actual AOD. If accuracy is known, we can better predict dust composition. Time-efficient code was written to process AERONET sites' data (actual AOD measurements), interpolate AOD for the desired wavelength, and return AOD information and sites in the same location, time, and date as an EMIT image. A program to compare actual and predicted AOD information is being developed. Moreover, because clouds in EMIT images distort data, the second task was to utilize machine learning to develop a program that identifies and removes clouds. Pixels in 10-12 images were annotated and classified. Code was written to process each pixel in annotated images, separate annotated pixels from the rest, calculate reflectance values at each pixel, train a model, test it, classify/map test data, and determine accuracy. The accuracy is currently 96%, which will be further improved!

Developing a GALEX Pipeline to Search for Evidence of Star-planet Interactions

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Scientists have theorized that planets can affect the chromospheric activity of their host star through star-planet interactions (SPI). These can be caused by the planet's magnetic field, gravitational effects, or the infall of material from the planet. This produces disruptions in the star's surface that increase the star's chromospheric activity. This increase could be observed through photometry or spectroscopy. We focus on GALEX photometry in the near and far ultraviolet. To facilitate this, we have developed a pipeline that takes a list of stars with exoplanets, and then compares their GALEX photometry with a similar control sample of stars without exoplanets retrieved from Hipparcos. The pipeline ensures that the two samples share similar distance and luminosity characteristics, and also consist of the same spectral types. The pipeline will retrieve GALEX photometry for all stars in each sample and summarize the relevant parameters. The user can then analyze the two datasets to look for evidence of SPI. We anticipate that this pipeline can be further developed to assist scientists in the search for an observational basis for the existence of SPI.

Machine Learning Applications for Exoplanet Categorization
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Mentors: Renyu Hu, Jet Propulsion Laboratory/California Institute of Technology, and Mario Damiano, Jet Propulsion Laboratory/California Institute of Technology

Currently, over 5,000 exoplanets have been confirmed and more are being discovered each year. This large number of exoplanets cover a wide variety of parameter space, in terms of radius, mass, period and so forth. With this diversity in planet parameters, we aim to find if there are intrinsically different categories of planets and explore any distributions as well as correlations within the planetary population. Here we designed a new approach to seek underlying planet populations using unsupervised machine learning. We found that certain planet types are naturally categorized. Additionally, we used various machine learning algorithms on these populations to identify and compare the importance of planetary parameters when classifying planets. From this work, we believe that we are in a prime position to carry out population studies with unsupervised machine learning and suggest that these methods be applied in future missions.

Mapping Dark Matter Using Weak Gravitational Lensing and SuperBIT
Sunanda (Mila) Thirunavukkarasu
Mentors: Spencer Everett and Eric Huff, Jet Propulsion Laboratory, California Institute of Technology

Galaxy clusters are one of the primary tools for constraining dark matter when combined with the distortion of light from distant galaxies as it travels through a cluster's gravitational potential. Constraining cosmology by measuring cluster abundance proves to be extremely challenging as cluster masses are not directly observable but can be estimated by how clusters gravitationally lens these background galaxies - though these observations are extremely expensive. The advent of long-duration balloon borne flights hopes to alleviate this problem by offering a new platform for cheap, space-like imaging. SuperBIT is a wide-field, 0.5m imaging telescope that will provide deep, diffraction-limited imaging from the near-ultraviolet to the near-infrared at ~1% the cost of an orbiting platform. Although the existing SuperBIT image pipeline measures cluster masses with minimal bias on simulated images, we currently assume that the cluster mass follows a simple form of a symmetric/spherical matter density profile. In this work, I replace these approximations with realistic dark matter halo profiles from the high-resolution, hydrodynamical BAHAMAS simulations to test whether our measurement methodology remains unbiased for realistic scenarios.

Juno Radio Occultation Ray-Tracing Analysis and Two-Way Radio Link Configuration for Upcoming Extended Mission
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Mentors: Dustin Buccino and Marzia Parisi (Jet Propulsion Laboratory, California Institute of Technology)

Juno's upcoming extended mission at Jupiter is expected to see many occultation geometries warranting an analysis on how such measurements should be executed and what to expect. Occultations occur when the signal is bent as it passes through a planetary atmosphere resulting in an observable Doppler shift. Ray-tracing limb-tracking software was used to analyze these occultations using a one-way method in which the initial direction and refractivity of the radio rays are iteratively determined through Newton-Raphson root finders. From these results, the expected ray bending, trajectory, and ray-altitude were computed. The grazing nature of perijoves 53 & 54 were observed, with ray paths never traveling below 50 km altitude above the 1 bar level and experiencing only slight bending. Later perijoves were seen to exhibit much stronger ray bending with rays traveling to pressure levels much lower than 1 bar. Additionally, Juno uses a two-way radio link with the Deep Space Network since it is not equipped with an Ultra-Stable-Oscillator. As such, the ray-tracing results were then adapted for two-way radio link occultation measurements by calculating the necessary uplink frequency profiles needed to transmit to the spacecraft. These results can be used to ensure proper execution and analysis of Juno's occultations.

Low-Cost Flight Test Platforms - Augmented Tractability of High Altitude Balloons
Benjamin Zeng (Jet Propulsion Laboratory/California Institute of Technology)
Mentors: Thomas Lu (Jet Propulsion Laboratory/California Institute of Technology) and Adrian Stoica (Jet Propulsion Laboratory/California Institute of Technology)

High Altitude Balloons (HABs) have long been used to perform atmospheric measurements and Earth observations. In recent years, their role has also been expanded to rapidly prototype and test scientific experiments in near-space conditions. The largest obstacles that HABs continue to face are their high dependence on optimal weather conditions and construction limitations. Our team has investigated the feasibility of implementing weather-agnostic control systems and minimized barriers to entry through the research and development of cohesive systems built using solely off-the-shelf consumer parts. This includes a next-generation balloon launcher which reduces the required personnel for a balloon launch by more than 75% and decreases launch time by more than 50%. We aim to decrease the cost of virtually geo-stationary short-term Earth observation and low-weight near-space science experiments by more than 1000x with our system. This would expand HAB applications significantly, including additional functionalities such as natural disaster monitoring.