SURF
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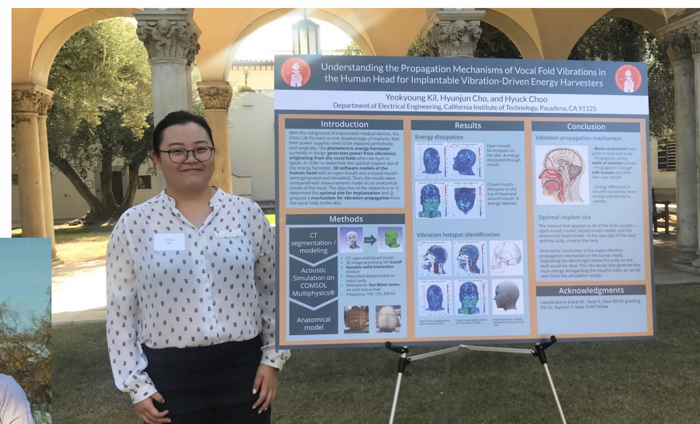

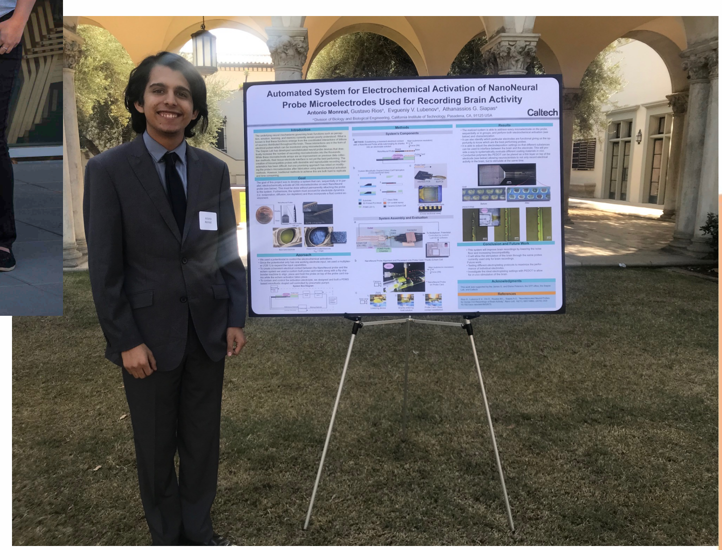

Student-Faculty Programs
2019 Student Abstract Book

STUDENT-FACULTY PROGRAMS

2019 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 2019.

Table of Contents

SURF

Summer Undergraduate Research Fellowships

S
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R
F

Functionalization of Shape Memory Polymers With Gold Nanoparticles
Sébastien Abadi
Mentors: Julia Greer and Luizetta Navrazhnykh

Shape changing materials are important for some biomedical devices, like neuronal probes, as a compact device can be inserted and then expanded when properly positioned, thereby reducing damage to tissue. Thermal shape memory polymers (tSMPs) can be programmed so that a temperature increase above its glass transition triggers such a shape change to occur. The objective of this study was the remote activation of this transition on a microscale tSMP. To do so, the tSMP was functionalized with gold nanoparticles (AuNPs), which have high absorbance at 532 nm due to localized surface plasmon resonance. A laser of this wavelength could therefore heat the attached tSMP, remotely triggering recovery. The tSMP in question is a benzyl-methacrylate based polymer that has been used to fabricate microscale shape memory structures, and contains BOC-protected amine groups. These amines were deprotected and then thiolated using S-acetylmercaptosuccinic anhydride, as thiols will bind AuNPs. These AuNPs can then be detected with solid-state UV-vis spectroscopy to confirm attachment. Moving forward, a focused 532nm laser beam could be used to activate individual microscale structures and perhaps control the sequence of SMP recovery.

Design and Creation of a Multirotor Testbed for Use With Autonomous Swarms
Kasey Adams
Mentors: Soon-Jo Chung and Kyunam Kim

In the emerging field of swarm robotics, algorithms for motion planning, collision avoidance, and goal-oriented task assignment are being developed to create distributed, robust systems. To test these algorithms, a robust and durable testbed is imperative. A quadcopter pair was developed to complement the previous generation as a dynamic test bed. The system supports various payload masses and was designed for longevity. The new generation drastically improved on the design of the previous generation, providing more modularity and greater ease of access/repair. In the new generation of agents, we replaced the previous NeuMotor 2025 Outrunner motors with the NeuMotor 4606 Outrunner motors. The new motors showed higher efficiency, lower current draw, and higher thrust at the given hover RPM. In addition to this, we increased the size of our LIPO battery from 4S to 6S. These two changes were the most significant changes that impacted the performance of the new generation, which showed longer flight times (10:11 when loaded with 1141g as opposed to ~10min when unloaded for the previous generation) and a higher max payload (1983g when stopped testing versus 1.4kg max payload for older generation).

Illusions in Extreme Peripheral Vision
Sara Adams
Mentors: Shinsuke Shimojo, Daw-An Wu, and Takashi Suegami

Despite a significantly lower density of photoreceptors in regions of the retina representing extreme peripheral vision, our peripheral vision appears clear. Thus, some of what we see in this region must be illusory; that is, the perception is not fully explained by direct retinal input. In particular, we found that motion perception is not uniform between the fovea and the periphery. Depending on the condition, a flickering peripheral stimulus may be perceived to be either faster or slower than an identical stimulus in the fovea. The direction of this perceptual change is significantly affected by the flicker frequency of the stimulus.

Chalcone Derivatives and Their Efficacy Against Castration Resistant Prostate Cancer
Arushi Agarwal
Mentors: Tanya Stoyanova, Meghan Rice, and David Van Valen

Prostate cancer is the most common non-cutaneous cancer in men in the United States. Although there are hormone-based treatments for prostate cancer, in many cases, the cancers develop an incurable resistance—leading to castration resistant prostate cancer (CRPC). The Malhotra Lab at the Department of Radiation Oncology at Stanford University developed a compound library of non-hormonal therapies based on natural product chalcones targeting other characteristics of cancer, such as glycolysis (Rice and Kumar et al. unpublished). In the Stoyanova lab, we applied nine of the chalcone compounds and tested their efficacy for the treatment of prostate cancer in vitro. To identify compounds with low toxicity and high efficacy, we first evaluated the half-inhibitory concentration (IC50) of each drug. The IC50 values ranged from 800nM to 20µM. Using the IC50 concentrations, we tested the effects of each drug on colony formation, cell proliferation, cell migration, and cell invasion of DU145, 22RV1, and C4-2 CRPC prostate cancer cell lines. Several compounds had strong antiproliferative abilities which we will translate to preclinical studies with pharmacokinetic analysis and toxicity analysis in vivo. This project identifies chalcone derivatives with potential as novel prostate cancer therapeutics.

Angular Calibration of the BICEP Array Receivers Using Far Field Beam Map Characterization
Shubh Agrawal
Mentors: Jamie Bock and Alessandro Schillaci

The BICEP Array is the latest generation of instruments of the BICEP Keck Collaboration for Cosmic Microwave Background polarimetric measurements. It comprises four 550 mm telescopes observing between 30 to 270 GHz, aiming to generate sensitive CMB polarization maps for the detection of B-mode polarization signal, which would be the first direct evidence of inflationary gravitational waves.
My project focused on designing, constructing, and implementing a movable configuration allowing for full optical far-field characterization of the receivers, using a chopped thermal hot source. A structure for orienting a flat aluminum honeycomb mirror panel, delineated using ray tracing applications of Zemax, was designed and tested for stability using SolidWorks and assembled after machining. The motion was made controllable and programmable by implementing code in C. A Python interface was created to generate beam maps by allowing step motions and data acquisition. Zemax was also used to analytically compare diffraction energies at receiver in the far-field or quasi-far-field.
Further work over summer and academic year would involve conducting far-field beam mapping for the current and future 30/40GHz receivers and result in generating fractional differential plots against two-dimensional Gaussian fits to characterize the optical performance of the BICEP Array.

Investigating the Functional Significance of O-GlcNAc Transferase Substrate/Interactor Networks
Rita Aksenfeld
Mentors: Linda Hsieh-Wilson and John Thompson

O-linked β-*N*-acetylglucosamine glycosylation (O-GlcNAcylation) is a dynamic, inducible post-translational modification (PTM) of thousands of intracellular proteins. There are only two enzymes responsible for O-GlcNAc cycling in higher eukaryotes, O-GlcNAc transferase (OGT) and O-GlcNAcase (OGA), which catalyze addition and removal, respectively. We hypothesized that constructing OGT substrate/interactor networks could serve as a useful foundation for understanding the functions of O-GlcNAcylation. Moreover, this approach might reveal novel insights into how OGT is able to coordinate the specific modification of thousands of proteins in response to individual stimuli. Here, we first sought to validate interactor-substrate relationships suggested by these networks. Specifically, we found that knockdown of OGT interacting proteins was sufficient to disrupt O-GlcNAcylation of non-interacting OGT substrates. This finding suggests that association between OGT and its interactors may allow OGT to engage different sets of substrates in different contexts. Finally, we investigate whether modulating global O-GlcNAcylation can affect peroxisome biogenesis and function, a potentially novel role for O-GlcNAcylation revealed by our network. Together, these studies demonstrate that our networking approach highlights functional connections between OGT interactors and substrates.

Identifying the Effects of Solar Heat on the Redness of KBOs
Alya Al-Kibbi
Mentor: Michael E. Brown

The Jupiter Trojan asteroids and distant KBOs exhibit bimodality in their g-i redness, with Trojan peak values being ~0.3 magnitudes less red than KBO counterparts. The standing hypothesis is that as KBOs approach the Sun and get warmer, heat mutes their redness. Our objective is to determine the heliocentric distance at which high eccentricity KBOs transition from typical KBO redness distributions to distributions resembling those of Trojan asteroids. We collected data from a sample of 28 KBOs with high eccentricities and a range of perihelion distances to link the Trojans and distant KBOs. Each object was imaged in the g' and i' filters of the WASP instrument on the Hale 200inch telescope. Magnitudes of objects in both filters were combined to calculate their g-i color, which allows for comparison with other solar system populations. Results show our sample KBOs exhibiting redness consistent with predictions: those with lower perihelia have g-i colors near the mean values for the red and less red populations of Trojans. We expect that extracting data from a larger object sample and simultaneous comparison with redness data for distant KBOs and Trojans will indicate the transitional heliocentric distance and potentially provide insight into these populations' dynamic evolutions.

Trapping Efficiency of Ioffe-Pritchard Coils for Tritium Beta Decay
Nezir Alic
Mentors: Joseph Formaggio and Ryan Patterson

Tritium Beta Decay allows for the indirect determination of neutrino mass through the collection of data regarding electron energies. To carry out such an experiment, it is first necessary to capture tritium atoms. In the case of Project 8, this is accomplished magnetically through the use of Ioffe-Pritchard coils. A particular design of Ioffe-Pritchard coils with specific shape, dimensions and current value is simulated in Kassiopeia, a particle tracking software. When the simulation is completed, it will be used to determine the trapping efficiency of the coils. The percentage of tritium atoms trapped, as well as the energy distribution of those trapped, will be analyzed. If time allows, loss mechanisms such as Majorana spin flips and atomic scattering, which could lead to the escape of the tritium atoms, will be studied as well.

Transient Radio Sources From the Variable and Slow Transients Survey
Bob Aloisi
Mentor: Tara Murphy

The Variable and Slow Transients survey is using the Australian Square Kilometer Array Pathfinder (ASKAP) radio telescope array to explore the transient radio sky. ASKAP is an array of 36 12-meter dishes, which covers 30 square degrees per field pointing. Observations were taken at 888 MHz frequency and at declinations < +40° for the Rapid ASKAP Continuum Survey (RACS). RACS observations were compared to prior surveys, including the Sydney University Molonglo Sky Survey and NRAO VLA Sky Survey. Available RACS images were searched for known source matches such as pulsars and radio stars. A search of 166 RACS fields matched 55 of the 100 brightest (S400) known pulsars in those fields, including all pulsars with S888 > 10 mJy and 33% of pulsars with S888 between 1 and 5 mJy. A search of 766 fields identified 103 matched radio sources, many of which evidenced flux changes compared to prior surveys. The latter results may include an estimated 1 to 4 random matches. Future work may include investigating matched cool (K or M) stars as well as identifying and classifying unmatched RACS sources.

Electronic Structures of Boronated Octahedral and Square Planar Cyanometalates
Alessio Amaolo
Mentors: Harry Gray and Brendon McNicholas

$[M^1(CN\text{-}B(C_6F_5)_3)_6]^{3-/4-}$ and $[M^2(CN\text{-}B(C_6F_5)_3)_4]^{2-}$ anions have been synthesized and characterized crystallographically for M^1 = Ru, Os and M^2 = Ni, Pt. The electronic structures of these boronated octahedral and square planar cyanometalates have been studied via IR/UV-vis/NIR spectroscopy and voltammetry. For boronated octahedral cyanometalates, the LMCT ($^2T_{2g} \rightarrow {}^2T_{1,2u}$) transitions have been measured and exhibit red-shifted absorptions compared to their non-boronated counterparts. For boronated hexacyanoosmate, the spin-orbit splitting of the $^2T_{2g}$ state appears as a NIR peak centered at 1708 nm. Axial distortion from octahedral symmetry splits the ground state (Γ_8) by 93 cm^{-1}. Surprisingly, both boronated and non-boronated cyanoosmate have identical spin-orbit splitting of the ground state. For square planar cyanometalates, energy shifts due to boronation on all observed bands ($^1A_{1g} \rightarrow {}^1E_g$, $^1A_{1g} \rightarrow {}^1A_{2g}$, $^1A_{1g} \rightarrow {}^1A_{2u}$, $^1A_{1g} \rightarrow {}^1E_u$) have been measured. Non-aqueous redox flow battery applications have also been explored.

First Principle Study of Electron Correlation in Rare Gas Crystals With Periodic Coupled Cluster Theory
Anushikha
Mentors: Austin Minnich and Gao Yang

Over the past few decades, Density Functional Theory(DFT) has mainly been the workhorse for the first principle study of condensed matter, but the approximating nature of the exchange correlation functional hinders systematic improvement in capturing the long range dispersion interaction, which could lead to large quantitative and even qualitative errors. On the other hand, the quantum chemistry community has achieved chemical accuracy in molecules with wave function approaches based on time independent perturbation theory. Among these correlated methods, coupled cluster theory provides a systematic framework towards the exact solution in a given basis set and is termed gold standard when perturbative triple excitation is added. With the development of super-computing technology, extension of coupled cluster theory to periodic systems has been recently realized. Here we propose to apply Coupled Cluster theory to study the ground state properties of rare gas crystals. It's a benchmarking study to validate the ability of Coupled Cluster theory in capturing long range van der waals interaction

Injection Rate Oscillations in a Radial Hele-Shaw Cell
Rahul Arun
Mentors: Beverley McKeon and Angeliki Laskari

Small spatial perturbations grow into fingers along the unstable interface of a fluid displacing a more viscous fluid in a porous medium or a Hele-Shaw cell. The mitigation of this Saffman-Taylor instability increases the efficiency of fluid displacement applications (e.g. oil recovery), whereas the amplification of perturbations is desirable for mixing applications. In this work, the Saffman-Taylor instability is experimentally investigated in a radial Hele-Shaw cell in which silicone oil is outwardly displaced by air injected with an oscillatory flow rate. The evolution of the interfacial morphology is tracked during expansion of the air bubble. The linear growth of perturbations about the mean interfacial radius is analyzed and compared for constant injection rates with and without superimposed oscillations. Low frequency oscillations are shown to suppress linear instability growth, whereas high frequency oscillations of large magnitude reliably destabilize the interface. The growth of perturbations of a given wavenumber varies across experiments since the excitation of different modes is governed by random perturbational noise. Stabilizing and destabilizing control schemes are optimized by targeting the dominant wavenumbers in the linear regime. Further characterization of the initial formation of perturbations subject to time-varying injection rates will improve the prediction of optimal control schemes.

Sensory Transduction of Radio Waves: Modeling Energy Conversion From Radio Waves to Ultrasound in Magnetite Crystals, and the Transduction of Ultrasound to Pressure-Sensitive Ion Channels
Yovan Badal
Mentors: Joseph L. Kirschvink and Isaac Hilburn

It has been observed that broadband radio frequency (Rf) electromagnetic noise prevents migratory birds from orienting with the geomagnetic field. Studies have since suggested that the biophysical mechanism of Rf detection could be explained by studying the magnetoacoustic effect, the transduction of Rf into ultrasonic pressure waves. This could occur in massively magnetic cells, followed by sensory transduction of ultrasound via a class of ultrasound-activated transmembrane ion channels. In previous work, we analyzed the effects of broadband Rf noise on magnetosome-like structures consisting of an array of magnetite crystals. The energetics are worked out in the small-field approximation to the Stoner-Wohlfarth model. This is compared to numerical solutions for the Landau-Lifshitz-Gilbert equation to confirm that the model captures relevant frequency-dependent dissipation terms. This should enable computation of the complex susceptibility spectrum of such arrays as a possible experimental test. Independently, the possibility of Rf transmission by biological systems is a longstanding interest of radiobiology programs but has never been observed. Assuming magnetite-based mechanisms, we explore requirements of Rf transmission in order to characterize such systems, of which we predict the corresponding remanence First Order Reversal Curve (remFORC) features. This provides a possible test for the presence of such structures in biological tissue.

Computationally Efficient Universal Adversarial Perturbation
Jihwan Bae
Mentors: Anima Anandkumar and Anqi Liu

Adversarial attacks for the neural networks have been a critical issue in the literature for the safety of applications such as autonomous vehicles and robotics. Among them, universal adversarial perturbation, which is very small image-agnostic vector that causes natural images in the same distribution to be misclassified with high probability, can be regarded as one of the most practical method. However, since it still has some drawbacks to be improved, I delved into relatively direct approach to get universal adversarial perturbation via out-domain distribution and geometry of decision boundary rather than iterating through the whole dataset every time. Structural similarities of universal gradient with respect to the input given as image plus out-domain noise seem to indicate the existence of such perturbation, and also curvature of decision boundary is an explicit evidence for it.

Analyzing the Efficacy of Induced Fibroblast Differentiation Using Single Cell mRNA Sequencing Data
Joeyta Banerjee
Mentor: Matt Thomson

Previously, it has been found that cells can be differentiated into muscle cells by changing the expression level of a single gene, myoD. This discovery has applications in regenerative medicine, as it may be possible to differentiate fibroblasts into muscle cells as needed. Similarly, the gene ETV2 may be able to differentiate fibroblasts into endothelial cells. We are examining the success of such a treatment option through the use of single-cell sequencing. Single-cell mRNA sequencing allows for large amounts of gene expression data to be collected and analyzed at once. By analyzing the total gene expression of the cells where myoD or ETV2 have been introduced, we determine the success of the differentiation. Inducing expression of myoD seems to cause the expression of some muscle genes but does not cause complete differentiation into muscle cells. ETV2 does not seem to cause expression of endothelial cell genes.

Preferences of Face Neurons
Alex Bardon
Mentors: Gabriel Kreiman and Markus Meister

The inferior temporal cortex (IT) is critical for visual object recognition. Some investigators have claimed that certain specialized regions contain neurons that may respond to specific categories such as faces. It is impossible to exhaustively evaluate all possible images to study neuronal tuning properties. To address this problem, images were evolved with a genetic algorithm that used live responses of IT neurons to optimize the images to the preference of the neuron (Ponce et al 2019). The evolved images presented as abstract, not easily recognizable objects. In order to gain understanding about what the IT neuronal preferences are, the evolved images were analyzed with psychophysics experiments and computer vision models. This data has important implications for the preferences of IT neurons and to test the hypothesis of whether neurons are tuned to semantic categories such as faces or not.

Real-Time Diagnostics in Unsteady Flows
Sarah Barrett
Mentors: Beverley McKeon and Morgan Hooper

To characterize flow experimentally, the McKeon group uses particle image velocimetry (PIV). PIV is a method of quantitative flow visualization, which consists of a laser, cameras, and software. The group also uses a Captive Trajectory System (CTS), an electro-mechanical system installed on a water tunnel, on which various objects can be mounted. While an effective method of determining flow velocity experimentally, traditional PIV setups are not able to make data available in real time. To facilitate future real-time analysis, software was written for the custom operation of a FLIR Flea3 camera to take images appropriate for PIV and ensure synchronous operation with the CTS, which will increase the rate at which processed vector fields are available. In addition, a camera mount was manufactured to capture images in the CTS reference frame. The success of the program will be verified by flying a trajectory and characterizing the flow (using PIV) around a cylinder moving in the shape of an ellipse.

Integrating Domain Knowledge Into Graph Neural Networks for Charged Particle Tracking
Thomas Barrett
Mentors: Maria Spiropulu and Jean-Roch Vlimant

Track reconstruction is an important step of the data processing pipeline required to analyze high-energy particle collisions at the LHC. The drastic increase in luminosity offered by the High Luminosity LHC poses a computational challenge for the current tracking algorithm - the Kalman Filter. Since current approaches are expected to require excessive computing resources, alternative approaches are under development in hopes of providing a more efficient solution. Recent advances in machine learning allow Graph Neural Networks to be used for particle tracking. Using this approach, hit data is first preprocessed into a graph data structure containing all possible tracks as determined by a rough heuristic. The Graph Neural Network then classifies edges as either true or false indicating whether or not two hits originated from the same particle. In an effort to improve the accuracy of this model, domain knowledge from physics, specifically knowledge about helical paths in a charged magnetic field, are applied to the model to guide training.

The Explosion Mechanism of Type Ia Supernova
Hrishika Basava
Mentors: Syed Uddin and Shrinivas Kulkarni

Type Ia Supernovae (SNe Ia) are standardizable candles that are used to determine distances across the universe and probe dark energy. There are uncertainties about their explosion mechanism, such as whether they explode in a binary system with just one white dwarf or in a system with two white dwarfs, and whether they can occur at sub- or super- Chandrashekar masses. Using data from the Carnegie Supernova Projects I and II, we constructed bolometric light curves for over 300 SNe Ia, and Arnett's law was employed to get the mass of Ni^{56} produced in each SNe Ia from the peak luminosity magnitude. We made plots to see if correlations could be found between ^{56}Ni mass and other SNe Ia properties, and we found a positive linear relationship between ^{56}Ni mass and sBV and a negative linear relationship between ^{56}Ni mass and dm15. We also compared the values of Ni^{56} mass with values from a range of different models of the explosion mechanism. In the future, a more model independent and accurate approach to finding the Ni^{56} mass is hoped to be used in order to refine these findings.

Modeling Mushroom Body Responses to Private and IR-Activating Odors in *Drosophila*
Matthew Bauer
Mentor: Elizabeth Hong

Constructing an accurate, dynamic, and broadly applicable model of early olfactory processing in *Drosophila* is an important milestone in the study of olfaction. In this paper, we use *in vivo* imaging techniques to better characterize mushroom body responses to narrowly-activating "private" odors, which activate only a small number of first-order olfactory receptor neurons at the periphery. These data allow us to build upon previous efforts to model mushroom body responses by improving model accuracy for private odors. By incorporating IR response data into the model inputs, we are also able to improve the accuracy of predicted responses for strongly IR-activating odors such as acids and amines.

Discovery and Directed Evolution of Fluorescent Biosensors for Cannabinoids, Opioid Peptides, Neonicotinoids, and Other Neural Drug Classes
Zoe Beatty
Mentors: Henry Lester and Anand Muthusamy

As the field of subcellular pharmacology has emerged as a winning technique for understanding neurological drugs, biosensors have become important tools for analysis of these drugs' pharmacokinetics. Contrary to traditional belief that ligands bind receptors of cells solely on the plasma membrane, researchers in the Lester lab have found evidence that ligands also engage receptors inside cells and coined this discovery as “inside-out pharmacology”. The Lester lab has used directed evolution to engineer a biosensor that allows subcellular visualization of nicotine, which has given insights into the drug’s addictive effects. This method has been extended to other drug classes: opioids and antidepressants. Through a preliminary “drug x biosensor” screen, I will assess promising pairs between 43 drugs (covering a wide range of classes) and 20 biosensor mutants. I will then choose a drug-ligand pair to evolve further for imaging in mammalian cells. This work will extend the “inside-out” pharmacology concept to other drug classes, revealing molecular mechanisms of chronic drug effects.

Effects of Different Stimuli on the Inducement of Secondary Structure in a Truncated Reflectin Protein Found in Cephalopods
Trinity Bento
Mentors: Alon Gorodetsky, Paul Rothemund, and Preeta Pratakshya

The inducement of secondary structure in reflectin, a naturally unstructured protein, is paramount in cephalopods’ dynamic color changing ability. Being able to control the secondary structure in vitro could have many applications in biomaterials. This SURF, focused on testing the effects of different stimuli on the structure of a reflectin A1 truncation mutant, for which tests suggest, is representative of the full length protein. The truncation mutant's shorter length makes it easier to work with. The stimuli tested were mechanical forces in the form of shaking; addition of NaCl, which would change electrostatic interactions in the protein; bioconjugation with an unnatural amino acid containing quinoline, a molecule that studies have found to induce secondary structure in short alpha peptides; and bioconjugation in conjunction with mechanical stimulus. Mechanical agitation appears to induce a ☐-sheet, salt addition did not seem to have any significant effect, and bioconjugation in conjunction with mechanical agitation seems to induce self assembly. Preliminary experiments suggest that inducement of a ☐-sheet via mechanical stimulus speeds up with increasing pH. The effects of mechanical agitation on the full length protein is also being investigated.

Characterizing Exciton Dynamics in Atomically Thin Materials
Damien Bérubé
Mentors: Hongkun Park, Giovanni Scuri, Trond Anderson, and Oskar Painter

Since the discovery of graphene, there has been growing interest in the study of atomically thin materials. Lately, a class of 2D semiconductor materials known as transition metal dichalcogenides (TMD) has grabbed some attention in the condensed matter physics community. Atomically thin TMDs such as $MoSe_2$ and WSe_2 can host tightly bound excitons, pairs of electrons and holes, stable at up to room temperature. These excitons have been noted for their potential to build many-body systems. Since TMDs lack dangling bonds between layers (only van der Waals interactions hold them together), they can easily be stacked in so-called van der Waals (vdW) heterostrucures. Recently, there has been growing interest in stacking two monolayer TMDs with a slight twist angle leading to the emergence of Moiré patterns. As they change the electron-hole separation, these patterns can result in new excitonic properties: a local, periodic accumulation of interlayer excitons may lend a new opportunity to study topological order. In this work, vdW heterostructures formed by twisting two layers of WSe_2 were prepared. Exciton lifetime, as well as polarization-specific photoluminescence, was measured for various twist angles. These will help better understand the rules by which interlayer excitons can form and decay.

Analysis of an Earthquake Early Warning System for the United States’ West Coast
Brenden Bixler
Mentors: Egill Hauksson, Jennifer Andrews, and Claude Felizardo

With today’s technology, earthquakes can be detected quick enough to send an alert that can reach some areas before strong shaking arrives. A few seconds after an earthquake begins, the ShakeAlert System will identify and characterize the earthquake, calculate the likely intensity, and deliver alerts to the people and infrastructure in harm's way. Earthquake Early Warning (EEW) is an important current R&D area in the west coast of the US, with the ShakeAlert system gradually becoming a public system. The EEW ShakeAlert system for the West Coast of the United States relies on rapid detection and transmission of ground motions from an on-going earthquake. A subset of technical procedures include: Seismic data being gathered from instruments via the regional seismic networks (RSN), database systems store and categorize the data, central processing systems run specialised EEW algorithms, EEW alerts are produced and distributed to 3rd parties for message distribution, and so on. My present research is to create applicable API enhancements to allow easier end-user message parsing and usage of the alert message created by the EEW ShakeAlert system, as well as performance testing of the messages delivered by the EEW system.

Stability of Granular Structures of Non-Convex Particles Under Compression and Vibration
Eleni Blatsouka Tsouraki
Mentor: Jose Andrade

Granular materials are collections of discrete particles in contact with each other. Since the particles are not bound to each other, granular materials are rapidly reconfigurable and recyclable, so their study is highly motivated by industrial and engineering applications (for example sustainable structures). This project focuses on the response of simple structures made of granular materials to compression and vibration. The particles used, mechanically entangle through particle interpenetration and form freestanding columns. The stability of the columns is tested through laboratory compression and vibration experiments. During our research, we vary multiple parameters such as the particle shape, weigth and size, the aspect ratio of the columns and the procedures used to form them, the frequency and acceleration of the vibration, and we observe and examine how each change affects the structure's properties and stability.

A Ground Mapping Autonomous Car for the Subterranean DARPA Challenge
Alexandra Bodrova
Mentor: Joel Burdick

Recent goals of robotics include rescue robots being used in potentially dangerous environments. This project focused on building a robotic autonomous scaled car that provides steady situational awareness in subterranean environments for the DARPA SubT Challenge, allowing faster first respondence in emergency situations such as people trapped under collapsed buildings or in natural caves. The car built in this project, Balto, is the smallest ground vehicle on the team, spanning 0.9x0.7x0.8 meters in length, width, and height respectively. Balto has a four-wheel drive system controlled via a remote or ran autonomously via the Visual Inertial Odometry. During the project the mechanical, electrical, and odometry subsystems were designed and built, predominantly using 3D printed mounts and connectors. The autonomy portion that uses a Time Elastic Band planner was adopted from the Jet Propulsion Laboratory data base and tuned to the specific design of Balto and the available odometry system. The resulting car can be ran in underground tunnels as narrow as 1.5 meters at speeds up to three meters per second in autonomous mode for over an hour long. Balto's purposes are building a 3D map of the environment, detecting obstacles and scoring objects, and communicating the results to the base outside of the tunnel.

Understanding Electronic Structure of Magic-Angle Twisted Bilayer Graphene
Maksim Borovkov
Mentor: Stevan Nadj-Perge

Magic-Angle Twisted Bilayer Graphene (TBG) is a system of two stacked graphene monolayers twisted by a specific angle that has emerged as a novel platform for strongly correlated phenomena. Among these are unconventional superconductivity, ferromagnetism and anomalous quantum spin Hall effect. Due to the complexity of the underlying structure of TBG, a theoretical description arises as a particular challenge. So far, no theoretical model can accurately depict all of the material properties, one of those being the effect of strain. In this project we address the influence of strain on the band structure of TBG by exploiting an existing effective tight-binding model. We introduce a perturbation term to the tight-binding Hamiltonian and investigate both the single-particle and mean-field cases via numerical simulations. We compare our results to a continuum model and argue that our approach leads to an effective strain model.

Achieving Ultra-Low Power High Precision LIDAR Ranging via Novel Passive Integrated Photonic Circuitry
Cole Brabec
Mentors: Ali Hajimiri and Parham Porsandeh

LIDAR has been used for decades to perform high accuracy ranging measurements. With major breakthroughs in silicon photonics, a new platform has emerged for LIDAR-based ranging. This platform has the advantage of requiring very little power and area while being able to exploit the range precision of LIDAR. A phase-modulated pulse generator and corresponding matched filter were designed to implement a passive LIDAR Integrated Photonic Circuit. The circuitry makes use of photonic couplers to achieve passive phase modulation, while a ring resonator is used to perform the integration needed for the matched filter. The circuit was able to generate sub-picosecond pulses while maintaining a high manufacturing error tolerance. The circuit was numerically simulated and shown to be able to resolve multiple distinct signals, even when obscured by 30db of noise power.

Structure of the Pom152 Immunoglobulin Domains of the Nuclear Pore Complex
Krystal Brodsky
Mentors: André Hoelz and Taylor Stevens

The nuclear pore complex (NPC) of eukaryotic cells allows for the bidirectional exchange of materials across the nuclear envelope (NE) and consists of proteins termed nucleoporins (Nups). Poms, a category of Nups, are integral membrane proteins of the pore membrane domain of the NE. Pom152 is widely conserved among fungi and contains transmembrane helices connecting a short, soluble unstructured region associated with the NPC to a chain of repeating immunoglobulin-like (Ig-like) domains located in the luminal space of the NE. These Ig-like domains are a distinctive feature of the fungi-specific Pom152 and are also found in a similar nucleoporin in plants and animals, Nup210. Here, biochemical approaches were taken to express, purify, and crystallize a fragment of Pom152 containing Ig-like domains 8-9. X-ray diffraction data was collected and efforts to solve the structure via molecular replacement are ongoing, with the possible requirement of higher resolution diffraction data. The structure will provide insight into the potential functions of Pom152, which can translate to similar proteins like Nup210; furthermore, the structural determination of Pom152 will contribute to the elucidation of the complete NPC structure, whose design could provide the basis for a mechanistic understanding of nucleocytoplasmic transport.

Optimization of Calibration Targets
Camila Buitrago
Mentors: Joel Burdick and Amanda Bouman

The Defense Advanced Research Projects Agency (DARPA) started a funded project called the DARPA Subterranean Challenge which is a national competition in which each team creates a multitude of heterogenous (different but interworking) robots that can navigate and perform various tasks like underground mapping, navigation, and transportation in different underground settings. Many of the robots will use thermal cameras as a means of visual odometry. We've created an optimized calibration target that will calibrate the thermal and visual cameras at the same time.

Investigating Optoelectronic Properties of Molybdenum Ditelluride in 2H and 1T' Phases With Electrostatic/Chemical Gating Using Solid Ionic Conductor Substrates
Eoin P. Caffrey
Mentors: Harry A. Atwater and Souvik Biswas

Transition Metal Dichalcogenides are a class of 2D van der Waals materials which exist in different polymorphs and are three atomic layers thick. Molybdenum Ditelluride (MoTe2) can exist in both the 2H (semiconducting) and 1T'/Td (semimetallic) phases. Phase change can be induced by heating, straining, chemical doping and electrostatic gating. The novelty of this project involves gating with solid-state superionic-substrates, to maintain compatibility with on chip devices. In this work thin flakes of MoTe2 (<10nm) were prepared by micromechanical cleavage, stamped onto superionic-substrates (LaF3 and Li CGCs) with prepatterned gold contacts and encapsulated with hexagonal-Boron Nitride as MoTe2 is air unstable. Raman spectra were acquired of the flakes with simultaneous gating to investigate the changes in vibrational modes of the sample. Field effect transistor (FET) measurements were also conducted on the devices to probe the effect of gating on the electrical properties. Changes in Raman peak intensities were observed in several devices and FET measurements indicated change in resistivity of the sample under applied gating. It was concluded that
solid-state gating can be successfully applied to MoTe2 flakes using superionic-substrates. Potential applications of this work include optical modulation and given full phase-change, phase-change memory storage devices at electronic timescales.

Mechanistic Modeling Is Needed to Capture Pairwise and Networked Bacterial Interactions via Different Signaling Pathways
Ann Caplin
Mentors: Richard Murray and Xinying (Cindy) Ren

In synthetic biology, chemical pathways can be divided among multiple strains of bacteria to lower burden, but interactions between strains often leads to unwanted population dynamics. Growth and interactions can be regulated via diverse mechanisms, such as diauxic growth, cross feeding, competition, and toxin production. This project evaluates LV models and two mechanistic models from literature of one- and two-strain systems. Models from literature describing bacterial growth were modified to simulate growth of one- and two-strain systems. All models show stable steady-state populations under competition, but only one, a mechanistic model, shows stable cross feeding interactions. Least-squares parameter fitting was used to test these models against experimental data, and these models were used to analyze larger networks. This can be used in designing stable synthetic bacterial networks.

Surface Morphology of Dealloyed Binary Cu Alloys for Electrochemical Reduction of Carbon Dioxide
Abigail Carbone
Mentors: Harry Atwater and Eowyn Lucas

Carbon dioxide levels in the atmosphere are rising at alarming rates. As a result, there is a significant effort to find methods to generate usable chemical fuels (e.g. formate, methanol, ethanol, etc) via the reduction of CO_2. However, this is challenging problem because CO_2 is a highly-stable molecule, and thus it requires extreme amounts of heat to break the carbon-oxygen bonds. Electrochemistry is the most promising method for CO_2 reduction on a commercial scale because it allows for the reduction of CO_2 using low applied potentials as opposed to extremely high temperatures. This work was focused on investigating the structure-property relationships of Cu electrocatalysts by varying the surface morphology of Cu-Al and Cu-Zn alloys via a dealloying process, then analyzing their resulting electrocatalytic activity. Samples surfaces were examined using transmission electron microscopy, scanning electron microscopy, selected area electron diffraction, and energy dispersive x-ray spectroscopy.

Low-Cost Perturbation Detection in Fiber Optics
Ali Cataltepe
Mentor: Alireza Marandi

Existing fiber optic networks, due to their ubiquity, potentially provide a valuable data resource for seismology and other pressure-sensing applications. The current state-of-the-art of digital acoustic sensing on fiber optics, is, however, reliant on very narrowly-pulsed and thus high-cost lasers for reasonable precision, limiting deployability. We aim to establish a proof-of-concept for a lower-cost perturbation detection method using a time-of-flight based commercial laser ranging system. It is observed that, upon perturbation, light in multimode cables is coupled into a different mode concentrated in a region of the fiber with a different refractive index, affecting its time of flight. Since this coupling begins at the site of perturbation, the change in time of flight is correlated with the location at which the fiber is perturbed. We experimentally establish a correlation between perturbation site and change in measured time of flight, and propose a prototpe and calibration method for a perturbation-sensing system.

A Coral Microatoll Record of Relative Sea-Level Change in Cabugao, Philippines
Andrew Chan
Mentors: Aron Meltzner and Paul Asimow

Relative sea level (RSL) is influenced by multiple drivers including ice melt, glacial isostatic adjustment (GIA), and tectonics. In the mid-Holocene RSL was still heavily influenced by ice melt and GIA. RSL change from GIA is difficult to separate from that resulting from tectonic processes as they project similar signals. This problem of separation can be resolved in part through the analysis of coral microatolls, coral colonies which characteristically have a level, non-living upper surface and a living outer layer. The upward growth of microatolls is limited by low-water level and their upper surfaces track RSL over the lifetime of the coral. Microatolls from several generations at a site in western Luzon island, the Philippines, were surveyed and slabbed, and their cross sections were x-rayed. We worked to mosaic and interpret the x-rays of these to reconstruct a continuous, high-precision record of RSL over the mid-Holocene. Comparing RSL records from other sites nearby will permit attribution of the RSL changes to their respective drivers. This will allow for the future constraint and revision of the GIA model.

Bistable Hinge Design for Reconfigurable Surfaces
Anjini Chandra
Mentors: Sergio Pellegrino and Yang Li

Origami, the art of folding paper, has inspired many designs for structures that change isometrically. Certain applications, however, need to change both metrically and isometrically, a difficult task. The purpose of this project was to explore the use of integrated bistable elements that change metrically and isometrically and are easy to manufacture; the elements were studied in the context of a reconfigurable surface for antenna applications. The antenna surface is made up of a series of bistable hinges arranged into a grid-like pattern and laser cut in polypropylene. When opened simultaneously, the hinges interact to form a multistable structure that can hold its shape in flat, cylindrical, and spherical configurations. This allows electronic devices placed on the surface to capture a wide field of vision and do so with accuracy. In addition, the surface is much easier to build than other structures with surrogate folds that require the assembly of many smaller components. To gain a deeper understanding of the behavior of the surface, individual hinges were modeled using beam theory, and the hinge models were used to analyze and revise the surface so that it opened with ease.

MySQL Database and Absorption Cross Section Calculator for Molecular Line Lists
Wenjun Chang
Mentors: Heather Knutson and Zhaoxi Zhang

Current molecular line lists are scattered around the internet with inconsistent formats, which is tedious for the astronomy community to work with. Thus, I developed a MySQL database (~2 TB in size) to contain all ExoMol, HITEMP, and HITRAN line lists for all molecules in a standard format. New line lists can be added to the database easily through python scripts I supplied. Astronomers are interested in absorption cross sections of certain molecules under given pressures and temperatures in order to analyze the composition of exoplanet atmospheres. Therefore, I created an absorption cross section calculator, which queries the database according to user inputs and computes cross sections for the specified temperature, pressure, and wavenumbers. The open-source calculator is faster, more straightforward, and easier to use than ExoCross, developed by the ExoMol team. By developing the database and the absorption calculator, I wish to prevent astronomers from wasting precious time manually downloading files and computing absorption cross sections.

Determining Helium Diffusivity in Olivine Fluid Inclusions
Rajorshi Chattopadhyay
Mentors: Paul Asimow and Daniel Weidendorfer

The physical transport of matter by diffusion is of paramount importance in earth sciences. Growth of a crystal from magma is determined by the diffusion of various chemical species into it. Diffusion also controls metamorphic and metasomatic processes and hence plays an important role in our understanding of various Earth processes. We aim to conduct a series of experiments to determine the diffusivity of helium gas in olivine fluid inclusions. MORBs have a typical He isotopic ratio of ~8Ra. However the Baffin Island olivines have He isotopic ratio of ~50Ra. Our diffusion experiments will be able to confirm whether olivine fluid inclusions can at all take up He from some external source by diffusion. We will also be able to calculate activation energy, pre-exponential factor for this diffusion process. Mobility of He through olivine crystal lattice can also be calculated. Together with other isotopic ratios (Sm,Nd, Os) these experiments will explain the crystallization history of these unique minerals.

Automatic Detection of Anatomic Overlap Artifacts for Efficient Magnetic Resonance Imaging
August Chen
Mentors: Shrevas Vasanawala, Christopher Sandino, and Mikhail Shapiro

Magnetic resonance imaging (MRI) is an extremely powerful diagnostic tool that enables assessment of soft tissue anatomy and physiology. Each scan is controlled by dozens of scan parameters the MRI technician inputs. Issues with these parameters may cause artifacts in the scan, leading to worse image quality and low diagnostic value. This then necessitates a re-scan. In this project, we focus on the field-of-view (FOV) parameter, which the technician must prescribe to determine the spatial coverage of the image. When the FOV is too small, part of the edge of the image can wrap around to the other side and obscure other anatomy in the image. This artifact is known as anatomy overlap, and can reduce diagnostic confidence if the overlap occurs on top of clinically relevant structures. Thus, it is extremely useful to determine whether an image has lowered quality due to the anatomy overlap artifact or not to take better images and reduce the time it takes to perform an MRI scan. In this project, we create a convolutional neural network that classifies if an image has the anatomy overlap artifact or not. By using data augmentation and tuning the parameters of the neural network, the classifier achieves an accuracy of almost 90 percent.

Regulating Transposable Elements as a Mechanism for Directed Evolution
Hao Chen
Mentor: Joseph Parker

Throughout history, free-living beetles have evolved into myrmecophiles—species that live symbiotically with ants. The greenhouse rove beetle, *Dalotia coriaria*, is not a myrmecophile, but its physical and chemical pre-adaptations make it poised to evolve such a lifestyle. Regulation of transposable elements (TEs) is one possible mechanism for rapid, directed evolution of *Dalotia coriaria* into a symbiont with the colonial raider ant, *Ooceraea biroi*. TEs are sources of new mutations and can be regulated by RNAi knockdown of *Piwi* and by inhibition of *Hsp90*. *Piwi* is critical to the piRNA pathway, which silences TE activity and prevents germline transposition. *Hsp90* acts as an evolutionary “capacitor”, protecting against genomic instability and mutations by assisting with protein folding. For RNAi knockdown of *Piwi*, dsRNA was designed and microinjected into *Dalotia*; relative expression was quantified using qPCR. For *Hsp90* inhibition, *Dalotia* were fed *Drosophila melanogaster* incubated in a solution of geldanamycin, an *Hsp90* inhibitor. Relative expression of TEs was quantified with qPCR. Both *Piwi* knockdown and *Hsp90* inhibition resulted in statistically significant upregulation of TEs. These experimental techniques are feasible mechanisms for inducing mutagenesis and may be relevant for the directed evolution of *Dalotia*.

Properties of Quaternionic Automorphic Forms
Haoxuan Chen
Mentor: Zavosh Amir-Khosravi

Automorphic forms, in particular holomorphic modular forms, have historically been an abundant source that generates many theorems in number theory. However, an interesting idea is to make a quaternionic analogue of the classical automorphic forms. In our project, based on some previous work on quaternionic analysis and discrete quaternionic series on the unit ball, we developed an analogue of automorphic forms for quaternions. Then we explored a concept called “n-Regularity”, which corresponds to holomorphicity in the classical case, for any quaternionic automorphic forms of weight n. We constructed an analogue of Eisenstein Series and the Weierstrass \wp-function for the quaternions. We also made progress in seeking the properties of such quaternionic Eisenstein series. Future work could include developing the link between quaternionic analysis and geometry, such as generalizing the Stokes’ theorem.

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

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

Valley Hall Effect on 2D Materials
Yinan Chen
Mentors: Nai-Chang Yeh and Duxing Hao

Valley Hall effect is a phenomenon originated from valley polarization on 2D materials with staggered hexagonal lattice, and is a potential basis for valleytronics devices. We aim to design instruments and a circuit to observe this phenomenon on 2D materials such as monolayer transition metal dichalcogenide. This design includes a homemade optical probe to generate circularly polarized light, which is used to preferentially inject excitons into K or K' valley, and a circuit to conduct the valley Hall effect measurement. We test the Stokes vectors for the circularly polarized light and find that our optical probe is able to generate high-quality circularly polarized light. Besides, we find the resolution of our circuit and predict the upper limit of contact resistance for a measured sample according to this resolution. We are at the stage of further developing our circuit, and using it to measure valley Hall effect on 2D materials as well as other transport properties under light on 2D or pseudo 1D materials.

Assistive Walking Devices: Validating Metabolic Cost of Transport Data Analysis Process and Developing a Flywheel Module for a Walking Cane
Allie Cheng
Mentors: Aaron Ames, Claudia Kann, and Maegan Tucker

Millions of people use assistive walking devices to maintain independent mobility. While there has been interest in robotic bipedal exoskeletons (RBE) that return walking functionality to people with paraplegia, these exoskeletons coupled with nonlinear control algorithms can help those with limited but existing lower-limb function rehabilitate and regain independent walking. To determine whether these controls and RBE induce rehabilitation, we measure the user's metabolic cost of transport (COT), a value that determines human effort contribution. COT is calculated using oxygen consumption (VO_2) and carbon dioxide production (VCO_2) data collected by Cosmed's $K4b^2$ metabolic measurement system. We expect COT to increase during rehabilitation and decrease during locomotion assistance. We conducted a pre-existing study and compared our results with those published to conclude that our COT trends are as expected, validating the robustness of our data analysis process. Due to certain constraints (size, cost, and energy supply), walking canes are more commonly used than RBE to aid with everyday mobility. To help people learn proper usage of a cane, we designed a module that has vibrational and rotary motors with a weighted flywheel to alert the user when the cane is at an unsafe angle and maintain optimal cane angle.

Tidally Excited Oscillations Due to Resonance Locking in Heartbeat Stars
Shelley J. Cheng
Mentor: Jim Fuller

Heartbeat stars are a class of eccentric binary stars with short-period orbits and characteristic "heartbeat" signals in their light curves, especially at orbital periastron where strong tidal interactions occur. In many heartbeat stars, tidally excited oscillations causes the star to oscillate throughout its orbit, with the frequency of tidally excited oscillations occurring at exact integer multiples of the orbital frequency. Here, we investigate whether resonance locking between tidal forcing and a stellar oscillation mode can explain the tidally excited oscillations in observations of the heartbeat star KIC 6117415. Using Kepler light curves and radial velocity data, we first model the heartbeat star using the binary modeling software ELLC, including gravity darkening, limb darkening, and reflection. We then apply tidal theories to the models of heartbeat star to determine whether any prominent tidally excited oscillations can be explained by the predictions of resonance locking.

Active Sensing for Bandwidth Constrained Video Search
Bhairav Chidambaram
Mentors: Mason McGill and Pietro Perona

In order to applying machine learning in practice, we must pay attention to both the bandwidth and compute constraints of available hardware. The goal of this project is to understand video analysis when we are constrained by bandwidth: how much data can be sent from the video camera to a processing server. In particular, we study optimal ways of storing a database of videos and optimally querying these databases in order to search for entities of interest, such as people, cars, etc. To do this, we ran experiments on the ImageNet-VID dataset of videos, and trained different query policies for detecting objects of interest. So far these experiments include agents which query at different scales and agents which query across time. Our results show that we can achieve a significant reduction in bandwidth usage (80% less bandwidth) while maintaining competitive performance (only 20% drop in performance) compared to a unlimited bandwidth detector.

Monocular-Based Pose Estimation of Uncooperative Spacecraft
Velissarios Christodoulou
Mentor: Soon-Jo Chung

Pose Estimation of spacecraft is a key capability during close-proximity operations. In these operations, relative navigation must be performed on board and autonomously. The current state-of-the-art approaches are often ineffective, particularly in cases of adverse lighting conditions and high rotational dynamics of the orbiting target. To overcome these challenges, it is possible to adopt a more robust learning-based solution, which makes use of a convolutional neural network. Two neural networks are considered, one that estimates the pose of a space object given one monocular image and one that estimates the variation of the pose over time given a sequence of images. The first goal of this project is the creation of two datasets of synthetic images required to train the neural networks. In addition, in monocular-based image-to-model processing, the extracted features might not correspond to the features of the model depending on the lighting conditions and morphological characteristics of the target, preventing a correct feature matching. To solve this problem, the second goal of the project is to create a model with the same features that will most likely be detected on board. The well-known Structure from Motion is modified using the feature extractors that will be used on board.

Revisiting the Intertemporal Choice Problem in the Context of Exercise Habits
Tadeusz Sebastian Ciecierski-Holmes
Mentors: Colin Camerer and Anastasia Buyalskaya

Consumer behaviours that are difficult to reconcile with standard preferences and beliefs assumed widely in economics are found when studying gym memberships. Della Vigna and Malmendier (2006) demonstrated this, where a sample of gym members were paying, on average, more per attendance than they would otherwise pay for day passes. Using a larger sample over a longer time period, our results provide further evidence of these behaviours. First, out of 17,938 gym members sampled from a major US gym chain, 38% were found to be paying more in gym memberships than they could have paid in day passes. Second, surveyed gym members from a US university had realised gym attendances that were only half their expected gym attendance. Lastly, further analysis investigated additional behaviours of interest, such as time delays between final gym attendances and cancellation of memberships. Simulations of time-inconsistent preferences and loss aversion models are run to explain observed behaviours. These analyses provides insight into the extent of consumer naivety to their own future consumption behaviours. The wider implication of the inconsistency between the observed behaviours and those we would expect using the rational expectations hypothesis include the impact of transaction costs in causing sub-optimal consumption decisions.

Can the Implicit Association Test Predict People's Biases?
Ryan Clark
Mentors: Ralph Adolphs and Damian Stanley

Implicit biases are automatic, rapidly formed prejudices which are often deployed without awareness and influence decision-making. Unlike explicit biases, implicit biases are not measured with surveys. Instead, they are assessed indirectly with reaction times and error rates, most commonly with the Implicit Association Test (IAT). Researchers have used the IAT to study a wide range of biases in isolation; however, less is known about broad patterns of implicit bias across different domains, such as racial prejudice and celebrity preference. The Open Science Foundation recently released a large dataset, consisting of survey questions, demographic information, and IATs across 95 attitude domains for 200,000 participants. We investigated whether demographic information about the participants (e.g., their sex) or the details of IAT administration (e.g., task order) might influence the test's ability to predict various measures of explicit bias. Initial analyses revealed little-to-no influence of administration detail on variation in IAT predictive power. Ongoing analyses are focused on how demographic variation might moderate the relationship between implicit and explicit measures of bias. Understanding how variation in test administration and participant background might influence the predictive power of the IAT is critical for the accurate interpretation of findings and their real-world implications.

Holographic Duals of n-Point Conformal Blocks in Arbitrary Dimension in the Comb Channel
Robert Clemenson
Mentor: Sarthak Parikh

The assumed correspondence between (d+1)-dimensional theories that include gravity in anti-de Sitter space, and d-dimensional conformal field theories that do not include gravity, is of enormous importance in the search for a quantum theory of gravity. Within the CFT, the objects we would most like to calculate are correlation functions. In the conformal bootstrap approach to conformal field theory, these correlators can be written non-perturbatively in terms of so called 'conformal blocks'. So far, the form of these conformal blocks in arbitrary dimensions is unknown. This project goes some way to finding explicit forms of the n-point conformal blocks within the 'comb channel', via their holographic duals in AdS space.

Characterization of Fiber Injection Unit Submodules for Keck II Telescope
Jennah Colborn
Mentors: Dimitri Mawet, Nemanja Jovanovic, and Jackie Pezzato

It is very difficult to observe and characterize the atmospheres of extrasolar planets, largely due to the strong stellar light that infiltrates both the infrared (IR) images and spectra gathered when observing exoplanetary light. However, the revolutionary new technique of High Dispersion Coronagraphy (HDC) involves the coupling of a well-established imaging instrument with a well-established spectrograph, thus enabling simultaneous differentiation between both stellar and planetary light and stellar and planetary spectra. The Keck Planet Imager and Characterizer (KPIC)– the first-ever instrument to employ HDC– will vastly improve the direct imaging and high resolution spectroscopy capabilities of two existing systems within the Keck II telescope: NIRC2, a high-contrast infrared imager, and NIRSPEC, a high-contrast infrared spectrograph. We are currently characterizing the first set of submodules for the Fiber Injection Unit (FIU) component of the second phase of KPIC: tested to-date are the phase-induced amplitude apodizer (PIAA), which shapes light and couples it more efficiently into the spectrograph, and the apodizer coronagraph, which suppresses infiltrating stellar light. Here, we will show that the preliminary set of optics for both submodules contain several design and manufacture imperfections; future work will include testing using updated optics, as they have since been re-ordered under new specifications.

Discovering Transiting Exoplanets With a Low-Cost Robotic Telescope System
Therese Cook
Mentors: Dimitri Mawet and Nemanja Jovanovic

The PANOPTES project (Panoptic Astronomical Networked Observatories for a Public Transiting Exoplanets Survey) is working to develop a worldwide network of individually-built, low-cost robotic telescope units that continuously image the night sky to observe transiting extrasolar planets. The fourth-ever completed PANOPTES unit, PAN012, was built by two students at Caltech last summer and used to make a successful detection of a planet transiting the star HD 189733. This project continues their work, having successfully deployed the unit to its permanent location on Mt. Wilson where it conducts transit observations and sky surveys nightly. Leading up to the unit's deployment, several weeks were spent designing a weatherproofing system to protect its computerized telescope mount, as well as testing its software and hardware from the lab and outdoors to ensure that the data acquisition and processing workflow operated as expected. In the time following the deployment, we are proceeding to extract the transit signals from its observations for scientific analysis using the cloud-based PANOPTES data processing pipeline. Now fully-operational, the PAN012 unit will continue to gather valuable data on both known and potential transiting systems, possibly facilitating hundreds of new exoplanet discoveries in the future.

Developing Additional Functionalities to the NIRC2 Data Reduction Pipeline
Will Cook
Mentors: Dimitri Mawet and Marie Ygouf

With the advancement hardware for telescopes being able to image objects that were once thought to never be possible there must be an advancement in how we interpret, process, and archive/present this data. The huge amounts of data that is received every observation night presents a large problem in being able to process it in a way that is both efficient yet thorough. The NIRC2 pipeline attempts the do this with its automatic sorting of FITS data files and its data reduction. The pipeline also offers a website to present the data in a format conducive for finding patterns and features. Though the foundations of the pipeline and website are well developed, the work presented in this article focuses on added features to the pipeline and its website that assist the pipeline in reducing data and the website in being more intuitive.

Local Unfolding Drives Active and Inactive Conformations of Chloroplast Signal Recognition Particle 43
Stephanie Cortez
Mentors: Shu-Ou Shan and Alex Siegel

To prevent the aggregation of light harvesting chlorophyll-a/b binding proteins (LHCP) on their way through the chloroplast, cells have evolved a dedicated membrane protein chaperone, the chloroplast signal recognition particle (cpSRP43). CpSRP43's activity can be regulated by binding partners that shift its conformation to enable it to capture LHCP in the stroma and release it into the thylakoid membrane. In order to probe the conformational changes behind these two opposite functions, we introduced phenylalanine at strategic locations throughout the substrate binding domain (SBD) and collected 1D NMR spectra of 19F-phenylalanine labeled cpSRP43. In the absence of binding partners, cpSRP43 exchanges between a well folded and a partially unfolded conformation resulting in two distinct peaks. The intensity of each peak allows us to quantify the local unfolding at sites throughout the SBD. We observed that residues closer to the C-terminus of the SBD's bridging helix (BH) are more unfolded, while the addition of activating binding partners drove folding of the BH. Given previous work showing that the BH is essential for cpSRP43's chaperone activity, this presents a potential regulatory mechanism where binding partners drive the folding or unfolding of the BH to regulate cpSRP43's chaperone activity.

Understanding Earth and Mars Through Spectroscopy of Carbonate Minerals
Molly Crotteau
Mentors: Bethany Ehlmann and Rebecca Greenberger

The accurate interpretation of the chemical composition of carbonate minerals, which are abundant on Earth, is essential for understanding the environments in which the carbonates precipitated and the exchange processes occurring between rocks and minerals and the environment. Thus, improving our interpretation of the infrared spectral features of carbonate minerals will enable better determinations of their chemistry. We synthesized carbonates of varying calcium, magnesium, and iron compositions, and measured reflectance spectra of the synthesized carbonates at visible-shortwave infrared wavelengths. We used the spectra obtained to develop a model that demonstrates the relationship between calcium, magnesium, and iron content of the carbonate and peak position of the absorption at 2.3 microns. Future work will involve the mixing of multiple carbonates of known compositions with serpentine minerals and the measurement of their spectra, testing possible indices and unmixing models to quantify the abundances of each mineral. We will be able to use the models developed to accurately determine the composition of carbonate minerals and carbonate mineral mixtures. This will be applicable to the study of carbonate minerals on Earth, specifically those present in the Samail Ophiolite, and on Mars, in the Jezero Crater Delta.

LEO Robot: Stabilization of Bipedal Robot Using Propellers
Brian Cruz
Mentors: Soon-Jo Chung and Kyunam Kim

Bipedal robots are becoming increasingly agile, but still fail when attempting extreme balancing and stabilization tasks. The Aerospace Robotics and Control Lab's LEO robot attempts to use stabilization propellers to address this problem. By using the propellers to create a balancing torque around the robot's feet, we aim to create a robot that is both more stable and mobile that a purely legged robot and more energy efficient than a purely flying robot. The project consists of simulation to test the feasibility of the design under various configurations and operating conditions, and a hardware implementation on the LEO robot.

Point Source Guided Local Fourier Domain Wavefront Correction in Brain Photoacoustic Tomography
Manxiu Cui
Mentor: Lihong Wang

Abstract withheld from publication at mentor's request.

Machine Learning Comes to Too Many Errors in Picking Generalized Seismic Phases of Signal-Component Data, Why?
Xin Cui
Mentors: Robert W.Clayton and Zachary E.Ross

A convolutional neural network (ConvNet) performs well in detecting and classifying seismic body-wave phases of three-component data over a broad range of situations. We trained another ConvNet to try to detect and classify seismic body-wave phases of single-component data. However, since there are only vertical signals, the result of the ConvNet either includes a number of "false" picks that need to identify. We use the result of three-component as conference to look for the "false" picks of single-component data. Short-term average/long-term average (STA/LTA) is a traditional algorithm for automatic picking of seismic signals. We use STA/LTA to find an initial picking region, then refined the pick by the ConvNet to optimize the results. Fast Fourier transform (FFT) is a method for quickly calculating the discrete Fourier transform of a sequence. Fourier analysis converts a signal from

the time domain to a representation of the frequency domain. We use FFT to find the features of “false” picks signal in frequency domain, and filter the high frequency interference noise to optimize the results.
Both methods perform well.

Temperature Dependence of Gap Induced by Time Reversal Symmetry Breaking in Bilayer Pure and Cr-doped $(BiSb)_2Te_3$ Using Scanning Tunneling Spectroscopy
Aiden Cullo
Mentors: Nai-Chang Yeh and Chien-Chang Chen

Cr-doped $(BiSb)_2Te_3$, a topological insulator (TI), is theorized to form a gap in the Dirac spectrum at low temperature due to time reversal symmetry (TRS) breaking induced by out-of-plane magnetization. Alternatively, many groups have posited that Cr will directly alter the band structure of TIs. Thus, we have created a way to break TRS via the proximity effect of magnetization. By positioning pure TI layers above Cr-doped magnetic TI samples, we break the TRS of the pure TI by magnetizing the Cr-doped TI. The magnetization of the Cr-doped TI can be compounded by an external magnetic field. Our preliminary results, suggest our TI is gapless at room temperature, but these claims must be substantiated with additional experiments due to high degree of noise and variability in our system. Moving forward, we would like to compare our findings on $(BiSb)_2Te_3$ to our previous measurements on Bi_2Sb_3. Finally, we are interested in examining different magnetic doping schemes and impurity concentrations.

Elucidating the Role of Gut Bacteria in Modulating Meningeal Lymphatic Development and Growth
George H. Daghlian
Mentors: Young-Kwon Hong and Sarkis Mazmanian

Meningeal lymphatic vessels drain neural metabolites and maintain brain fluid homeostasis. Their impairment can lead to neurodegenerative illnesses including Alzheimer’s, Parkinson’s, and hydrocephalus, thus making it important to elucidate how these structures develop and function. We sought to understand the role, if any, of the gut microbiome in modulating the development of these meningeal lymphatic vessels via the gut-brain axis. Using C57b1/6 mice lacking gut microbiota (germ-free), we compared the morphology and functionality of the meningeal lymphatic vessels with those of wild-type mice. Immunofluorescence staining was used to compare the prevalence and characteristics of dorsal and basal meningeal lymphatic vessels, while fluorescent tracer drainage assay was used to understand functionality. Given that a possible pathway active in wild-type but not germ-free mice that may modulate meningeal lymphatics is Toll-like receptor 4 (TLR4), we assessed TLR4 knockout mice for morphological and functional alterations. We then conducted a battery of cognitive and behavioral tests to assess anxiety (using the elevated plus maze and open field test), spontaneous alterations and short-term memory (using the y-maze), and long-term memory (using the novel object recognition and the Barnes maze). We noticed subtle variations in the presence of dorsal meningeal lymphatic vessels in germ-free and TLR4 knockout mice when compared to wild-type. Moreover, fluorescent drainage assay in TLR4 mice showed a change in drainage patterns. Finally, our behavioral tests in TLR4 knockout mice confirmed an increase in anxiety, a decrease in both short and long-term memory, and a noticeable loss of motor function. These findings indicate a possible involvement of the gut microbiome in the development of these structures. We will continue to expand our analysis of both germ-free and lymphatic-specific TLR4 knockout mice to study the potential role the gut microbiome plays in modulating meningeal lymphatic vessels.

Extending the Neural Rendering Model: Top-Down Inference and Applications
Sihui Dai
Mentors: Anima Anandkumar, Tan Nguyen, and Yujia Huang

Humans have the remarkable ability to correctly classify images despite possible noise, blur, and missing data. This feature of human vision may be due to the feedback provided by the top-down pathways of the visual cortex, which tries to match the current observation with our internal model of the world. The top-down pathways allow the brain to do image inpainting, denoising, and deblurring efficiently. The combined feedback from the top-down pathways and bottom-up pathways, which extract information from the observation, can allow for more robust classification. To mimic the top-down and bottom-up pathways of the brain, we modify the Neural Rendering Model (NRM), a generative model whose inference process is a Convolutional Neural Network (CNN), to use both bottom-up and top-down inference when inferring latent variables. We show that the addition of top-down inference allows the model to have better performance in image inpainting, denoising, and deblurring. Additionally, we show that the addition of top-down inference allows for more robust prediction.

Modeling of Microwave Transistors Based on Network Analyzer Measurements
Luc Davis
Mentors: Austin Minnich and Sander Weinreb

Low-noise amplifiers are a critical component in radio astronomy, and the ability to predict the noise introduced by an amplifier is necessary for improving low noise amplifier design and optimizing amplifiers. In order to simulate noise from a low noise amplifier, an accurate model for the transistors inside the amplifier is important. We developed a process for reconstructing an accurate computer model of microwave transistors using known S-Parameter data measurements from a network analyzer, and a general circuit model for the transistor, through the program Microwave Office. The resulting schematics from test cases were shown to be sufficiently similar to known, accurate schematics.

Using Transient ASASSN-18zp's Complex Nature to Study Black Hole Physics
Gianfranco de Castro
Mentors: Thomas W-S Holoien and George Djorgovski

Supermassive Black Holes (SMBHs) are highly energetic phenomena that we can study through transient (short-lived) and variable emission events related to accretion. ASASSN-18zp is a transient event discovered by the All-Sky Automated Survey for Supernovae (ASAS-SN), that is likely either an Active Galactic Nucleus (AGN) or Tidal Disruption Event (TDE), both of which are accretion-related phenomena. Using transient ASASSN-18zp's complex nature allows us to study black hole physics, potentially providing insights to broader concepts such as galaxy formation. We use photometric and spectroscopic observations to analyze ASASSN-18zp in order to determine its nature and study the black hole and accretion disk of the host. We present our conclusions regarding the nature of ASASSN-18zp and the results of our analysis that may be of significance.

Investigating Transport Properties in Magic Angle Twisted Bilayer Graphene Devices
Ryan de Silva
Mentor: Stevan Nadj-Perge

Twisted bilayer graphene (TBG) has been one of the most fascinating topics in condensed matter physics in recent times. Stacking two layers of graphene and twisting them to angles close to the theoretically predicted "magic angle" of 1.1° gives rise to a flat band structure near the Dirac point which results in strongly correlated electron states. This project deals with looking into the transport properties brought about by this correlation in these graphene moiré superlattices. The devices are fabricated by encapsulating the graphene in layers of hexagonal- Boron Nitride and cooled down to temperatures of less than 1K. Measurements of the devices are taken at these temperatures in search for superconducting and ferromagnetic behavior.

Designing a 10GHz Flexible Phased Array for Space Solar Power Transmission
Maximilien Debbas
Mentor: Ali Hajimiri

Solar energy can be collected in space via satellite mounted photovoltaic cells and then transmitted back to earth using a microwave phased array. Such a system is attractive because solar power is continuously available in space and can be sent anywhere on earth with less atmospheric attenuation that ground to ground transmissions. Through this project, an electronically steerable phased array was designed to radiate efficiently at 10GHz. Since satellite cost is a strong function of mass and volume and the antenna arrays necessarily cover a large area to maximize aperture, the antennas and board were designed to be flexible such that they can be rolled up during launch and then deployed in space. For the radiating elements, both dipole and loop antennas were designed to deploy perpendicularly to a metallic ground plane such that they can efficiently radiate a broadside beam in the farfield. These antennas will be tested both individually and in an array on the flexible board to see how they compare to theoretical simulations.

A Search for Transiting Planets Around the Most Metal-Poor Stars
Cayla Dedrick
Mentors: Josh Simon, Johanna Teske, and Dimitri Mawet

Planetary formation models predict that there should not be any planets around very metal-poor stars. However, there have been very few studies that have actually looked for planets in samples of low metallicity stars. The launch of the new Transiting Exoplanet Survey Satellite (TESS) has given us the opportunity to study these types of stars in more robust numbers so that we can draw conclusions about the actual occurrence of planets compared to the theory. We are carrying out a survey of the ~200 brightest metal-poor ([Fe/H] < -1.0) dwarfs that have been observed by TESS in Sectors 1 through 12. Any star from this survey that is found to have a planet will be the lowest metallicity star known to host a planet to date. If we do not detect any planets, we will set an empirical upper bound on the planet occurrence rate of planets around very metal-poor stars.

Conditional Guide RNA Status Controls Gene-Specific Silencing via dCas9-KRAB-MeCP2 in Mammalian Cells
Lachlan Deimel
Mentors: Niles A. Pierce and Lisa Hochrein

Developing RNA nanotechnologies that offer spatiotemporal control of gene function/expression may become a powerful tool for biochemical and embryological research, as well as therapeutics. Here, the utilisation of the CRISPR/Cas pathway is of particular interest due to its programmability, portability and range of possible effector functions. Previously, our laboratory has engineered conditional guide (cg)RNAs, which can be switched "OFF" in the presence of an RNA-based trigger to prevent Cas9 affecting the target. Utilising cgRNAs and dCas9-KRAB-MeCP2 (a catalytically dead Cas9 variant, conjugated to two potent transcriptional repressors), we have developed repressible gene silencing logic gates in mammalian cells. Through flow cytometric analysis, we observed that among transfected HEK 293T cells, a response of ~*2*-fold was generated by the addition of the trigger. This has been shown for three unique cgRNA/trigger sets of orthogonal character. Whilst there remains considerable scope to harness greater dynamic range, there are strong prospects of cgRNA-based circuitry being optimised for many biological applications.

Silver Delafossite Template Synthesis of Layered Sodium Oxide Batteries Materials
Daniel Delgado Cornejo
Mentors: Michael Toney, Bor-Rong Chen, and David Hsieh

In recent decades, next generation batteries have attracted much attention for their innovative energy-efficient storage mechanisms which are useful towards the enhancement of many electrical systems. The sodium-ion battery, compared to its lithium-ion cousin, appear to be a promising alternative due to the lower costs and natural abundance of sodium. Previous literature indicates that certain layered structures of $NaMO_2$ (where M is a transition metal) may contain stacking sequences that result in greater electrochemical storage capacity and stability. While conventional solid-state reactions have been shown to successfully synthesize layered sodium-oxides, prolonged high temperature conditions yield a significant loss of energy such that the process is rendered unfavorable. Nevertheless, silver delafossite compounds (taking the form $AgMO_2$) share a similar layering structure as $NaMO_2$ and can be made using solution synthesis techniques in lieu of prolonged high temperature solid-state reactions. Accordingly, the synthesis of $AgMO_2$ results in the layering template which can be used to create layered Na-oxides via ion-exchange reactions. By examining the most reliable methods for creating this delafossite template, and characterizing the crystal structure using X-ray diffraction techniques, we can develop an energy efficient method for synthesizing layered Na-oxides for usage in cheaper and more efficient Na-ion type batteries.

Synthesis and Analysis of Nitrogen-Rich Graphene Models and Their Metal Complexes
Vidhya Dev
Mentors: Theodor Agapie and Arnaud Thevenon

Single atom catalysts have shown promising selectivity and activity in CO_2 reduction. However, these catalysts are synthesized from a top-down approach leading to poorly defined heterogeneous structures. In order to get a better understanding of the mechanism, a well-defined graphene nanostructure doped with twelve peripheral nitrogen atoms (LN_{12}) was synthesized during SURF 2018. The compound was characterized through single crystal x-ray diffraction, multinuclear NMR, UV-Vis absorption spectroscopy, and mass spectroscopy. Due to our lack of success in cleanly isolating a metal complex derived from LN_{12}, two new ligands were synthesized during SURF 2019. The first ligand is closely related to LN_{12}, and consists of six phenol groups ($LN_{12}(OH_6)$) which will have three "salen-type" binding pockets to target trinuclear complexes. The ligand was synthesized and characterized following a similar procedure as LN_{12}. The second ligand is another type of N-doped graphene model with an internal binding pocket. The ligand was synthesized from 9-bromoanthracene and di(2-pyridyl) ketone and later coordinated to a square planar metal precursor (such as Pt). Future work will entail dehydrogenation via a reduction on a gold surface and characterization of the complex.

Improving the Command Transfer Speed to Infrared Imaging Spectrograph
Jeremiah Dibble
Mentors: Roger Smith and Timothee Greffe

Modern sky surveying equipment used for astronomy research is tremendously expensive and as a result observation time with this equipment is coveted. The effective observation time can be increased by making the instruments run more quickly. The TMT Infrared Imaging Spectrograph (IRIS) could have its efficiency improved during high frame rate sub window readouts by increasing the speed at which instructions are serialized and sent to the detector. The Dibble Board will serialize the window locations and send them to the detector, so the processor in the controller can perform operations while the serialization occurs simultaneously. The addition of this board can increase the speed we send data from 1MHz to 50MHz which would improve the overall speed of these readouts by 38%.

Synthetic Spectra of Potential Exo-Earths: Quantifying Biotic Signatures With AROC
Schuyler Dick
Mentors: Yuk Yung and Pin Chen

Previously, atmospheric and aqueous chemistry models have been used independently to investigate atmospheric and surface processes occurring on terrestrial exoplanets. However, these two models cannot be treated discretely, and thus, the AROC (Atmosphere-Rock-Ocean Chemistry) model was formulated. This model couples KINETICS (the Caltech/JPL 1-D photochemical and transport model, Allen et al. 1981) with PHREEQC (the USGS multiphase chemistry model, Parkhurst and Appelo 2013) to incorporate atmosphere-ocean-rock interactions in near-surface exoplanet chemistry for terrestrial exoplanets. The KINETICS model for early Earth includes 50 (9 fixed, 41 varied) chemical species linked by 297 reactions. At each time step, PHREEQC calculates a gaseous flux input for KINETICS in order for AROC to achieve surface-atmospheric equilibrium. The output from AROC is then fed to petitRADTRANS (Mollière et al. 2019) to generate synthetic transmission spectra. This model is being used to generate transmission spectra of three early Earth instances: a pre-GOE (Great Oxidation Event), abiotic Earth; an abiotic Earth during the GOE with increasing oxygen fluxes; and a post-GOE, biotic Earth modeled with microbial outgassing. Overall, AROC will aid in quantifying the effect of biological processes on transmission spectroscopy and can be used to make predictions for future telescopes that would observe potentially habitable planets.

Characterizing a 3D Magnetic Field to Track ATOMS
Grace Ding
Mentors: Azita Emami and Saransh Sharma

Intramedullary nailing is a technique used to treat long bone fractures. This consists of the insertion of a metallic nail into the fractured bone, followed by locking of screws to prevent the displacement of bone fragments around the nail. These screws are inserted along the proximal and distal points of the nail. The Addressable Transmitters Operated as Magnetic Spins (ATOMS) chip was proposed as an alternative to the fluoroscopic imaging techniques commonly used to visualize the location of the distal screw. By detecting a magnetic field in a unique 3D magnetic field gradient and transmitting that information to a computer, the chip can be located through a 1:1 mapping of the field to a set of coordinates in the gradient. This would require a high resolution in the magnetic field, meaning that the 3D gradient must be very precise. The ATOMS chip would be a fully implantable silicon chip attached to both the screw and the drill bit used to insert the locking screw into the bone. The ATOMS chip also has applications in the area of gastrointestinal (GI) study, where it will be encapsulated in a pill casing and swallowed, and then tracked to detect abnormalities in the patient's GI tract. Because of the nature of this application, the resolution of this magnetic field gradient needs only to be about 1 cm, while the resolution of the intramedullary nailing application would need to be less than 5 um. By passing a current of 20A through three coils that produce monotonic fields in the X, Y, and Z axes, a unique field gradient can be produced where each coordinate in the gradient corresponds to the X, Y and Z coil magnitudes.

Quadrotor Obstacle Avoidance via Control-Invariant Sets for Fourth Order Integrator System and Differential Flatness
Ludvig Doeser
Mentors: Richard M. Murray and Petter Nilsson

Ensuring that safety-critical systems are indeed safe through the method- ology of control barrier functions and invariance of a set have proven successful in a variety of applications in robotics. However, finding analytical expressions for the maximal invariant set, which in turn can be used for constructing a control barrier function and thus guaranteeing safety, is generally hard for dy-namical systems with input and state constraints. Here we present a generic method, based on finding roots of polynomials, for constructing functions that characterize invariant sets for the n-order integrator system by using the mono- tonicity of the integrator chain; additionally, we derive analytical expressions for the orders $n \leq 4$. Moreover, using differential flatness we demonstrate the usage of the invariant set for $n = 4$ in obstacle avoidance for a quadrotor. Our results demonstrate the usefulness of finding analytical expressions for invari- ant sets as they decrease the computational power required and still ensure that the system, such as a drone, can be rendered safe.

Mechanical Search
Marcus Dominguez-Kuhne
Mentors: Silvio Savarese, Roberto Martin-Martin, and Yisong Yue

One basic, but still not fully developed skill in robots, is the ability to search an environment and retrieve a desired object. A command as simple as fetch me a item in a very messy bin is a very hard problem in robotics. It involves computer vision and interaction with a cluttered environment which means that we have to identify the objects that we are looking at and know how to move in the environment to optimize for fetching our object. Progress has recently been made by the Stanford Vision and Learning Lab (SVL) and the Berkeley Artificial Intelligence Research lab (BAIR) last year. However, this work relies heavily on being able segment the objects in the bin (with objects dumped into it randomly, filling the bin) well, which is not always an assumption that holds, especially with lower quality RGBD (Red, Green, Blue, Distance) cameras commonly used in robotics. Additionally, object agnostic segmentation, is a difficult problem in its own right and is still an open problem. This project makes a contribution in this space by retrieving items in bins without using image segmentation. We instead use a probability map of how likely a pixel belongs to a specified object. Using this new approach, with reinforcement learning, we are working on having a robot arm grab a specified object in a cluttered bin. This work aims to this difficult object retrieval problem more tractable.

Wireless Biosensors for Health
Kaliden Drango
Mentors: Wei Gao and Jihong Min

The Gao Group develops different types of wireless bioelectronic devices that use electrochemical sensors to detect certain biomarkers in sweat or blood which then provide insights into an individual's health. Wireless bioelectronic devices and sensors have important applications in the medical field, specifically, continuous monitoring and personalized medicine. Overtime they can help observe changes in health, leading to earlier diagnoses and more efficient treatment of illnesses. It is important that the electronics that drive these electrochemical sensors be small and power efficient so that they can operate longer. We are designing a fully integrated wireless system that acquires and transmits amperometry data over RF communications, along with a graphene based electrochemical sensor for sweat glucose monitoring. We aim to monitor exercise induced sweat glucose using amperometry, applying a voltage differential across electrodes and measuring the resulting current. We are using a transimpedance amplifier to convert the current to voltage, and an analog to digital converter to measure the results. To try and keep the power consumption of the device low, we will be using a low power wireless microcontroller and putting the device in sleep mode when no measurement is being taken.

Generating Tetrasubstituted Alpha-Hydroxy Unsaturated Carboxylic Acids via the Ireland-Claisen Reaction
Emily Du
Mentors: Brian M. Stoltz and Tyler Fulton

The Ireland–Claisen rearrangement is one of the most versatile methods for the generation of sterically demanding carbon–carbon bonds. Mechanistically, the reaction proceeds via the [3,3]-sigmatropic rearrangement of allyl O-trialkylsilylketene acetals to generate g,d-unsaturated carboxylic acids. A central challenge in accessing stereodiads in high stereoselectivity via the Ireland–Claisen rearrangement in acyclic systems is control of enolate geometry in the intermediates of the reaction. This research demonstrates the utilization of an operationally simple enolization procedure with acyclic a-hydroxy allyl esters to generate tetrasubstituted a-hydroxy,d-unsaturated carboxylic acids in excellent stereoselectivity and mild conditions. The reaction tolerates free and protected hydroxyl groups in generally high product diastereoselectivity. We further seek to study the stereoselectivity of the rearrangement with different substituents. Additionally, investigations of the enolate geometry and the effect of N,N-dimethylethylamine as an additive are presented.

The Initial Stellar Mass Function: Fundamental Input to Galaxy Evolution and Star Formation Modeling
Isabella Dula
Mentors: Barry Madore, Kristi Macklin, and Lynne Hllenbrand

The stellar Initial Mass Function (IMF) describes the distribution of stellar masses at the conception of a galaxy or cluster. A precise measure of this function will improve our understanding of galactic and stellar evolution. In this paper, we report an evaluation of the IMF based on a survey of open clusters using data from GAIA's recent second data release. We utilize a Density-Based Spatial Clustering of Applications with Noise (DBSCAN) approach to effectively isolate clusters from field stars. This method successfully isolates 56 out of 59 analyzed clusters. To further refine the data, we apply statistical methods to identify binary stars, and, from there, develop a model to decouple these binaries. After correcting for reddening, we found the luminosity functions of each cluster to then derive their present day mass functions. Utilizing knowledge of stellar evolution and aggregating these functions, we reach a final IMF.

Free Standing Nanoporous Gold for CO_2 Reduction
Emily Dunn
Mentor: Harry Atwater

Here we report the first gas diffusion electrode (GDE) for CO_2 reduction created solely out of a metal foam. The conventional GDE is made from commercially purchased porous carbon paper that lacks uniformity in its porosity which limits the types and length scale of pores that can be investigated. Nanoporous metal foam GDEs enable greater control of thickness and uniformity by excluding carbon paper. Furthermore, in this architecture the entire electrode is catalytically active instead of only one part. The first step in fabrication of the electrode is to obtain an alloy from which we can selectively remove one component. In this work, we focus on Au and Ag. The alloy can be synthesized via electron-beam deposition by depositing silver onto a clean Si substrate as a removable base layer followed by the Au/Ag alloy. Photolithography is then used to create a gold grid structure on top of the alloy for increased mechanical stability after etching. The alloy also can be obtained from purchased white gold leaf. The nanoporous morphology is obtained by etching out the Ag component of the alloy in 70% nitric acid. Future research will explore the effects of porosity/thickness on the electrochemical performance of GDEs.

Double Network Hydrogels as Low-Friction Materials to Mimic Articular Cartilage
Josh Dvorak
Mentor: Robert Grubbs

Articular Cartilage is vital to proper joint function in order to carry out everyday motion and work. Diseases such as rheumatoid arthritis make normal motions painful or impossible. The body is very limited in its ability to heal damaged cartilage, so a synthetic mimic would be an attractive alternative to attempting to surgically repair the tissue. The substitute must be bio-compatible, tough, and able to mimic the lubricity of natural cartilage. This project attempts to create a synthetic substitute for articular cartilage by embedding polyzwitterionic brush polymers inside double network hydrogels to mimic the properties of the natural tissue. Several different model systems have been studied, including double network hydrogels consisting of dimethyl acrylamide (DMA) and 2-acrylamino-2-methylpropane sulfonic acid (AMPS), and a poly(ethylene glycol) bottlebrush polymer (non-polyzwitterionic) was imbedded into DMA double network gels to explore effects on the material's properties. We have measured the Young's modulus of our hydrogels and have identified a suitable system that has a modulus similar to that of natural cartilage.

Using Real-World Training Data and Machine Learning to Detect Voter Fraud in Honduras
Ethan Eason
Mentor: R. Michael Alvarez

Utilization of synthetic data with machine learning algorithms to build a model capable of voter fraud detection has been applied in the past, but the utilization of non-synthetic data to perform this same task is rather unprecedented. In 2017, there was a presidential election in Honduras that warranted a re-election. For my project, the original election data serves as a labelled training data set that was capable of training a model using supervised machine learning and could then be tested on unlabeled recount election data. I first used the python packages requests, pandas, and os to scrape data from a Honduran government website to construct data sets for both the original and recount elections. After working with extensive issues regarding the original election's data set, I elected to focus on vote shares and turnout data when implementing supervised machine learning. My continuation of this project will focus on finishing construction of the classifier (model) and testing said classifier on the recount election data.

Finding Asteroids With the Zwicky Transient Facility
Bassel El Amine
Mentors: George Helou and Frank Masci

Near-Earth Asteroids (NEAs) are of primary concern as they pose threats to our civilization and provide considerable opportunities for resource utilization in future space activities. Although many NEAs have successfully been discovered using previously implemented detection algorithms, efforts to accurately detect fainter and thicker streaks have been hindered due to a lack of sensitivity and precision in the current methods used. As a tradeoff, increasing the number of real asteroid streaks (i.e. the "true positives") inevitably leads to the increase of falsely detected streaks (the "false positives"), which we aim to reduce. To overcome these limitations, an image-segmentation approach has been devised using an online resource named ASTRiDE (Automated Streak Detection for Astronomical Images) to trace out the boundary of various shapes in astronomical images and output their morphological parameters, which are in turn used to classify the objects and filter out false positives using carefully constructed filtering schemes. The newly implemented algorithms are expected to yield additional fainter and thicker streaks and to reduce false positives.

Shearing of Granular Material: Measurements Using a Powder Rheometer
Olivia Ernst
Mentors: Melany Hunt and Shahrzad Roshankhah

Flows of granular materials and complex fluids, such as sand, powders, or slurries are less understood than single-phase Newtonian fluids, such as water and air. This behavior is hard to predict because granular matter can act as both a solid and a liquid within the same flow. Granular material is especially important in civil engineering applications, geophysical phenomena, as well as in the food and pharmaceutical industry. Understanding the behavior of powders can be helpful in these industries in order to streamline transportation and storage.
The Anton Paar MCR 302 Rheometer has been used to collect data using four different types of granular material (Kelso Dune Base, Kelso Dune Crest, along with glass beads with mean sizes of 300 and 400 micrometers) with three types of plates (stainless steel, Teflon, and Warren Spring). The stainless steel and Teflon plates are used to determine the wall friction angle, while the Warren Spring provides information on undrained shear strength of the material. The initial conditions of the materials should be very similar, so we consider physical properties such as particle shape, size, and angle of repose when explaining the data.

Bounding Entanglement in Two-Player Non-Local Quantum Games
Sergio Escobar
Mentors: Thomas Vidick, Andrea Coladangelo, Alexandru Gheorghiu, and Anand Natarajan

We study tests for verifying entanglement based on parallel repeated quantum games. Such tests are an important ingredient of device-independent quantum cryptographic protocols which are secure even if implemented on faulty or partially malicious devices. In this work we (hope to) show that any devices that are capable of winning the n – fold threshold CHSH game (in parallel) with probability better than the classical bound must share $\Omega(\sqrt{n})$ qubits of distillable entanglement. Our guarantees hold even for devices that pass the test with exponentially small probability, improving on prior work based on self-tests. This analysis builds on techniques from the proofs of parallel repetition theorems for classical and quantum games.

On-Board Implementation of Distributed Pose Estimation for Robot Swarms
Aaron Feldman
Mentors: Soon-Jo Chung and Kai Matsuka

Coordinating movement within a swarm of spacecraft requires each robot to accurately know its pose (position and attitude) with respect to the other robots, a process referred to as relative pose estimation. Individual robots can perform relative pose estimation using, for instance, standard computer vision algorithms. However, measurement error and deviations from expected dynamics introduce inaccuracy and uncertainty. These relative pose estimates can be improved by leveraging a robot's communication with its neighbors. Each robot collects the measured pose estimates from nearby robots and incorporates this information into its pose estimation filter. While previously tested in off-line simulation, this work implemented the algorithm so that it can simultaneously run on-board several robots in a decentralized fashion. By using visual markers, robots obtain pose measurements of their neighbors which are broadcast and then collected for filtering. The effectiveness of the algorithm is shown through robotic experiments wherein each robot's relative pose estimates are dynamically graphed, analyzed, and compared against a standard approach.

Towards Semantic Interpretation of Sketches
Nicole Feng
Mentors: Julie Dorsey, Sherry Qiu, and Al Barr

Sketching is an extremely common tool for rapid exploration of early design ideas, yet there has been little work in computer vision or graphics on understanding sketches themselves. In this work, we develop methods towards machine understanding of this often messy mode of human visual output, such as segmentation of sketches into semantically meaningful components, extraction of depicted regions, and identification of various stroke types. Using a dataset of sketches collected in vector format from an online drawing interface, we explore the applications of semantic interpretation of sketches for enabling new methods of sketch analysis, and exploration of 2D sketches without perfect or physically realizable geometry.

A Simple, Sn(II)-mediated C-H Functionalization of Azine N-oxides
Weida Feng
Mentors: Brian M. Stoltz and Christopher Reimann

Natural products containing nitrogen are an essential category of targets in organic synthesis, with nitrogen-bearing functional groups present in a majority of pharmaceuticals. In recent research, our group found that Sn(II) can act as an N-oxide activator to accomplish C—H functionalization of azine N-oxides, which is a potential method for the synthesis of compounds containing nitrogen. The goal of this work is to explore the best conditions of the reaction between amines and azine N-oxides to form C—N bonds. We screened different solvents, tin salts, bases, temperatures as well as reaction times of the reaction to find the best condition. We will also try different scales, amines and azine N-oxides to investigate whether the reaction is widely applicable. If successful, this reaction can offer a new method of building C—N bonds in many complex molecules through the strategy of C—H bond functionalization.

Dry Granular Transport Over Bedrock as a Potential Process for Gully Erosion
Jade Fischer
Mentors: Michael Lamb and Alexander Beer

Bedrock gullies with alcoves and channels are found on rocky slopes of Mars, Earth, and the Moon. Their formation is typically associated with fluvial or debris flow processes. It remains unclear how dry granular transport contributes to gully formation, and specifically how surface slope, grain size, and grain angularity affect this potential erosion process. We report on experiments of dry granular transport in tiltable flumes filled with polyurethane foam, whose erosive resistance scales with bedrock tensile strength. Grains of multiple sizes and angularities were imaged while traversing down flumes at 165 fps from lateral and vertical perspectives using machine cameras. We calculated grain trajectories, hop dimensions, and impact velocities, angles, and energies using lateral images, and analyzed grain dispersion across the width of one flume using vertical images. Initial results on grain runout, trajectories, and associated erosivity show that angular grains start bedrock channelization on slopes near the angle of repose (35°), and that round grains erode bedrock even at slopes far below this angle (20°). Based thereon, we discuss implications for resulting topography and erosion process interaction. Potential application of this work is assessing the contribution of dry granular erosion towards channel formation on planetary surfaces.

Investigating the Degradation of the Phenazines Iodinin and Myxin
Sofia Flores-Rojas
Mentors: Dianne K. Newman and Daniel Dar

Phenazines are secondary metabolites present in the rhizosphere, the area around plant roots that hosts a complex microbial community. Member of this community produce redox-active metabolites called phenazines that are involved in signalling, act as biocontrol agents and stimulate biofilm development. However, phenazines can also be consumed by bacterial degraders that utilize phenazines for energy; degradation may thus influence phenazine biocontrol efficiency. Accordingly, we set out to observe phenazine producer/degrader interactions. The Newman lab recently isolated the degraders *Mycobacterium fortuitum* and *Sphingomonas wittchii* in the same soil as a phenazine producer, *Dyella japonica*. To test whether *M. fortuitum* and *S. wittchii* degrade the phenazines, Myxin and Iodinin, produced by *D. japonica,* we optimized a medium for maximum phenazine production. This medium was extracted to partially purify phenazines for future degradation trials in which the degraders will be inoculated into a phenazine-enriched medium. If phenazine consumption is confirmed, we will sequence and search the genomes of the degraders for known phenazine-degradation genes. Finally, interactions between phenazine producers and degraders in the presence of a host plant such as *Zea mays* will also be tested. These studies will contribute to assessing whether phenazine-based interactions are important in the rhizosphere.

A Proof-Theoretic Model of Chemical Inference
Carlos Focil Espinosa
Mentors: Erik Winfree and Andrés Ortiz-Muñoz

Various models have been developed with the aim of understanding and characterizing the fundamental properties of living systems and guide the design of artificial life-like forms. However, our knowledge about how the molecular mechanisms inside the cell help it to make complex decisions remains obscure. To address this question, we hypothesize that the molecular systems inside the cell could have learning properties that help them to infer information about its environment. Here we design a model of a compartmentalized molecular system based on the syntactical and deductive properties of propositional calculus. Our model is able to incorporate information from the environment in the form of axioms and use an internal deduction processes to generate knowledge that can be used in decision-making. We are interested in two aspects of the model: evolution and autonomy. In order to study the ability of the system to adapt to its environment we put it in the context of the replicator equation from evolutionary game theory. The concept of autocatalytic sets, which is roughly a chemical system's ability to generate a complete set of catalysts, provides the context for the study of the self-maintaining and self-generating properties of our model. Future research will explore similarities between formal logic and molecular systems and how this approach can help us increase our understanding about living systems.

Creating an Extensible Virtual Reality Classroom Experience Compatible With Third Party Services
Sasha Fomina
Mentors: Santiago Lombeyda and George Djorgovski

The gaming industry has catalyzed the fast-paced advancement of immersive Virtual Reality (VR) technology. However, there exists somewhat untapped educational benefits in the realm of VR. A VR classroom can create a shared virtual space that mimics in-person teacher-student interaction and student collaboration without the obstacle of physical distance. Additionally, this VR classroom creates an opportunity for a new brand of "lab" exercises only feasible in a virtual, immersive space. In this project, I have continued work on a prototypical VR classroom built in the Unity game engine, refining existing features to make for a more natural student experience with the advantages of the newest updates in the core technology. Using low-level networking interfaces, I have also created a server-client protocol in order to incorporate MATLAB functionality into the VR space and create a lab exercise for visualizing multivariable mathematical functions. Through the generic plugin architecture of the server's design, this project aims to facilitate future collaboration with Caltech educators, and, in turn, integration of more labs with extensions in MATLAB or other third-party services.

Interaction of Neuroligin With PSD-95 in the Postsynaptic Density of Excitatory Synapses
Scott Fordham
Mentors: Mary Kennedy and Tara Mastro

Neuroligin-1 is a transmembrane protein which binds to a presynaptic protein in the synaptic cleft in order to help form the synaptic junction. It is anchored on any one of the three PDZ binding domains of the scaffolding protein, PSD-95. In order to quantify its affinity for PDZ123 binding sites, a fusion protein of maltose binding protein with cytoplasmic tail of neuroligin-1 is being purified in a HaloLink resin and will be tested with surface plasmon resonance (Biacore). Understanding the affinity of neuroligin-1 for the PDZ domains is important for understanding the competition for the binding sites themselves in the post-synaptic density. Once quantified, the affinity of neuroligin-1 for the domains will be compared to other synaptic proteins such as SynGAP that are able to compete for binding of the PDZ domains of PSD-95. Quantifying the competition between these molecules will illuminate the biochemical mechanisms that underlie long-term potentiation. Further research should explore the binding of other proteins in the postsynaptic density and the importance of avidity to the competition between the proteins that compete for binding to the PDZ domains of PSD-95.

Evaluation of 2D Material Nanoribbons Created Using Electron Beam Versus Helium Ion Beam Lithography
Matthew Fu
Mentors: Nai-Chang Yeh and Matthew Hunt

Two-dimensional (2D) materials are defined as single layer crystals, some of which, like transition metal dichalcogenides (TMDCs) and graphene, have unique properties that have allowed researchers to imagine many novel electronic devices, but are incredibly thin and easily damaged during nano-fabrication. Here we introduce helium ion beam lithography (HIBL) as a patterning technique for creating 2D material nanoribbons with potentially higher resolution than electron beam lithography (EBL) because the helium ion beam probe size at (0.5 nm) is significantly smaller than that of the electron beam at (2-3 nm). The damage imparted by the two beams to the resultant nanoribbons can be quantified and compared via Raman spectroscopy, a technique that has been used to successfully quantify graphene edge defects in other studies. In order to attain the highest resolution lithographed patterns, we performed dose tests of HIBL versus EBL on two electron beam resists, PMMA and ZEP520A, each at multiple thicknesses on arrays of nanoribbons having widths ranging from 10 to 150 nm. In addition to these experiments, first principle Density Functional Theory calculations have been conducted on nanoribbons with various edge terminations and geometries in order to determine the Raman spectrum as a function of edge defects.

Design and Construction of an Inverted Pendulum on a Cart for Nonlinear Controls Research
Andrew Galassi
Mentors: Aaron Ames and Andrew Singletary

The inverted pendulum on a cart is a classic nonlinear controls problem that can be applied to many robotic systems from legged robots to drones, prosthetics, and exosuits. This project involves the design and development of a robust pendulum-cart testbed on which novel nonlinear control strategies can be experimentally developed. Structural analyses were performed to ensure the mechanical reliability of the testbed, and the dynamic loading of the cart bearings was examined in order to minimize friction. The system is controlled in real-time with an Intel NUC using Robot Operating System (ROS), and is actuated with a Nippon Pulse linear motor and ELMO Solo Gold Twitter motor controller with CAN communication. A second actuated cart will ultimately be added in parallel with the initial pendulum cart via a force-torque sensor, enabling experimental research focusing on cooperative actuation.

Towards the Synthesis of a M_4O_4 Cubane Cluster to Model Oxygen Evolution Catalysts
Elisabeth Gallmeier
Mentors: Theodor Agapie and Angela Shiau

Artificial Photosynthesis has the potential to replace our dependence on fossil fuels by turning sunlight into clean, renewable fuels such as H_2. Unfortunately, artificial photosynthesis is hindered by a lack of cheap, efficient catalysts that can compete with the efficiency of the Oxygen Evolution Complex (OEC) in Photosystem II to produce molecular oxygen and four protons from water. Developing model complexes to understand the mechanism of the catalytic cycle of oxygen evolution can contribute to developing and improving catalysts, such as cobalt-oxide materials that have been explored as potential heterogeneous catalysts. This work focuses on the synthesis and study of M_4O_4 cubane clusters supported by a naphthyridine-based ligand currently being synthesized. An open edge on the cubane will serve as a molecular model of the surface of heterogeneous metal oxide catalysts. Following metalation, future work will entail characterization via x-ray crystallography, electrochemistry, and reactivity studies of oxygenous ligands supported by the M_4O_4 cubane cluster.

Gastric Cancer Patient-Derived Organoids and Organoid Review
Thomas Gallup
Mentors: Charles Lee, Jieun Lee, and Mikhail Shapiro

The Lee lab at Ewha University focuses on pancreatic and gastric cancer, using gastric cancer patient-derived and patient-derived xenograft (PDX) material to generate personalized cancer models in culture. Using newly developed culturing techniques, the Lee lab can grow patient and mouse samples as “organoids” – 3D, self-organizing cell clusters that more closely mimic patient tissue than conventional, 2D cell lines. These organoids have multiple applications in cancer research, including high-throughput screening for drug development and personalized treatment. This SURF focused on the generation and expansion of gastric cancer organoid cultures from PDX tissue for use in drug testing for novel gastric cancer therapeutic agents. Secondly, as organoid cultures are a recent development in biology research, an extensive literature review of organoid technology across multiple tissue types (breast, bladder, pancreatic, gastric, and more) was conducted in preparation for publication.

Engineering MARS Dyes for Live Cell Multicolor Imaging
Jia Gao
Mentors: Lu Wei and Jiajun Du

Live cell multiplex imaging is highly desired because current fluorescence microscopy can only resolve no more than five colors. Raman microscopy is a promising candidate for multiplexed imaging owing to narrow Raman peaks. However, the inherently weak Raman signals make imaging of many bio-targets with Raman microscopy impossible. Recently developed electronic pre-resonance stimulated Raman scattering (epr-SRS) pushes the detection limitation down to 250 nanomolar on a serial of triple-bond-conjugated near-infrared dyes, comparable with fluorescence imaging[1]. But these palettes are not applicable to live cell imaging for their severe non-specific staining. Here we propose to modify the existing epr-SRS dyes with previously reported acetoxy-trifluoro methylbenzyl (AcOTFMB) group protecting sulfonate esters[2]. This chemically stable but esterase labile protection group can preserve high cell loading of dyes while reducing backgrounds. Based on our preliminary data, we design three target molecules and possible synthesis routes, trying to filling the gaps between existing epr-SRS microscopy and live cell imaging.

The Influence of Continuum Emission on Intensity Mapping Predictions for SPHEREx
Zucheng Gao
Mentor: James Bock

Intensity mapping (IM) has been an emerging tool for studies concerning large-scale structures (LSS) and early universe. As the problem of difference in H0 results grew more intense (3σ), it indicates that we need to obtain a more precise information about history of universe and _CDM model. It has been proved that IM could apply a strict constrain on the universe model through baryon acoustic oscillation (BAO) measurement. However, in actual observation, there remains several degeneracies and contamination for each line that we intend to measure. Among which, the influence of continuum emission is hard to deal with. The observation of the intensity map for a given line from a particular redshift will contain intensity of continuum emissions from other redshifts, whose influence we do not actually know how to deal with. Thus, our goal is to build an mock observation for this promising device, the Spectro-Photometer for the History of the Universe, Epoch of Reionization, and Ices Explorer (SPHEREx), and to analyze the influence of continuum for each line and then to develop a method to extract relatively pure intensity mapping signal. To approach this goal, we use the recent large simulation, Hidden Valley simulation, assigning continuum to each catalog and to generate intensity maps for SPHEREx accordingly.

Thermal Studies on the Sensors for the Barrel Timing Layer of the MIP Timing Detector
Madeline Gardner
Mentors: Maria Spiropulu and Lautaro Narvaeze

Cern's particle accelerator (the LHC) is becoming the High-Luminosity Large Hadron Collider to study Beyond the Standard Model Physics. Bunched collisions will increase, so the MIP Timing Detector is being developed by CMS. The BTL of the MTD utilizes SiPM sensors whose operating temperature must be reduced below -30°C to reduce dark current. This project conducted thermal studies on the cooling system for these sensors. We approximated the thermal effects of the SIPMs with PCBs of resistors lining brackets on a prototype of the cooling plate. We cooled this setup in a -40°C freezer with initial nitrogen gas flow to reduce humidity. The resultant steady state temperature gradient was measured by thermistors placed at points of interest. There is a larger difference in the temperature of the heat sources and that of the cooling system than expected. We made various changes to improve thermal contact. We have studied the effects of ceramic contacts with Alumina strips with this setup, simulations, and a liquid chiller. Ceramics cause a larger gradient from the heat sources across the plate but may not cause them to be higher in temperature. The setup developed here will be employed in further thermal studies with the SiPMs.

The Synthesis and Characterization of the Biologically Relevant Phenazines Iodinin and Myxin
Dana P. Gephart
Mentors: Sarah Reisman and Caitlin Lacker

Many microbes, such as *Psuedomonas aeruginosa*, produce brightly colored pigments when cultured in the lab. These secondary metabolites can play metabolic, antimicrobial, and other roles to not only the species that produces them, but also any other microbes within the microbiome. One family of secondary metabolites produced by *P. aeruginosa* is phenazines, which are used as extracellular electron shuttles and antibiotics due to their redox-active properties. Importantly, this allows *P. aeruginosa* to survive in reducing environments, such as the lung sputum of patients with cystic fibrosis. However, there are many phenazines whose roles in the microbial environment are somewhat unknown. Two such phenazines are iodinin and myxin. These closely-related di-N-Oxide phenazines are able to undergo one electron reductions in anoxic conditions to yield nitroxide-hosted radical species. This reactivity, along with their ability to their ability to intercalate with DNA, most likely explains the cytotoxic and antimicrobial effects previously documented. We have successfully synthesized small amounts of both iodinin and myxin and will be documenting their redox properties and effects on microbial communities such as biofilms in the future.

Constructing a Fully Optimized A2A-fullGs Protein Complex Using the A2A-miniGs Cryo-EM Structure
Monika P. Getsova
Mentors: William Goddard and Saber Naserifar

Using a structure of the human beta2 GPCR receptor protein anchored onto a full Gs protein, we attempt to complete the mini-Gs protein in the cryoEM structure of the A2A GPCR which is found on the protein data bank website (rcsb.org) with PDB ID 6GDG. We attempt to create anchors like those in the original A2A structure in our new structure using distance constrains on MacroModel Minimization in Maestro.

Nonlinear Elastic Ribbon Structures: Applications to Space Structures and Biorobotics
Luca Girardi
Mentors: Sergio Pellegrino and Armanj Hasanyan

Nonlinear elastic structures suffer from uncertainty in their spatial configurations, thus limiting their fields of application. In the present work, an analysis of a particular ribbon-based nonlinear structure is presented, with possible applications in the fields of deployable structures and biorobotics. The structure is composed of a set of thin elastic ribbons bounded to a rigid rod. It has two degrees of freedom where its kinematic boundary conditions are imposed by applying a rigid rotation and/or a vertical translation at one end of the ribbon bundle. The study proposes a characterization of the stability of its equilibrium configurations, based on the adaptation of existing mathematical models for thin elastic rods, and aided by finite element analyses. The ribbon structure has been laser-scanned at different configurations and, to validate both the mathematical and the finite element models, an algorithm for the detection of the ribbon centerline and the local directors frame from the 3D-scanned point-cloud data has been developed. An experimental analysis of the path-dependence and reversibility regions in the two-dimensional parameters space has been accomplished in order to define operating patterns of such a structure. Among the proposed applications, the study and realization of a table-top prototype of a biomimetic crawling robot is presented.

Modeling Grain Boundary Evolution Due to Energetic Anisotropy
Mahi Gokuli
Mentors: Brandon Runnels and Julia Greer

Due to their electronic and structural properties, crystalline materials (e.g. metals) have many uses, from computer chips to vehicular and body armor in space and military applications. In single-phase crystals, interfaces called grain boundaries separate differently oriented regions of the crystal lattice, affecting material properties and processes on varying length scales. These boundaries are characterized by tilt and twist rotations coinciding the grains about axes perpendicular and parallel to the normal of the boundary plane, respectively. The interfacial energy is therefore anisotropic and nonconvex, exhibiting cuspy minima for energy-minimizing orientations. An experimentally observed consequence of minimizing this nonconvex energy is that grain boundaries display a faceted “zig-zag” structure. We model the development of this complex microstructure starting from a very energetically anisotropic interface using a nonconvex energy profile, obtained by matching atomic positions to a perfect (energy-minimizing) lattice and quantifying the local energy from the resulting mismatch. To evolve the interface, we use a phase-field model, in which a field tracking the presence of the phase at each point is evolved towards a minimal energy configuration. This allows us to model anisotropy-dependent microstructural evolution varying with crystal structure, lattice constant, temperature, and rotation axis and direction.

***Caenorhabditis elegans* Dauer Development as a Model to Understand Different Neurological Processes**
Carolina Gonzalez-Cavazos
Mentors: Paul Sternberg and Mengyi Cao

The relatively simple nervous system of *C. elegans* makes it a potential model to study different complex neural diseases, such as autism spectrum disorder (ASD). A published study in Sternberg laboratory identified conserved human ASD-missense variants in *C. elegans* orthologs that have a role on locomotion and egg-laying behaviors, suggesting *C. elegans* as an efficient phenotypic model to study conserved ASD mutants. The aim of this project is to further explore if *C. elegans* dauer-entry decision is affected by the previously published ASD-associated alleles. We assessed the dauer-entry percentage of previous generated autism-associated missense mutation strains, using crude pheromone as a signal of high population density and heat killed bacteria as a low food supply. We first tested a group of ASD-associated missense mutants of *daf-18,* a *C. elegans* ortholog of human protein PTEN. Our data show that *daf-18* missense mutants H168Q and D66E have a wild type phenotype, while H138R and T176I mutations have a severe dauer defect phenotype. Since H138R is predicted as a conserved amino acid at DAF-18 phosphatase active site, we rationalized that *daf-18* missense variants that are shown to affect dauer-entry decision (H138R and T176I) reveal crucial amino acid positions that engage in protein functions. These data support our model that dauer-decision could be a robust assay to screen functionally important ASD-associated missense alleles. We are currently testing more ASD-associated missense variants in multiple other genes. The results obtained in this project will help to prioritize functionally important missense variants for further detailed studies in vertebrates.

Studying the Hydrogen Loss Rate in the Martian Atmosphere
Aikaterini Gorou
Mentors: Mitchio Okumura, Douglas Ober, and Gregory Jones

To learn about the history of water on Mars, atmospheric chemists look to the presence of hydrogen in the Martian atmosphere, since water is the ultimate source of all atmospheric hydrogen species. However, to understand what happened to Mars's water from the concentration of atmospheric H, scientists need to also understand the chemical reactions occurring in the atmosphere for the H concentration to reach its current conditions. The program Kinetics, run by the Yung group at Caltech, was used to test the sensitivity of Mars's atmosphere to rate coefficient changes. The mixing ratios of HO_x species in the Martian atmosphere were most sensitive to changes in the rate of the termolecular reaction $H + O_2 + M$. This result is in accordance with a recent paper proposing a large increase in the rate of this reaction (134-310%) for Earth's atmospheric conditions (Li et al., 2017). Given the sensitivity of the atmosphere to changes in the rate of this reaction and the uncertainty in its rate for Martian conditions, the proposed rate coefficient increase could have a very large effect on the escape of hydrogen from Mars's atmosphere.

DNA Robotic Systems With Embedded Reversible Boolean Circuit Computation
Gokul S. Gowri
Mentors: Lulu Qian and Sam Davidson

DNA is an extremely versatile engineering material. It is used widely both for its structural properties as well as its information bearing capabilities. Thus, DNA systems are particularly well-suited for tasks that have both nanomechanical and computational components. In 2017, the Qian lab demonstrated a DNA cargo sorting robot which simultaneously performed the nanomechanical task of transporting cargo and the computational task of sorting. Here, we show that the same system could be modified to exhibit more complex computational behavior. In particular, we present designs for decentralized groups of DNA robots whose destinations for molecular transportation are determined by their interactions with each other, which collectively encode reversible Boolean logic computation. Furthermore, we assess the speed and reliability of these designs through simulation and initial experimental characterization.

Evaluating Bonus, Mep1, and Mi2 as Putative Intermediates in piRNA-Mediated Chromatin Repression
Anastasiya Grebin
Mentors: Alexei Aravin, Baira Godneeva, and Maria Ninova

Transposable elements (TEs) are genomic parasites suppressed by the cell. The model developed by the Aravin group for the connection between piRNA-mediated repression of TE transcripts and repressive chromatin modification involves Su(var)2-10, which has been established as a SUMO E3-ligase. Candidates include Bonus, a *D. melanogaster* homolog of KAP1, Mep1, and Mi2. KAP1 is a mammalian SUMO E3-ligase that interacts with KRAB-ZFPs and also with Mep1 and Mi2, proteins associated with HDAC activity. Yeast two-hybrid assay identified Mep1 and Mi2 as potential effectors in the Su(var)2-10 pathway. This project evaluates Bonus, Mep1, and Mi2 as participants in the mechanism. We found upregulation of TEs for Mep1 and Mi2 germ-line knockdown (GLKD), as well as upregulation of sensor genes that typically respond to pathway disruptions. We found the reverse in Bonus GLKD -- downregulation of TEs and sensors; we plan to perform RNA-seq to reveal global changes in TE and gene expression upon Bonus GLKD. Co-IP experiments on Mep1 show that it is SUMOylated *in vivo*, potentially by Bonus or Su(var)2-10. Future work includes H3K9me3 ChIP-qPCR on Mep1 and Mi2 KD to tie them to chromatin condensation as well as confirmation of the Bonus qPCR results.

Fracture Mechanics of Micro-Lattices
Ivan Grega
Mentors: Julia Greer, Bryce Edwards, and Widianto Moestopo

Lattices are an intriguing class of materials. They are light, because they mostly consist of empty space, yet they can be made relatively stiff thanks to clever architectural design. The aim of this project is to examine fracture properties of lattices and to explore the design space of toughening mechanisms in fracture resistance. *Octet-truss* and *3D-Kagome* architectures were chosen because octet is a simple stretching-dominated structure and Kagome is reported to exhibit crack tip blunting. Compact tension samples with lattice size of 100 μm, and other dimensions adhering to ASTM standard were manufactured from polymer using two-photon lithography. Unit cell size of 5 μm was chosen in an attempt for separation of scales to enable the use of continuum approach. Frictionless pins are not realisable on this length-scale and torsion is present in the test. Therefore, theoretical work has been done to estimate the role of torsion, while experimental data was analysed to calculate the torque acting on the sample. Using a nano-indenter inside SEM makes it possible to record a video of the test. Digital image correlation was used to obtain the crack length, torque, and crack opening.

Preliminary results give critical stress intensity factors K_{IC} on the order of 0.1 MPa√m. The hypothesis is that if obstacles are introduced that could shape the crack surface, the increased crack surface area should lead to an increased fracture resistance.

Eruption Timescales of the Columbia River Basalts
Marcel Griffioen
Mentors: Joseph Kirschvink and Joseph Biasi

The Columbia River Basalts (CRBs) make up the youngest and best-studied flood basalt province in the world, covering most of Oregon and parts of the neighboring states with a volume of almost 175,000 km^3. However, one quantity that is not well-constrained is how long the eruption events lasted. Our aim is to use paleomagnetics to provide a constraint. We took transects of dikes in some of the large dike swarms that fed the CRBs in order to determine how far away from the dike the wall rock was heated enough to reset its magnetic moment. By measuring the magnetic properties of these samples using superconducting quantum interference device (SQUID) magnetometry techniques, we can calculate how long each dike was erupting for. The volume of samples we gathered is too great to be analyzed in a few weeks, however the preliminary results are in line with predictions from other research groups, indicating that this methodology should yield valid results. The remaining samples will be analyzed over the coming months.

Linear Mixed Model APOE-Stratified Genome-Wide Association Studies of Alzheimer's Disease
Nora Griffith
Mentors: Michael Greicius, Michael Belloy, and Marianne Bronner

Alzheimer's Disease (AD) is known to have a strong genetic component. Of the known sources of heritability, the E4 allele of the apolipoprotein E gene (*APOE4*) is the most potent genetic risk factor for sporadic and late-onset familial Alzheimer's. The *APOE* ε4 and ε2 alleles explain about 25% of genetic variance of AD, leaving almost 70% explained by undiscovered single nucleotide polymorphisms (SNPs). We plan to perform genome-wide association studies (GWAS) to find a list of candidate variants contributing to the genetic risk of AD. However, using a generalized linear model restricts our analysis to unrelated subjects. By implementing a linear mixed statistical model (BOLT-LMM package), we are able to include related subjects, thus increasing statistical power and, as a result, the likelihood of finding variants that may have been overlooked. We will perform a variety of genetic association tests on publicly available SNP-array data of Northwest European subjects spanning 28 cohorts. We plan on following up on candidate variants by exploring their potential relevance with literature searches and in-silico functional assays.

Enhancing of a Parallel Transport Unfolding Python Library
Olivia Grobowsky
Mentor: Mathieu Desbrun

Isomap is a commonly-used algorithm that exploits the Manifold Hypothesis in order to project high dimensional data sets into lower dimensions. Isomap, however, only produces precise parameterizations for geodesically convex regions. Thus, any input with a void in the data points yields a parameterization where the void is larger in the lower dimension that in the higher dimension. The Parallel Transport Unfolding method uses metric connection to approximate distances between neighboring points and MultiDimensional Scaling to find the optimal low dimensional projection of the set. The parameterizations of datasets with voids using the Parallel Transport Unfolding method are accurate for irregular as well as non geodeiscally convex regions without increasing the runtime complexity. The goal of this project is to release an open source library written in Python that implements the Parallel Transport Unfolding method. The library allows users to input high dimensional data sets, and it returns accurate projections regardless of the geodesic convexity.

Observation of Single Photon Emitters in Defective 2D WSe_2
Jakob Grzesik
Mentors: Andrei Faraon and Ding Zhong

As silicon technology begins to reach the limits of Moore's Law, there is a rapidly growing need for new quantum-based technology. As a result, research in quantum information and quantum computation (QIQC) has been burgeoning in order to develop new devices to replace silicon in future communication and computation technological schemes. Among the many components involved in making such devices, one of the most central is the single photon emitter (SPE). SPEs are light sources that enable creation of photons "on-demand," making them valuable for various quantum communication and computing schemes. One promising platform is in the realm of two-dimensional (2D) materials, which are atom-thick variants of naturally present materials. In particular, we investigate monolayer WSe_2, produced by mechanical exfoliation primarily by use of optical photoluminescence (PL) experiments, verifying the presence of SPEs through previously reported optical properties. In the end, we were able to detect and verify SPEs through spatial-dependent PL, polarization-dependent PL, and the photon autocorrelation ($g^2(\tau)$) measurement. This work serves as a starting point into studies of intentionally induced and designed defect SPEs for future projects.

Expanding the Sense of Touch in Virtual Reality
Steve Guo
Mentors: Shinsuke Shimojo and Christopher Berger

The purpose of this project is to examine the psychophysical mechanisms of the out-of-body cutaneous rabbit illusion in VR, particularly the illusory expansion of touch outside the body using visuotactile sensory stimulation in virtual reality. Previous work has demonstrated that it is possible to elicit an illusory sense of touch in the space between the hands, though the scope of this application is limited. We aim to test the boundaries of this illusion by utilizing multisensory cues (e.g., visual and/or auditory cues), and altering shape and size of virtual objects rendered between the participants hands. The results from this project will help us understand the underlying psychophysical and neural mechanisms of the integration of auditory, visual, and tactile stimuli.

The Jacobson Conjecture
Arushi Gupta
Mentor: Dinakar Ramakrishnan

The Jacobson conjecture asks if the intersection of all powers of the Jacobson radical in a (left and right) Noetherian ring is zero. The conjecture has been proven in the cases where our ring is commutative or Krull dimension one. We attempt to clarify the proof for Krull dimension one, as well as examine some cases of rings of Krull dimension two.

Model Predictive Control to Predict the Dynamics of Biochemical Networks
Sabina Gutheim
Mentors: John Doyle and Carmen Amo Alonso

The study of biochemical networks has become increasingly important in recent years, especially in genome-scale metabolic network reconstructions. Dynamic Flux Balance Analysis (dFBA) is a commonly used mathematical tool for this purpose, however, it cannot offer information about the concentrations of internal metabolites, and predictions are only of steady state. Therefore, this project proposes the adaption of the optimal control method Model Predictive Control (MPC) to biochemical networks. Its goal is to overcome dFBA's limitations and give a richer insight into the behaviour of the system being studied, while preserving dFBA's key feature: being able to predict rich dynamic behaviours through sparse minimal data. The laws of thermodynamics are introduced as constraints, taken from the non-dynamical Energy Balance Analysis (EBA), together with an imposed locality constraint that is solved through the optimal control framework System Level Synthesis (SLS). In short, the extension of dFBA with MPC produces a simple but information heavy method of predicting the behaviour of metabolic networks, amongst others useful within the growing area of synthetic biology as well as in the study of the microbiome.

Decoding Approximate Holographic Quantum Error Correcting Codes
Sultana Hadi
Mentors: John Preskill and Grant Salton

Holographic theories of quantum gravity are some of the most successful marriages of quantum information theory and gravitational physics. Most notably, the AdS/CFT (Anti- de Sitter/Conformal Field Theory) correspondence is a duality between a conformal field theory (CFT) in flat spacetime and a theory of (quantum) gravity in one higher dimension. Since the two theories are dual, all the information in the bulk spacetime can be represented in one fewer dimension, reminiscent of an optical hologram. Recently, AdS/CFT has been reinterpreted using the language of quantum error correction. Toy models of these holo- graphic quantum codes have been proposed using tensor network models; one such network (known as the HaPPY code) is based on the well-known 5 qubit code. Continuous variable analogs of the HaPPY code have also been proposed, some of which have the property of being U(1) covariant codes. Independently of AdS/CFT, it is known that finite dimensional covariant codes cannot be perfectly error correcting, and bounds on the quality of such a code have been placed. In this work, we built simulations of both the 5 qubit HaPPY code and a U(1) covariant, continuous variable generalization of the HaPPY code. Our simula- tion uses the recently released TensorNetwork Python library. In addition to building the holographic tensor network, we also implement explicit decoders for each of the codes, as well as the so-called Petz map and twirled Petz map recovery channels. We then compare the recovery fidelity using each of these decoding methods to one another and, in the case of the covariant codes, to the known bounds on the quality of approximate covariant codes. Our results can help inform the development of more realistic, continuous variable tensor network toy models of AdS/CFT.

Computational Benefits of Optical Architectures for Neural Networks
Rashida Hakim
Mentor: Alireza Marandi

Optical architectures have recently attracted interest because they could potentially reduce the time and power required to run and train neural networks. A neural network is a sequence of layers of neurons, each consisting of a matrix multiplication and an elementwise nonlinearity. Specialized photonic architectures can perform the linear part (the matrix multiply) of each layer in a passive optical circuit at high speed and with little energy consumption. This project compares multiple proposed architectures of this type to traditional computers and suggests sizes and layouts of neural networks where there is potential computational benefit to using optics. In addition, this project investigates low power optical methods of generating the nonlinear portion of the neural network, including Kerr-type instability and electromagnetic induced transparency. This investigation suggests guidelines for baseline component performance before all-optical architectures can provide a power benefit as compared to current architectures.

Autonomous UAV Design for Aerial Spectroscopy
Richard Hamel
Mentor: Mory Gharib

In this paper we detail the design of an autonomous UAV for aerial spectroscopy in harsh, outdoor conditions for long periods. This vehicle is able to land autonomously on a designated landing pad under windy conditions, and is built to withstand minor bumps to maximize reliability during dangerous phases of flight. This UAV is part of a larger system involving an unmanned base station that provides power and shelter to the vehicle, allowing it to perform repeated flights over long periods of time without human intervention. In particular, this system will be placed on Little Ambergris Cay in the Caribbean for the USGS to perform routine surveys of microbial mats on the small oceanic island.

A Genome-Wide SNP Study: Population Structure of Myrmecophilus Rove Beetles
Austin Harvard
Mentors: Joseph Parker and Sheila Kitchen

Myrmecophiles, species that live in association with ants, have evolved numerous times over the past 100 million years. One species of rove beetle, *Sceptobius lativentris*, has evolved to live symbiotically within *Liometopum occidentale* ant colonies. Being obligate symbionts and having lost the ability of flight, it was hypothesized that *S. lativentris* dispersal range is limited and is aided by the use of ant trails, however the population structure of *S.lativentris* has yet to be characterized. Over the past year samples of both *S. lativentris* and *L. occidentale* from various colonies around Southern California were collected and their genomes were re-sequenced at 8-15x coverage. Using this low-coverage sequencing data we identified 1.28 million single nucleotide polymorphisms within the beetle sample and 1.05 million single nucleotide polymorphisms within the ant samples, which can be used to analyse gene flow and population structure of both partners. We found that *S. lativentris* form two main genetic populations irrespective of collection location, whereas the ants show more localized substructure with colony collection sites. In the case of *S. lativentris*, we found that samples collected from the same site are not always from the same genetic population indicating vast gene flow and dispersal potential contrary to our predictions. We did, however, identify around 20,000 SNPs under positive selection that might underlie recent local adaptation of the *S. lativentris* to their respective ant colony. Altogether, our results suggests that despite *S. lativentris* being flightless, they maintain high genetic relatedness across a broad geographic range in Southern California.

Vortex Fiber Nulling and Keck Planet Imager and Characterizer
Thomas Hayama
Mentors: Dimitri Mawet and Daniel Echeverri

The characterization of exoplanets is vital for understanding the formation of the universe and to plan future space exploration. Vortex Fiber Nulling (VFN) is a way to suppress the starlight for planets much closer to the star than was previously possible with conventional direct imaging techniques.
VFN feeds starlight into a vortex to create a phase pattern orthogonal to the mode of a single-mode fiber to suppress it, while still coupling planet light. VFN has already been proven to work with monochromatic light at 6×10^{-5} suppression, so now we are using a charge 2 vortex in the pupil plane and a polychromatic light source to prove that VFN works with polychromatic light.

We managed to achieve starlight suppression of 2.2×10^{-4} ($\pm.3 \times 10^{-4}$) with 3nm bandwidth and roughly 4.5×10^{-4} with 80nm bandwidth polychromatic light while maintaining 4.7% (±.2) averaged peak coupling by finding the optimal wavelengths to use as the light source and ensuring that the optical vortex is orthogonal to the optical axis. These results validate the VFN concept and show that it is a viable tool for exoplanet research.

Genetic Screen to Identify Factors Involved in Mitochondrial DNA Quality Control
Olivia Healey
Mentors: Bruce Hay and Marlene Biller

Neurodegenerative disorders such as Alzheimer's and Parkinson's diseases are currently untreatable, and affect almost half of those over 85. Recent studies have demonstrated a link between an increase in dysfunctional mitochondria and mitochondrial DNA (mtDNA), and the onset of these diseases. Improved removal of dysfunctional mtDNA may therefore impede the progression of neurodegenerative disorders. The Hay lab has previously developed a line of *D. melanogaster* with increased levels of dysfunctional mtDNA, and so increased levels of cell death, in specific tissues. This project seeks to identify genes which affect mitochondrial quality control by crossing this line with *Drosophila* either deficient in or with overexpressed genes of interest. This included *Drosophila* lines deficient in regions of the third chromosome, and lines containing RNAi against or overexpression of genes involved in metabolism or mitochondrial turnover. Preliminary results have identified some potential enhancers and suppressors of mitochondrial quality control. Further work will seek to expand the number of genes tested, and to determine which genes within deficiency regions are responsible for the phenotypes seen.

In-Vivo Evaluation of Engineered AAV Candidates for Acoustically Targeted Chemogenetics
John Heath
Mentors: Mikhail Shapiro and Jerzy Szablowski

Abstract withheld from publication at mentor's request.

Transposon-Mediated Transgenesis in *Dalotia coriaria*
Nicole Heflin
Mentors: Joseph Parker and Mina Yousefelahiyeh

Several species of Aleocharine rove beetles have convergently evolved into myrmecoids. Not only have these species adapted a unique body structure resembling army ants, but they have also developed chemicals to attract and appease ants. As a result of these evolutionary developments, myrmecoid beetle species are able to inhabit ant nests where they groom with ants and feed off of the brood. Although these species are distinct, they all have a similar physical appearance to the free-living rove beetle *Dalotia coriaria*. My research aims to develop *Dalotia* into a new model organism to further understand this convergent evolution. By using transposable elements and, in the future, the Gal4/UAS system to alter the genome of *Dalotia*, we hope to create a transgenic line of beetles that will enable us to conduct calcium imaging in the brain, giving insight into how these free-living beetles think and behave during their interactions with army ants. Although we are still in the preliminary stages of developing a transgenic line of beetles expressing a red fluorescence throughout their body plan, further research will allow us to draw conclusions about predispositions towards this evolutionary relationship.

Analyzing the Inhibition of DNA2 by Rad51 and FANCD2
Sophia Marguerite Hewitt
Mentors: Judith Campbell and Piotr Polaczek

When cellular DNA experiences a double strand break, initial processing requires that the ends be resected. However, this must be regulated so as not to degrade the whole genome. We are studying two potential regulators of this resection. DNA2 is an ATP-dependent helicase/nuclease that plays a role in several parts of DNA replication and repair, including homologous recombination. Rad51 is a DNA repair protein that forms filaments along single strands of DNA and inhibits the function of DNA2. FANCD2 is activated in response to DNA damage, and the lab hypothesizes that it behaves similarly to BRCA2 in that it helps stabilize Rad51 strands and therefore increases the inhibition of DNA2. To analyze the interactions between the three proteins, we used a strand exchange assay, in which one long single-stranded DNA invades a shorter 5' radiolabeled double-stranded hybrid; the single strand replaces one of the double strands, and the new complex now contains the radiolabel. The amount of successful strand invasion can thus be measured by separating the different double-strand complexes on a native gel. We have been able to characterize the effects of Rad51 on DNA2 by titrating Rad51 in the presence of DNA2. We have also been able to show that the presence of FANCD2 increases inhibition in the presence of Rad51. A mutant form of FANCD2 that cannot bind to double-stranded DNA behaved as wild-type in the presence of Rad51, suggesting that FANCD2 normally interacts with the Rad51 filament and not the double strand. We conclude that FANCD2 interacts with and helps stabilize the Rad51 filament, which increases Rad51's inhibition of DNA2.

Magnetic Shielding Characterization for Bicep Array Telescope
Edgar Hildebrandt Rojo
Mentors: Jamie Bock and Ritoban Basu Thakur

The Cosmic Microwave Background (CMB) is electromagnetic radiation from the beginning of the universe. The BICEP2 and Keck Array telescopes at the South Pole measure the CMB very finely to better understand the beginnings of our universe. This study was centered around the new BICEP Array telescope and ensuring its functionality before deployment to the South Pole. Specifically, we focused on the newly installed magnetic shielding. We generate external magnetic fields and measure that same signal in the sensors inside the telescope, deriving the effectiveness of the shielding. The main difficulty lies in detecting the shadowed signal inside the telescope, which is very low and easily confused with instrumental noise, and extract the actual attenuation. My method is able to easily detect signals that are 10x smaller than the noise. Looking at previous data, we are only able to detect the magnetic signal at the highest levels. Now, we will proceed to analyze the most recent data.

Analyzing Single Cell RNA-Seq Data With PopAlign
Zev Hirt
Mentors: Matt Thomson and Sisi Chen

Implementing single-cell RNA sequencing (scRNA seq) data to evaluate an individual's health status is a new and uncharted territory. With a single sample of blood, scRNA seq can output the full gene expression profile of thousands of individual cells, which can be analyzed to give a thorough analysis of the cell populations and subpopulations in heterogenous cell-environments. Our lab has developed PopAlign, a pipeline which aids a user to analyze heterogenous cell populations with the help of dimension reduction and Gaussian mixture models. By running single-cell RNA sequencing data through the PopAlign pipeline, we are able to showcase the accuracy to which PopAlign can compare datasets and cell populations in the course of less than two hours. This project demonstrates PopAlign's ability to promote further research and to potentially be used to guide treatment for diseased cell populations.

A Quasi Geostrophic Model to Simulate Vortices in the Jovian Atmosphere
Carmen R. Hoek
Mentor: Andrew P. Ingersoll

Looking at the Jovian atmosphere we find several patterns of cyclones, which are evolving over time. The goal of this project is to create a new model based on the Quasi Geostrophic Equations (QGE) to describe the time evolution of the vortex patterns. In order to describe the vortex patterns, the equations must be solved for the stream function. The QGE give an equation similar to the Poisson equation with some added terms, and from this equation the stream function is found using Fourier Transforms. In order to evolve in time, the strong stability Runge Kutta 3rd order method is used. The second part of the project consists of comparing the results of the new model with the ones obtained from the Shallow Water Model (SWM). By running the simulations with equal input as for the SWM the new algorithms can give more insight in the results of SWM. The last part of the research involves adding a second layer to the model, creating a more realistic model of the cyclones. The extra layer in the model allows different flow directions in different layers which is a better approximation of the atmosphere of Jupiter.

A Fully-Integrated CMOS Biofuel-Cell-Based Energy Harvesting System
Gudrun Hoskuldsdottir
Mentor: Azita Emami

In this project, an integrated energy harvester system in a 65-nm CMOS process is to be characterized. The chip, including the energy harvester and a glucose sensor along with electrodes coated with proper enzymes form a system that would eventually be able to get powered from a lactate solution to measure glucose levels in the body. My involvement in this project includes wire-bonding several samples of the CMOS chips to a test PCB with extreme electro-static discharge protection procedures for the measurements. I am also involved in developing a VHDL code for an FPGA board to communicate with and debug the CMOS chip. Other responsibilities in this project have been using an oscilloscope to capture meaningful waveforms generated from the chip and post-processing them. A MATLAB code is developed to calculate power efficiency and frequency from the captured waveforms. Another code is also developed to model the whole system with relatively simpler electrical components. The measurement results will be used to characterize the simplified model as well as to be compared with previous simulation results. So far, initial measurements show that the chip is functioning as expected.

Identifying and Repairing Catastrophic Errors in Galaxy Properties Using Dimensionality Reduction
Beryl Hovis-Afflerbach
Mentors: Charles Steinhardt and Peter Capak

Our understanding of galaxy evolution is derived from large surveys designed to maximize efficiency by only observing the minimum amount of information needed to infer properties for a typical galaxy. However, for a few percent of galaxies in every survey, this is insufficient and derived properties can be catastrophically wrong, including identifying a relatively nearby object as one of the most distant in the Universe. Further, it is currently impossible to determine which objects have failed, so that these contaminate every study of galaxy properties. We develop a novel method to identify and repair these objects by combining the astronomical codes which infer galaxy properties with dimensionality reduction algorithms which group similar objects to determine which inferred properties are out of place. This method provides an improvement over the best existing techniques by at least a factor of two, which will improve every study that relies on large populations.

Characterizing Fracture Toughness of 3D Printed Lattice Structures
Sophie Howell
Mentors: Julia Greer and Bryce Edwards

Architected materials such as lattice structures can take advantage of geometric configurations to create materials with enhanced, previously unattainable mechanical properties. Much work has been done to characterize the mechanical properties of certain lattice geometries; however, there is little research available on the fracture properties of such lattices. Such properties are important for predicting how a material or structure will fail under stress. We designed and 3D printed single-edge notched beam specimens of both octet-truss and 3D Kagome geometry of both low and 26% relative density in order to calculate values of fracture toughness for these lattices and derive scaling laws relating relative density and fracture toughness. Four-point bend tests were performed using an Instron machine and K_{IC} values of fracture toughness were calculated for each sample according to ASTM standard E1820. Preliminary results indicate that fracture toughness does increase with relative density, as the 26% carbon octet lattice had a K_{IC} value of 26 MPa•$m^{1/2}$, over double that of any other sample. Future work will focus on testing more samples of varying relative density in order to determine precise scaling laws.

Identifying the Progenitor Stars of Stripped-Envelope Supernovae
Yu Hsiao
Mentors: Shri Kulkarni, Ulf Christoffer Fremling, and Lin Yan

Stripped-envelope supernovae are type IIb, Ib and Ic SN. These are all caused by the core collapse of massive stars. SN of different type show different spectroscopical features. The main question in the study of SE SN is about what is causing the lack of e.g. hydrogen in a Type Ib SN. Which is linked to what the origin of these SN is. There are two competing models currently: very massive stars and less massive stars in binary systems. In this project we focus on organizing the collection and analysis of late-time spectra of SE SN. At late times the outer parts of the SN ejecta is thin enough to allow us to probe the nucleosynthesis that happened in the center of the exploding star. Typically the oxygen mass can be derived, which is very strongly linked to the mass of the star when it was born. There are mainly three parts in this project. 1. Scanning for new SE SN, and classifying these supernovae using spectra. 2. Planning follow-up late-time observations of previously found SE SN 3. collecting, organizing of all nebular spectroscopy data on SE SN found thus far by ZTF.

Tandem Replicon Insertion After Transformation (TRINiTy): Large-Scale Genome Engineering in Eukaryotes
Hannah Hu
Mentor: Kihang Wang

The design and synthesis of entire genomes provide a powerful strategy for understanding basic biology and developing biomedical applications. However, the state of the art in the engineering of eukaryotic genomes is limited to that of small genomic fragments (≤100 kb). This is due to issues arising from the lack of effective negative selection markers for eukaryotic cells and their slow cell replication cycles. To solve such issues, we created Tandem Replicon Insertion after Transformation (TRINiTy) - a novel system that can potentially drive the precise, iterative insertion of large sequences of DNA into eukaryotic genomes by using the true gain of a unique positive selection marker in a set of three purposely designed replicons. The replicons, which are themselves iteratively inserted into the genome in a cyclical fashion, contain a promoter-less positive selection cassette in tandem with a single guide RNA (sgRNA) and a constitutively expressed Cas9. The sgRNA in the incoming replicon controls for the excision of the previously integrated marker, while the preceding replicon in the system targets for the linearization and integration of the incoming replicon. Only when the incoming replicon is successfully inserted into the genome does the unique positive marker gain its promoter activity. This system can therefore allow us to modularly engineer eukaryotic genomes with unprecedented scale, precision, and efficiency.

Whole Intestinal Imaging for Complete Enteric Neuronal Quantitation in Health, Disease, and Growth
Xinyue (Claire) Hu
Mentors: Marianne Bronner and Wael El-Nachef

The enteric nervous system (ENS) is intrinsic to the gastrointestinal tract and crucial for digestion, nutrient absorption, immune and endocrine function, and epithelial barrier homeostasis. Neuropathies in the ENS such as diabetic gastroparesis can manifest, where delayed gastric emptying occurs from the death of enteric neurons caused by elevated blood glucose levels. Previously believed to be terminally differentiated after development, there is also emerging evidence that post-embryonic enteric neurogenesis can still occur. However, a lack of reliable assays to assess for enteric neurogenesis and degeneration in adulthood has limited its study, since quantifying enteric neurons with standard histopathology has been controversial due to sample variability and the subsequent extrapolation of values to the entire organ. To bypass these issues, we developed an assay to image the whole intestine of an adult zebrafish, which shares many homologous genes and structures with humans. The sample is fixed into the shape of a tube, imaged with a light sheet microscope, reconstructed into a 3D model, and analyzed with a cell counting software. This assay has allowed us to successfully quantify enteric neurons in zebrafish and would allow for the study of ENS homeostasis in adult stages to further understand and treat enteric neuropathies.

Investigating Cooperative CO_2 Capture in Diamine-Appended M_2Cl_2(btdd) Metal–Organic Frameworks
Adrian Huang
Mentors: Jeffrey Long, Eugene Kim, and Gregory Fu

Mechanisms for the capture and sequestration of CO2 have been studied as a solution to the reduction of greenhouse gases in the atmosphere. Solid-state CO2 adsorbents are an attractive method for removing CO2 from effluent streams, and diamine-appended metal-organic frameworks have been successfully shown to capture CO2 from coal flue gas and natural gas flue gas streams. Reaching a critical threshold pressure of CO2 results in adsorption by reorganizing appended diamines into ammonium carbamate chains via a cooperative insertion mechanism, which produces unique step-shaped isobars and isotherms. Altering the diamine structure significantly affects the pressure and temperature thresholds of cooperative CO2 adsorption. Similarly, replacing the metal center and ligand used in the metal–organic framework drastically alters the ligand field properties of the framework. Here we assess the properties of the ligand BTDD
(BTDD = bis(1H-1,2,3-triazolo[4,5-b],[4',5'-i])dibenzo[1,4]dioxin) as a framework ligand for CO2 capture purposes across three different metal-organic frameworks using seven diamine-appended variants of each framework, each of which we expect to exhibit similar step-shaped sorption behavior.

Deep Learning for 3D Cell Segmentation and Augmented Microscopy
Kevin Huang
Mentor: David Van Valen

Deep learning holds enormous amounts of potential, including in the field of biology. The Van Valen Lab has been developing tools that help integrate deep learning with many problem domains in biological analysis, including DeepCell, a deep learning python library designed for cell segmentation. One capability of DeepCell is the segmentation of three dimensional cell image data, which was adapted to successfully segmented three dimensional organoid images. Another area of interest is augmented microscopy, the prediction of fluorescent cell labels from bright field microscopy images. The primary model used is a fully convolutional network, which has been successful in various tasks ranging from segmentation to image to image regression. The architecture, hyperparameters, and training methods were modified and optimized to apply to different problems, demonstrating the versatility of DeepCell.

The Structures of Several Parts of Human Sonic Hedgehog (SHH) Protein
Yiran Huang
Mentor: William A. Goddard III

The Hedgehog (Hh) signaling pathway is known for its links to Holoprosencephaly(HPE), Medulloblastoma and many other cancers. The human hedgehog proteins (Dessert, Indian and Sonic) in this pathway have some identified domains: N-terminal domain, C-terminal domains and the tail segment of the C-terminal domain, the sterol recognition region (SRR), which is help with cholesterol transfer in auto-processing that leads the cholesterol attack at the carboxyl-terminal of the N-terminal domain and promoting the pathway. Despite the importance of how that reaction occurs on a molecular level, the C-terminal structure has never been solved or predicted. We obtained some SRR structures from wet lab, then set up Molecular Dynamics and dock cholesterol at the end of C-terminal. By comparing the energies and structures of them, we will determine a reliable prediction structure. Additionally, by using the fly C-terminal structure to build homology humanized C-terminal structure, we can model the full-length Human Hh protein and use it to simulate the auto-processing. Ultimately, modeling will clarify more about the function of the Hh proteins and enable more development of Hh pathway-driven drug.

Cosmic Ray Impact on Thermal Kinetic Inductance Detectors (TKIDs)
Katie Hughes
Mentors: Jamie Bock and Bryan Steinbach

Thermal Kinetic Inductance Detectors, or TKIDs, are comprised of an LC circuit with a temperature-dependent inductor that rests upon a thermally isolated bolometer island. If they are ever to be used in space cosmology experiments, the impact of cosmic rays on their readout must be well understood. Our goal is to obtain an upper limit on the amplitude of the response in a TKID during a cosmic ray hit elsewhere to the wafer. We tested on a 6x6 TKID wafer at JPL in which half of the detectors are unreleased (meaning the bolometer island is not yet thermally isolated), making them extremely sensitive to any hit. A real-time triggering function that only records data in the vicinity of a glitch was integrated into the current USRP readout system to take extended noise data acquisitions. Applying exponential fits to the glitches from the unreleased detectors gave information on the quasiparticle recombination time constant in the wafer (around 200μs), while an analysis of glitch magnitudes will yield the deposited energy from each hit. Repeated fits to the expected bolometer response in the released detectors' timestreams during triggered hits elsewhere on the wafer will place this upper limit on their response.

Optimization of Effective Blocking by Electrodeposition for Electrochemical Probes
Yoo-Jin Hwang
Mentor: Jessica Arlett

Biochemical sensors can help us monitor neurotransmitters closely and are crucial in aiding our understanding of neurodegenerative diseases. To accurately measure the sensing of target neurotransmitters, we must be able to minimize the noise from other interfering chemicals. This project seeks to optimize the sensor's ability to block interferents such as dopamine and ascorbic acid while having minimal changes in our target signal. In order to do so, we are experimenting with the thickness of the phenol and now PPD layer by electropolymerization. Future work includes in vivo experiments, where we will utilize neurochemical probes with electrophysiology and electrochemical sensors that will be functionalized to create an enzymatic layer. This layer generates hydrogen peroxide, which is oxidized at the electrode to create a signal that is proportional to the detected concentration. In parallel to the progress on the blocking layer, infrastructure to facilitate the transition to in vivo has been made through CAD design and an electronic design automatic application called Eagle. Some of the infrastructure includes a PCB board that will be wire bonded to electrochemical sensors and a holder to manipulate the movement of the probe.

Analysis of Vote Share Drifts During Post-Election Canvass in Orange County
Michelle Hyun
Mentor: R. Michael Alvarez

In 2018, a phenomenon was observed in Orange County elections of state representatives: a "democratic drift", or a tendency for the number of Democratic votes to spike in the latter runs of the election count. Using R, data was mined from the county's record of election results for elections in 2012, 2014, 2016, and 2018, and used to construct graphs and plots to better understand the perceived trend. By observing the difference of votes for candidates of the Democratic and Republican parties at various times of the election, it has been concluded that the democratic drift has existed in past elections. Multivariate regression analysis was then performed using factors such as age, gender, ethnicity, party affiliation, and permanent absentee voter status, in order to understand why the trend exists and what factors make it more likely to occur. Further results and analysis may provide more insight into the drift of coming elections, and may also be applied to other counties to better predict and analyze voting trends.

Electrolyte Additives for Li-Rich Oxide Cathodes
Teresa Insinna
Mentors: Kimberly See and Joshua Zak

Li-rich batteries are promising alternatives to traditional Li-ion batteries thanks to the higher capacity that can be reached upon intercalation of more than one equivalent of Li ions. Reversible anionic redox involving the oxide ions in the cathode is proposed as the reason for this high observed capacity. The suggested mechanism involves a structural distortion and oxo- to peroxo- dimerization which can lead to O_2 evolution. By stabilizing the cathode-electrolyte interphase, this phenomenon can be prevented and the battery lifetime prolonged. Here, we propose phosphite additives as cathode-electrolyte interphase stabilizers due to their low phosphite/phosphate oxidation potential compared to potential limits imposed by the carbonate-based electrolyte. Electrochemical studies on trimethyl phosphite and triethyl phosphite both on C and on Li_2RuO_3 and $Li_2Ru_{0.3}Mn_{0.7}O_3$ showed that the additive stabilizes the cathode's surface. Galvanostatic cycling produced increasing discharge capacities and slower capacity fading which were ascribed to the formation of a protective phosphate layer coordinating O-atoms at the cathode's surface. Concentration studies suggest an optimal concentration exists which aids the formation of the film without obstructing Li ion diffusion. Surface specific techniques such as scanning electron microscopy and X-Ray photoelectron spectroscopy could be employed to further confirm this hypothesis.

Noninvasive Characterisation of Blood Vessel Material Properties
Daniel Jackson
Mentors: Mory Gharib and Chris Roh

The material properties of physiological features such as blood vessels are essential to determining their pressure characteristics. Increased stiffness or thickening of blood vessels increases the impedance to flow, causing blood pressure to rise. Hypertension is one of the leading medical problems today however current methods of material characterisation such as tonometry are invasive, inaccurate and require a trained medical professional to be carried out and consequently can only be performed infrequently. This paper describes an approach using the natural pulsation of vessels due to cardiovascular flow to characterise elastic properties. Model arteries were subjected to step and impulse pressure inputs while measuring the pressure within the model. These responses allow the further characterisation of the pressure response to more complex signals. A 3-layer neural net, implemented with a 70-30% train-test split, classified the data with an accuracy of 96%. It was then used to accurately predict material properties of untested models. In order to more closely model the pulsatile nature of blood flow, tests were performed under sinusoidal pressure input and the harmonics analysed. These experiments may be extended to include other geometries such as spherical shells, in order to characterise material properties and pressure of the eye.

Heavy Hitters and Detecting Anomalies in the Heart
Atishay Jain
Mentor: Kanianthra Mani Chandy

Nowadays, we receive most of the data as continuous streams and a very important task is to analyze them while using limited resources and as quickly as possible. This project explores two applications of streaming data - counting the most frequently occurring items in a stream and detecting anomalies in one's heart using ECG or stethoscope data. The first part of the project implements various heavy hitter algorithms like Misra-Gries, count sketch and count min sketch using a streaming framework called IoTPy. The second part of the project tries to use a spectrogram of the heartbeat and a convolutional neural network (CNN) to detect whether the given heartbeat shows signs of an anomaly. The model will be tested on multiple heartbeats and its accuracy will be used to judge its reliability.

Assembling Light Curves of ZTF Superluminous Supernovae
Deepnika Jain
Mentors: S.R. Kulkarni, Lin Yan, and Christoffer Fremling

A star that collapses under its own gravitational force, results in a core-collapse supernova (CC-SN). Superluminous supernovae (SLSNe) are CC SNe which can be about a 100 times more luminous than an average CC SN. The extra luminosity in Type-I SLSNe is generally explained by the formation of magnetar; supported by high rise time and hence high total energy; where the massive magnetic energy is transferred to surrounding supernova ejecta. Interestingly, the late time spectra of SLSNe-I closely resembles that of Type Ic CC SNe. The luminosity of Type Ic SNe can be explained by radioactive decay of nickel formed when the core of the progenitor star collapses. It is possible that both of these classes always have some level of magnetar power and radioactive power at the same time, but the relative strength of the two varies. To gain more insight into the powering mechanism and relation between these two types, high quality lightcurves needed for model fitting are produced by reprocessing ZTF pipeline data. This method performs forced point spread function (PSF) photometry. SN fluxes at quiescent phases are recomputed and errors rescaled to apply any existing offsets to the pipeline data. Non-detections over carefully selected multi-epoch are coadded using inverse flux model to achieve better depths. This coherent lightcurve database can be directly fed into modeling softwares to derive physical parameters.

Isolating the Cause of Photocurrent Dropoff in the Tandem Luminescent Solar Concentrator InGaP Module
Laura Jaliff
Mentors: Harry Atwater, David Needell, and Megan Phelan

The purpose of the luminescent solar concentrator (LSC) tandem on Silicon project is to achieve a high-efficiency, commercially viable, and architecturally adaptable photovoltaic module. The current luminophores being used by our module, CdSe/CdS quantum dots (QDs), are particularly appealing for their ability to absorb and emit in wavelengths determined by the QD size. The QDs, embedded in the poly-laurel methacrylate (PLMA) waveguide, emit light into the waveguide where it is trapped by total internal reflection and reflected toward the micro-scale InGaP cells within the waveguide. In practice, however, photons are exhibiting a high rate of escape from the waveguide such that, when photons are no longer incident directly above the solar cell, photoluminescence drops by 97% due to QD degradation. In my project, I will explore the effects of sunlight and exposure to air on the photoluminescent quantum yield of the waveguide in order to determine solutions for preserving the efficiency of the module over the course of its usage.

Data Analysis in Virtual Reality
Alex Janosi
Mentors: Stanislav Djorgovski and Santiago Lombeyda

Conventional methods of data analysis and visualization are becoming less efficient as data science grows as a field, so the development of new platforms using a virtual environment may offer a solution. A popular field where traditional methods, i.e. analysis through programming using Python, MATLAB, R, etc. or software like Excel, fail or become obsolete is machine learning. The first step of developing models for machine learning is handling the data. By discovering correlation between variables, outliers, or clustering, the process of manipulating the data for training becomes easier and produces better results. However, this process becomes difficult as datasets become more complex, usually in the form of more variables or dimensions. Visualization becomes nearly impossible for traditional methods, and analysis is confusing. By exploring the benefits of a virtual environment, differences will be observed between the two methods. Therefore, by examining the limits of conventional methods and finding the border where newer methods become more efficient, this research plans to benefit many different fields that deal with large quantities of data.

Construction of Bacterial Chimeras Using Gene-Inferred Genome Sequence Assembly Windows (GiGSAW)
Rashi Jeeda
Mentors: Kaihang Wang, Charles Sanfiorenzo, and Bryan Gerber

The transfer and integration of large (>350 kb) DNA segments in organisms has limited artificial genome synthesis. By designing large-scale genome recombineering techniques, our group has successfully transferred and exchanged DNA fragments over 500 kb. Harnessing this technology, we have set out to generate chimeras by splitting and exchanging genomic fragments of high-magnitude lengths in two distinct bacterial species: *Escheria coli* and *Shigella flexneri.* To achieve this, we leveraged transposon and single-gene knockout studies to characterize essential genes in both species. We then generated computational models to identify interchangeable genomic sequence windows that preserved essential genes for both species - a technique we called Gene-inferred Genome Sequence Assembly Windows (**GiGSAW**). GiGSAW requires two steps: (i) the splitting of a genome into two discrete replicating fragments, and (ii) the conjugation and selection of an equivalent donor fragment. Our group has split genomes into discrete replicating fragments, and efforts are on the way to produce a bacterial chimera throughout antibiotic selection-driven conjugation. Our proposed "*Shigolli*" is a chimera in the true sense of greek-mythology, conceivably considered to be synthetic life. Generating bacterial chimeras would provide novel functional scaffolds for industrial applications, while allowing us to further understand the dynamics and limitations of life.

Boundary Layer Transition and Shockwave Interaction on a Hypersonic Control Surface at Angle of Attack
Maheck Jerez Terceros
Mentors: Daniel Araya and Guillaume Blanquart

Hypersonic vehicles fly in a regime where flow can be transitioning from laminar to turbulent somewhere along their bodies. Transitional boundary layers can produce significant effects on these vehicles' control surfaces. Here, a hypersonic sharp cone with a flap is investigated computationally using the commercial RANS solver CFD++ at angle of attack ranging from $\alpha = 0°$ to $\alpha = 10°$ and using the SST k-ω turbulence model. Computations were run at $Re/m = 9.2 \times 10^6$ conditions that matched shock tunnel tests conducted for this geometry at Purdue University. Fully laminar, fully turbulent, and transitioning flows were studied to determine the effect of transition on surface pressure. It was observed that the pitching moment for the transitional case was greater than that for either the laminar or the turbulent case. This is a counter-intuitive observation that is potentially significant for hypersonic design, as the point of transition is difficult to predict. It was also found that this difference in pitching moment was sensitive to the axial station along which the boundary layer underwent transition. Some potential explanations for this include the effect of boundary layer thickness differences between the transition and fully turbulent cases and earlier re-attachment of a transitional separated region.

Investigating Increases in Exoplanet Radius as a Function of Temperature
Christian Kragh Jespersen
Mentor: David J. Stevenson

Exoplanet observations focus mostly on mass and radius measurements. This means that many exoplanetary properties are derived from these two numbers, making both correct observational methods and theoretical interpretation of the mass-radius relationships crucial to the field of planetary science. When inferring exoplanetary composition, mean density is often used as an indication of the primary components of the exoplanet. However, studies that infer exoplanetary composition from mean density often fail to consider the probable thermal expansion due to retaining most of their gravitational energy as heat, an underestimated effect as shown by Bodenheimer et al. (2018). The project uses different computational model of planetary density as a function of radius, considering the Murnaghan Equation-of-State and the thermal pressure and assuming hydrostatic equilibrium, showing that the radius of an exoplanet may increase drastically if it reaches thermal and internal energy comparable to the gravitational energy of formation. The limit of the radius increase was found by calculations of the gravitational binding energy. This effect is most relevant for higher mass rocky planets, e.g. for a planet of 10 $M_\oplus$, the maximum possible radius increase was found to be as much as 198%, making this a very valuable consideration when studying Super-Earths.

Simulating Dense Hydrogen With Molecular Dynamics
Jared Jetter
Mentors: William A. Goddard III and Saber Naserifar

The study of dense hydrogen is an important topic in fundamental physics and astrophysics. There are numerous exciting hypotheses surrounding dense hydrogen that make it the holy grail of high-pressure physics. Dense hydrogen is proposed to have a metallic liquid ground state at 0 K with unorthodox properties such as superfluidity and superconductivity. Dense hydrogen has also been proposed to be superconductive at room temperature. At pressures above 400 GPa and room temperature, solid dense hydrogen is thought to make a transition from an insulating molecular structure to a metallic atomic structure. To achieve such high pressures in the lab, experiments are restricted to microscopic samples compressed in a diamond anvil cell. Consequently, Raman spectroscopy is the most suitable tool available for illuminating the properties of dense hydrogen. There is also no experimental way of visualizing the structure of high-pressure dense hydrogen since neutron diffraction cannot be used. Therefore, I conducted a computational study of dense hydrogen using the LAMMPS molecular dynamics package and the 2PT package. I calculated the radial distribution function and infrared spectrum of a cluster of 384 hydrogen molecules from 1 atm up to 500 GPa. These calculations were used to visualize the structure of high-pressure dense hydrogen, and the infrared spectra were compared to those of experimental studies.

SpatialDB: Enabling Rigorous Geospatial Queries Using a PostgreSQL + PostGIS Database
Rupesh Jeyaram
Mentor: Christian Frankenberg

With the rise of increasingly powerful and comprehensive satellite spectrometers such as the TROPOspheric Monitoring Instrument (TROPOMI), researchers need to be equipped with powerful tools to access, explore, and navigate the terabytes of data at their fingertips. Spatial databases offer these capabilities by incorporating unique spatial-data optimizations such as spatial indexes, predicates, and functions. This SURF project specifically focuses on building a PostgreSQL database with PostGIS extension to store TROPOMI data, extract temporally and spatially constrained datasets, merge different datasets, and enable scientific inquiries that were previously constrained by suboptimal data storage formats. The project's results have unequivocally demonstrated the advantages of using such a database for querying spatial data. Common queries, such as obtaining custom-averaged time series of data points inside a geographic shape, have become faster by several orders of magnitude; queries that used to take hours now take < 1 second. Alongside the database, the development of a front-end TROPOMI exploration tool has allowed researchers to quickly explore data trends across the world without having to write scripts to extract select data beforehand. The development of a Python utility package has also enabled researchers to interact with the database and pull data directly into their code, enabling flexible use of query results.

Towards Low Noise Soliton Microwave Source
Qing-Xin Ji
Mentors: Kerry J. Vahala and Qi-Fan Yang

Microresonator-based combs at microwave rates are providing a new pathway to coherently link microwave-rate electrical signals with optical-rate signals derived from atomic transitions. They are revolutionizing a variety of applications. However, minimizing the phase noise of the oscillator is still a great challenge. With the aim of pushing the noise to a record-low level, the study of noise sources in the microcomb system is of vital importance. In this paper, we report a phase noise "shoulder" at an offset frequency of 100 kHz level in a chip-based ultra-low noise soliton microcomb system. Both numerical simulations and calculations based on Lagrangian perturbation method have been utilized to analyze this phenomenon. So far, the mechanism of the "shoulder" is still not well-understood.

Investigating Data-Driven Models for Generating Justifications Based on Encapsulated Fashion Concepts
Qixuan (Alice) Jin
Mentors: Ranjitha Kumar and Yisong Yue

Recent advancements in computer vision and natural language processing have opened up new possibilities of formalizing abstract fashion concepts for applications in e-commerce websites and fashion recommendation systems. Before the rise of e-commerce, the primary avenue for obtaining personalized fashion advice was through the service of stylists. Stylists justify their product recommendations through a combination of exhibiting the actual product (visual) and verbally explaining their reasoning (text). Similarly, e-commerce search engines can offer their users a much more holistic experience through displaying textual justifications along with product images in the search results. Our project's primary objective is to utilize data-driven deep learning methods to encapsulate abstract fashion concepts for ranking and justifying fashion products within a web search engine framework. From the product metadata crawled from popular e-commerce sites, we extracted a fashion lexicon of more than 3000 concepts. We trained a multi-label image classifier to learn the lexicon and use the model's predicted concept scores to rank and justify products relevant to the user search query. After implementing the search engine framework, we will conduct a user study investigating the effect of justifications on the user experience of the search engine interface.

Designing 3D Point Spread Functions for Quantum-Limited Measurement Precision
James M. Jusuf
Mentors: Matthew D. Lew and Andrei Faraon

Super-resolved fluorescence microscopy is a powerful tool for nanoscale imaging, with wide-ranging applications in biology and materials science. Creating a super-resolved image typically involves estimating the positions of individual fluorophores using statistical methods. Since standard microscopes are designed primarily for imaging objects within a two-dimensional focal plane, such microscopes are ill-suited for constructing super-resolved images of three-dimensional structures. Using a phase mask, which introduces a position-dependent phase shift in the image's Fourier space, the image of a point emitter can be engineered to rotate, translate, or otherwise change shape rapidly as a function of the emitter's axial position. In this study, we search for phase masks that perform optimally (in an information-theoretic sense) for three-dimensional localization by designing and testing various cost functions for mathematical optimization. We conclude that existing phase masks are optimal for single-emitter localization, and we present a new phase mask specialized for resolving two nearby emitters and imaging high-density collections of emitters. We quantify the optimality of our phase mask in terms of both classical and quantum information theory.

Exploring the Mechanical Properties of a Free-Standing Column Built Out of Designed Granular Particles
Omkar Kadam
Mentor: Jose Andrade

Designed granular materials are being explored to get stable structures and various properties that are generally not encountered when structures are created using continuous media. Structures built out of granular particles are easy to both assemble and disassemble hence, they can be used for quick and easy constructions. Our present objective deals with obtaining an optimized designed granular particle for building a column to achieve maximum possible compressive strength. We are using LS-DEM (Level set- Discrete element method) to simulate the behavior of particles. To start with we chose S-shaped particles for both experimentation and simulation. The study is useful to achieve the best designed granular particles relative to a set of prioritized constraints. SLSQP is used for obtaining optimized shape, which also takes care of constraints. The framework is written using python and C++ and is also robust to handle both symmetric and unsymmetric granular particles. The subsequent work is to carry out experiments using the optimized granular particles and validate the results obtained through simulations.

Analysis of Noise and Decoherence in Laser-Driven Ultra-Cold Atoms
Anant Kale
Mentors: Manuel Endres and Jacob Covey

High fidelity control of individually trapped cold atoms is essential for quantum computing and simulation applications. Interactions between these atoms (including entanglement) can be generated using highly excited Rydberg states in which the principle quantum number $n \gtrsim 20$. The maximum fidelity achievable in these systems is limited by several factors including laser noise, finite temperature motional effects, black body radiation, off-resonant scattering from the trap potential and imperfect pulse control. In this report, we shall focus on the effects of laser noise and finite temperature. Using second order time-dependent perturbation theory, we derive an analytic expression for the effect of laser noise with a given frequency-noise power spectral density (PSD). This PSD noise profile can be experimentally measured by locking the laser to a stable optical cavity and measuring the Pound-Drever-Hall error signal. We compare our results to stochastic numerical simulation of the density matrix. We also analyze the effects of motional degrees of freedom at finite temperature in a weak-driving regime (sideband resolved case) as well as strong-driving regime and compare to numerical simulations. This work provides crucial insight for upcoming experiments aiming to entangle two alkaline-earth atoms for the first time.

The Presence of the Dural Lymphatic System in Cases of Chronic Subdural Hematomas
Jaeyoung Kang
Mentors: Jefferson Chen and David Chan

The dural lymphatic system is currently an important topic of clinical research as a potential pathway for mitigating toxicity in neurodegenerative disorders such as Alzheimer's disease. However, comparatively little is known about the role of dural lymphatic vessels in the healing process in cases of traumatic brain injury (TBI). To demonstrate the presence of dural lymphatics in the pathology of TBI, we quantified dural lymphatic vessels in patients with chronic subdural hematomas (cSH), a common manifestation of TBI in which blood collects under the dura mater. D2-40 monoclonal antibodies were used in a validated immunohistochemical protocol to label dura mater specimens from a representative cSH patient group and an acute subdural hematoma (aSH) patient control group. Statistical comparison of the images between the cSH and aSH groups found that chronic subdural hematoma samples displayed significantly higher levels of lymphatic vessel staining, suggesting that the dural lymphatic system plays a role in relieving secondary injuries, such as increased intracranial pressure (ICP), in cases of mild, sustained TBI, via manipulation of cerebrospinal fluid (CSF) flow. Further studies to assess the activity of the dural lymphatic system in other TBI cases such as cerebral contusions will be conducted to elucidate the role of dural lymphatics in the physiological progression of TBI.

The Effects of Temperature on the Conformation of Thermophilic Laccase, a Blue Copper Protein
Janice Kang
Mentors: Harry B. Gray and Jieun Shin

The potential of the type 1 copper (T1 Cu) in the active site of thermophilic laccase from *Thermus thermophilus* HB27 has been observed to decrease at high temperature conditions. To elucidate the reason for this change in the potential of T1 Cu, resonance Raman spectroscopy was used to investigate the temperature dependence of the local conformational changes of T1 Cu. The resonance Raman spectroscopy with a HeNe laser allowed selective enhancement of the signals indicating the Cys(S)-T1 Cu^{2+} stretches since the wavelength of HeNe (632.8nm) closely matches the ligand-to-metal charge transfer (LMCT) transition of the T1 Cu^{2+} (605nm) which confers the characteristic blue color to the protein. The Cys(S)-T1 Cu^{2+} stretches at 377cm^{-1} and 427cm^{-1}, and C_β-Cys(S) stretches at 750 cm^{-1} shifted by 2cm^{-1}, 4cm^{-1}, and 5 to 8 cm^{-1}, respectively, to lower frequency compared to those of 20°C. In addition to the shift in peak positions, the peak amplitude decreased, and the peak width broadened at higher temperatures. These changes indicate the loosening of the T1 Cu^{2+} coordination at high temperature conditions, which explains the decreasing reduction potential of T1 Cu with increasing temperature as its oxidized state is more favored with less negative reduction enthalpy. Furthermore, the resonance Raman spectra of WT at different temperatures were compared to those of mutants, M455H and M455L, since the replacement of the axial methionine near T1 Cu^{2+} with either another copper-coordinating histidine or a non-coordinating leucine residue drastically alters the T1 Cu^{2+} potential as well as the geometry of the copper coordination sphere. From these studies, the local coordination around the active site copper was found to be affected by both the temperature factor and the mutation around it, and thus it ultimately influences the potential of the active copper itself.

Regulation of Uni-Strand piRNA Cluster Transcription in *Drosophila melanogaster*

Nivedita Kanrar
Mentors: Alexei Aravin and Yicheng Luo

PIWI-interacting RNAs (piRNAs) are a class of small RNAs that interact with PIWI proteins to silence transposons during animal germline development. In *Drosophila melanogaster*, most piRNAs originate from discrete genomic loci composed of transposons, termed piRNA clusters. piRNA clusters are classified into two types, uni-strand and dual-strand clusters, based on their ability to make piRNAs from one or both genomic strands, respectively. Uni-strand clusters are characterized by a promoter region, with most transposon insertions oriented antisense to the promoter. In our study, the transcription regulation of uni-strand clusters was investigated through the development of a reporter system in the *Flamenco* (*Flam*) and *20A* uni-strand clusters. We found that the activity of these reporters was dependent on their insertion orientation. The level of transcription of these reporters is correlated with H3K9me3, a histone modification associated with gene silencing. Furthermore, we have shown that the transcriptional activity of differently oriented reporters may depend on the piRNAs produced from the target reporters. Overall, we have given insight into how uni-strand clusters regulate transposon insertions in order to better understand the mechanisms of cluster origin and development.

Fabrication of 3D-Architected Solid–Liquid Contacts for Biosensors

Nidhi Kapate
Mentors: Axel Scherer, Matthew Hunt, and Alex Wertheim

Creating biosensor devices for *in vivo* environments has been hindered by a lack of surface architectures that allow for high sensitivities. To enhance integration in these environments, biosensors can be designed with 3-dimensional structures that maximize the sensor's surface area and minimize electrical impedance, which are necessities when designing electrophysiological contacts. In this study, we developed a novel nanofabrication process to create biosensors patterned with notched pillars and then examined their electrical impedance. The nanostructures were fabricated by sputtering layers of Tungsten (W) and Silicon (Si) onto the device. An Al_2O_3 hard mask and pseudo-Bosch etch were used to define and etch the pillars. The process continued for an additional period of time to etch the pillars inward. Because W and Si have different etch rates, radial variation within the pillars was produced. Electrochemical impedance spectroscopy was conducted on each device in 0.8 mmol peroxide solution. The frequency of the input AC signal was swept from 1 MHz to 0.1 Hz with a DC bias of 0.32 V. Sensors with varying pillar diameters, pillar spacings, and pillar layer thicknesses were tested. Any changes in the dimensions of the nanostructures that correspond with increased surface area led to decreased electrical impedance.

Ackerman Platform for Cave Exploration

Jake Ketchum
Mentor: Joel Burdick

Existing small robotic platforms are generally have limited mobility in rough terrain, or are too expensive for general use. In this project we use an off-the-shelf RC car to provide the chassis and mobility systems for an Ackerman drive robotic platform. Additional systems were then added to provide throttle control, steering, vision, compute, communication, and emergency stop capabilities. The combination of off-the-shelf hardware and 3D printed parts means that the entire system can be built up using only a 3D printer and soldering iron, with no other specialized tooling. A Time Elastic Band planner was used to accommodate the Ackerman steering system. The robot will be used as part of the CoSTAR DARPA Grand Challenge team.

Extracting the Hydrolysis Rate Constant From a Single-Molecule Controlled Rotation Experimental Data on a F1-ATPase
Oganes Khatchikian
Mentors: Sandor Volkan-Kacso and Rudolph A. Marcus

The chemo-mechanical energy transduction of the ATP Synthase is at the heart of the biological function, and it can be elucidated by studying the water soluble F1-ATPase, focusing on the individual sub-steps of the reactions in the enzyme. In controlled rotation experiment single F1-ATPase molecules deposited on a microscope slide are rotated by magnetic tweezers. Simultaneously the individual ATP binding and ADP release events are monitored by single molecule fluorescence imaging in real time. Goal is to extract the ATP hydrolysis and synthesis rate constants as a function of rotor angle from the single molecule binding and release data. This work requires advanced analysis because these processes occurring in the binding pocket are "hidden", and not directly monitored. Our approach is based on the treatment of composite events developed by Volkan-Kacso and Marcus, for a constant rotation rate. We will use high-quality single-molecule trajectories provided by our experimentalist collaborator K. Adachi, who pioneered the method of controlled rotation. Preliminary results indicate that fluorescent Cy3-ATP hydrolyses about 100 times slower than the wild species (ATP), at rotor angle of 240°, its rate is about $1.7*10^{-3}\ s^{-1}$. We plan to extract the hidden hydrolysis and synthesis rates for the complete 360° cycle.

Open-Source Fraction Collector for Microfluidic Time Course Sampling
Yeokyoung (Anne) Kil
Mentors: Lior Pachter and A. Sina Booeshaghi

The colosseum fraction collector is an open source alternative to commercial systems. While commercial fraction collectors can easily cost over $10k, this open source device costs less than $100. Moreover, for this device, the user can customize the number and size of the containers to collect the fractions in, unlike the commercial fraction collectors which have designated tube sizes and numbers. The hardware is built with parts that are either 3D-printable or available for purchase on Amazon. The system runs on an Arduino microcontroller, and the code to control the device is written on open-source software programs Arduino IDE and Qt Designer.

Chemotactic Relaxation of Active Brownian Particles
Chan Gi Kim
Mentors: John F. Brady and Austin R. Dulaney

Bacteria exhibit interesting swimming behavior due to the nature of their motion and their response to external stimuli. Here we study chemotaxis, the motile response to chemical gradients. We use the active Brownian particle (ABP) model as the basis for our study and mimic the relatively well understood response of run-and-tumble bacteria in the presence of chemoattractants. We derive a Smoluchowski description for ABPs in the presence of chemical gradients and utilize Brownian dynamic simulations to study particle motion. Our simulations are compared against passive systems and ABPs in the absence of such gradients to study the relaxation dynamics of chemotactic particles. We focus primarily on active systems released from an instantaneous source and ignore the time dependence in the solute concentration profile. Our goal is to further extend this work to include the temporal evolution of solute and to incorporate interparticle interactions to better replicate actual experimentally observed swarming behavior. This work will also serve as the basis for engineering design strategies for improving the remediation capabilities of synthetic active systems.

Subliminal Processing in the Blind Spot
Lily Kitagawa
Mentors: Shinsuke Shimojo and Shao-Mion Hung

The functions of rods and cones, the classical photoreceptors, are well established. On the contrary, our general knowledge on a third class of photoreceptor called intrinsically photosensitive retinal ganglion cells (ipRGCs) is lacking. Animal studies have shown that such ganglion photoreceptors are associated with controlling pupil reflex, entraining circadian rhythm, etc. However, a good psychophysical model that we can rely on to explore these ganglion photoreceptors on humans is missing. Recent studies show that light stimulation in the blind spot triggers pupil constriction, which opens a new possibility to study ipRGCs on humans. The blind spot offers a unique way to study these ipRGCs as well as the effects of unconscious visual perception as there are no rods and cones present, meaning information about stimuli still reaches the brain but is not consciously perceived. This study sought to discover whether this unconscious visual perception in the blind spot could go so far as to affect involuntary eye movements and pupil responses. Though we found that involuntary eye movements and brightness discrimination, there are still many undiscovered aspects of unconscious visual perception. In the future, other methods of eliciting unconscious visual perception can be used to try to modulate behavior.

Modeling of Cyclonic Vortices at the Poles of Jupiter
Alexandra Klipfel
Mentors: Andrew Ingersoll and Cheng Li

Jupiter's polar atmosphere was observed for the first time by the Juno spacecraft. Both visible and infrared images from its cameras show active vortices and weather systems that are unlike those of any polar regions previously seen or modeled on any of the planets in our solar system. In the north, eight cyclones surround one central cyclone, and in the south, five cyclones encircle a central cyclone. Formation of polygonal arrays of vortices was observed in laboratory experiments using electrons confined in magnetic fields. These vortices in Jupiter's atmosphere are a real-world analogy to a laboratory phenomenon. We study the stability of the vortices using a one-layer shallow water model centered at the pole. We find that the cyclones develop a rim of anticyclonic vorticity, known previously as a "vortex sheath". The vortices drift toward the pole due to the beta effect, and they repel each other by inducing a vortex dipole between the center of the cyclonic core and the center of the anticyclonic sheath. Thereby, a stably crystalline structure is formed. A stability regime diagram spanned by the number of vortices, their strengths, the deformation radius, and initial latitude is mapped out.

Quantifying Clusters Around Herbig Ae/Be Stars
Viktor Köhlin Lövfors
Mentor: Lynne Hillenbrand

Herbig Ae/Be stars serve as important intermediaries between high mass and low mass star formation, and thus, study of the clusters that accompany their formation might help constrain star formation models. With the advent of high precision astrometry from the Gaia mission, we have seen an increase in both the number of known Herbig Ae/Be stars and the amount of information available on the stars in their vicinity, warranting a new study of Herbig Ae/Be cluster parameters. In this study, we are constructing an infrastructure for the analysis of the clusters around Herbig Ae/Be stars, based on a combination of photometric all sky surveys and astrometric Gaia data. For sources with parallax and proper motion, we use the DBSCAN clustering algorithm together with gaussian fits to differentiate between cluster stars and unrelated objects. Furthermore, we use photometric color cuts in the infrared from 2MASS and AllWISE. Radiation in the wavelength ranges of these surveys, 1 - 2.5 μm and 3.5 - 22 μm respectively, indicates the presence of circumstellar dust found around young stars, which renders the photometric cuts a good complement to the astrometric analysis.

A Study of Cygnus X-3 Utilizing MAXI X-ray Data
Claire Komori
Mentors: Nobuyuki Kawai and Yoichi Yatsu

Cygnus X-3 is an X-ray Binary System (XRB) located 37,000 light years away. It is the only known system hosting a massive Wolf-Rayet star, and has a compact object thought to be either a neutron star or a black hole. While being visually invisible, it is a bright source of gamma-ray, radio, and especially X-ray emission. While being investigating ever since it was first observed in 1966, much of its nature is still unknown. MAXI, short for Monitor All-Sky X-ray Image, is a Japanese X-Ray detector onboard the International Space Station. Through this project using the data obtained through MAXI, we are trying to understand the nature of Cygnus X-3, to characterize the features seen in observation to variety of black hole activities and associate our observations and data analysis results with the physical model of black hole accretion.

Spin-Phonon Coupling in Transition Metal Complexes: Applications to Cobalt(III) Coordination Complexes
Patryk Kozlowski
Mentor: Ryan Hadt

Transition metals are key components of next-generation architectures for classical and quantum computing and play important roles in the photocatalytic syntheses of solar fuels. A fundamental issue in these fields is understanding how molecular vibrations couple to transition metal spin state dynamics on an ultrafast timescale (i.e., spin-phonon coupling). Here, we have developed an *ab initio* methodology to understand and quantify spin-phonon coupling in Co(III) coordination complexes (e.g., $[Co(III)(NH_3)_6]^{3+}$ and $[Co(III)(CN)_6]^{3-}$), for which a range of high resolution spectroscopic and photochemical data exists. Density functional theory (DFT) calculations correlated to experiment were used to obtain ground and excited state geometries and their corresponding normal modes of vibration. A CASSCF/NEVPT2 approach was then used to identify the modes that are active for spin-phonon coupling. Furthermore, high resolution scans near intersystem crossing points have enabled analyses of the role of spin-phonon coupling and how dynamics might be controlled via the interactions between the zero-field split, magnetic spin (M_s) sublevels of the transition metal. The model developed here will be extended to a variety of transition metal complexes in photocatalysis and quantum information science. This work will also guide the development of new experimental methods to probe spin-phonon coupling on an ultrafast timescale.

Exploring Pulsed-Laser Ablation in Liquids as a Novel Synthetic Route to Li-Ion Electrode Nanomaterials
Daniel Krajovic
Mentor: Kimberly See

Lithium-ion batteries are prolific in portable electronic devices but limited in applications requiring high discharge rates, such as hybrid electric vehicles. Rate capability and Li-ion diffusive mobility demonstrably improve by replacing bulk electrodes with nanostructured materials, which few synthetic methods can sustainably and size-selectively generate. In this investigation, pulsed-laser ablation in liquids (PLAL) is evaluated as a new route to nanocrystalline electrode materials. Raman spectroscopy, X-ray diffraction, and scanning electron microscopy have confirmed the success of PLAL in synthesizing Co_3O_4 nanoparticles from aqueous confinement of a cobalt metal target, and the procedure has been optimized to increase initial yields by more than two orders of magnitude. Cyclic voltammetry, galvanostatic cycling, and electrochemical impedance spectroscopy have thoroughly characterized bulk Co_3O_4 as a control for comparison with the PLAL nanoparticles. Ongoing and future work will probe the reactivity of species dissolved in the confining liquid and examine variations in product identity with the use of cobalt oxides as ablation targets. The results obtained highlight PLAL as a viable candidate for facilitating the economical transition from bulk to nanoscale electrodes throughout the Li-ion battery industry.

Quantification of Cellular and Intracellular Granule Biovolumes Using Serial Block Face Imaging to Determine Carbon and Iron Storage Functions Within Uncultured Symbiotic Archaeal-Bacterial Aggregates
Halle Krieger
Mentor: Victoria Orphan

Syntrophic consortia of anaerobic methanotrophic (ANME) archaea and sulfate-reducing bacteria found in marine methane-seep sediments accomplish anaerobic oxidation of methane (AOM), a significant process to environmental carbon cycling. To better understand carbon budgets within aggregates, accurate quantification of cellular biovolumes and their intracellular carbon storage granules is needed. Serial sections of electron microscopy images of two methane-oxidizing aggregates (containing phylogenetically-divergent ANME archaea and their associated syntrophic sulfate-reducing bacteria) were manually segmented on image-processing software IMOD and fed into machine learning algorithms as training sets for the purpose of future automatic data segmentation. We meshed and rendered the data as a 3D model for morphological and spatial mapping analysis. We quantified archaeal and bacterial cell bio-volumes and the volumes, orientation, and location of their ultrastructural features including archaeal polyphosphate storage granules and bacterial magnetosome chains to aid in understanding the contributions these features provide their host cells. Though bacterial magnetosomes typically serve a motile purpose in their hosts (magnetotaxis), our data suggest they accomplish other functions in AOM sulfate-reducing bacteria. Our data also suggest polyphosphate storage granules in ANME-2b archaea cells are indispensable to cell survival and the presence of more than one storage granule within an archaea cell may predict fission.

River Mapping Using an Autonomous Surface Vehicle Equipped With LiDAR
Lars F. Kronstorm
Mentors: Richard Murray and Alistair Hayden

River floodings are one of the most costly natural hazards today. With more knowledge and data about rivers these expenses can be reduced. However, the data collection is a time consuming procedure and an automated way of doing this would save both time and other resources. This paper presents the work on an Autonomous Surface Vehicle (ASV) used for river mapping. With an Acoustic Doppler Current Profiler (ADCP) the depth of the river is measured together with the velocity of the water currents. This makes it possible to create depth profiles as well as calculating the river discharge. The main improvement presented is a new controller which uses LiDAR and ADCP measurements to automate transects as well as keeping a constant distance to the shore while going upstream. This allows new data to be collected and simplifies the work in the field. The implementation has been tested in Kern River, California, with current velocities of around 1.4m/s.

Design and Optimization of an On-Chip Hong-Ou-Mandel Interferometer
Alex Krotz
Mentors: Scott Cushing and Szilard Szoke

An on-chip Hong-Ou-Mandel (HOM) interferometer was designed and simulated computationally using COMSOL multiphysics. The on-chip generation of entangled photon pairs using a periodically poled lithium niobate (PPLN) waveguide was numerically optimized to a quasi phase matching (QPM) condition, resulting in broadband entangled photon generation centered around 812 nm via spontaneous parametric down conversion (SPDC) of a continuous wave (CW) 406 nm pump beam. Optical coupling efficiency into the device was optimized to commercially available fibers and on-chip designs for time delay and sample interactions were developed utilizing micro-ring resonators and slot-waveguides. Experimental verification of the on-chip design is underway.

Empirically Identifying Habitual Behavior in Gym Attendance
Anthony Kukavica
Mentors: Colin F. Camerer and Anastasia Buyalskaya

Understanding how individuals build and break habits, particularly healthy habits like regular exercise, is a crucial component of behavior change. We partner with a large gym chain to obtain a panel dataset on over 70,000 individuals spanning over a decade of gym attendance. We then apply computational modeling techniques to identify moderators, or state variables, associated with more habitual attendance, as well as to understand how exogenous shocks such as a sudden weather changes are likely to disrupt habitual behavior. Our primary objective is to clarify what constitutes a habit in this context, followed by a careful analysis of whether certain circumstances lead to favorable habit formation. This is the first study which identifies habitual decision-making within a large dataset of natural human behavior.

Stability of Causal Models Under Perturbations of a Single Intervention Variable
Vinayak Kumar
Mentors: Leonard Schulman and Spencer Gordon

A causal inference model is a set of random variables where the probability distribution of each variable is a function of the values of a subset of the other variables. In the joint distribution of a causal model, we usually see the resulting distribution upon conditionally observing the values of variables, which would respect the dependencies portrayed by the functions. We can also intervene and forcefully set variables to a desired value, disregarding any dependencies, and then observe the causal effect this has on the resulting distribution.
The dependencies resulting from the functions mapping variable values to individual probability distributions can be represented graphically as DAGs, where the nodes are the variables and the directed edges are dependences. The Identifiability Algorithm decides whether given a DAG G and the distribution restricted to a subgraph, whether it is possible to calculate the probability that a subset of nodes $Y = y$ given that we intervene and set another disjoint set of nodes $X=x$. We provide a rigorous exposition building the theory behind the algorithm and attempt to show the distribution on Y upon intervening on a single node X is stable under perturbation of the value we set X to.

Building an Ankle Exoskeleton for Assisted Walking to Reduce Metabolic Rates
Sofia Kwok
Mentors: Aaron Ames, Claudia Kann, and Maegan Tucker

Ankle exoskeletons have the potential to reduce the metabolic cost of walking with very little effort, as the ankle joint provides more than fifty percent of the mechanical power during the push-off stage of walking. Exoskeletons can also be used to correct gait irregularities and can reduce metabolic rate. However, some ankle exoskeletons fail to provide enough power to compensate for their weight, resulting in an increase in metabolic rates. Other ankle exoskeletons are too bulky to comfortably wear for long amounts of time or have control systems that are off-board, which limits their use to within a laboratory. AMBER lab is currently working to build an exoskeleton with on-board power and controls that successfully reduces metabolic rate while also staying lightweight. In order to do this, we are using a moment arm to apply torque during the push-off stage of walking paired with a motor and motor controller mounted on the user's thigh. To control this system, we are using a Teensy Arduino paired with a pressure sensor that lets us know the instant of push-off. For future work, measuring metabolic rates with and without the exoskeleton will help us determine whether it actually helps to reduce metabolic rates.

CRISPR-Based Design of Small Molecule Transfer Motifs in Mammalian Cells
Colin Lee
Mentor: Alison Ondrus

Abstract withheld from publication at mentor's request.

Analysis of Pre-Training of Deep Bidirectional Transformers (BERT) on Korean and English Binary Sentiment Classification
Inhoo Lee
Mentors: Alice Oh and Adam Wierman

Deep learning has become an integral part of Natural Language Processing (NLP), which is a subfield of computer science dedicated to the relationship between computers and human languages. One task within the domain of NLP is binary sentiment classification. The goal is to determine whether the sentiment of a piece of text is positive or negative. BERT is a language model, which is a probability distribution over words in a language. The recent introduction of BERT showed great improvements in a wide range of NLP tasks with the addition of just one fine tuning layer. Moreover, this novel model has shown great multilingual performance. The focus of this project is to explore the discrepancies in English and Korean performance of this model on binary sentiment classification tasks. We used movie reviews for our datasets and we used the cased, multilingual model. The Korean dataset was composed of movie reviews from a Korean website called Naver and the English dataset was composed of movie reviews from IMDB. The sets were labelled 1 for positive reviews and 0 for negative reviews.

Investigation of Organic-Inorganic Halide Perovskite Photodamage via Ultrafast Terahertz Spectroscopy
Jina Lee
Mentors: Geoffrey Blake, Harry Atwater, and Kyle Virgil

Perovskites are an expansive class of materials unified through stoichiometric balance of two cations and one anion. Recently, perovskites that contain a mix of organic and inorganic components, particularly halide anions, have been heavily researched for new photovoltaics. These hybrid halide perovskites display many desirable properties that need further exploration with greater depth and rigor. The focus of this project is to observe the perovskite response to photodamage and potential self-healing, a remarkable property of reversibility that these structures possess. Methylammonium lead iodide ($MAPbI_3$) and formamidinium cesium lead iodide ($FACsPbI_3$) perovskites are exposed to pulsed laser light of different wavelengths to induce photodamage, then left in the dark with dry atmosphere to induce recovery. At each vital point in the experiment, ultrafast terahertz (THz) spectroscopy was used to monitor the perovskite samples. Terahertz (or far-infrared) spectroscopy is a valuable and growing method of investigation, sensitive to lattice vibrational modes and electron dynamics. These spectroscopic studies give us insight into material conductivity trends and other characteristics more difficult to conventionally measure in notoriously delicate perovskite systems. Additional characterization techniques, like photoluminescence, can provide deeper insight into any photodamage-recovery mechanism and contribute to broadening the versatility of future perovskite devices.

Mapping Causal Connections in Leech Ganglia
Lin Lin Lee
Mentor: Frederick D. Eberhardt

One important area of research in neuroscience is understanding how networks of neurons are connected as they respond to stimuli – which neurons are activated as a result of other neurons activating? Finding these causal connections is an arduous task; typically, many experiments and interventions are required to determine causal connections. Thus, we apply the Fast Greedy Equivalence Search (FGES) causal discovery method to find them based on mostly observational data alone, in order to efficiently identify connections for entire structures. Specifically, we aim to map these causal connections in the medicinal leech's midbody ganglia, a brain-like structure which consists of 300 cells arranged in two monolayers (one cell thick). Causal discovery methods have been applied to other species such as rodents and humans as well, and structures such as symmetric connections in the left and right hemispheres and homotopic connections (between corresponding areas in each hemisphere) were found. In applying FGES to data from the 300 cells in leech ganglia, we find that analogous structures also exist in the medicinal leech.

Analysis of Spectral Initialization for Sparse Phase Retrieval
Madison Lee
Mentors: Babak Hassibi and Fariborz Salehi

Phase retrieval is the problem of recovering a complex signal given the knowledge of magnitude-only measurements. This problem is particularly important because the measurement of phase information is often costly and/or infeasible for many applications in imaging, acoustics, and interferometry. In recent years, there has been a plethora of methods using convex and non-convex optimization techniques for solving the phase retrieval problem. Most such techniques rely on some initial estimate of the underlying signal. In this project, we seek a precise analysis of a commonly used initialization technique known as "spectral initialization". More specifically, we investigate the performance of this method when the underlying signal is sparse. Our analysis consists of two steps. In the first step, we develop an analysis of the efficacy of the support estimation method. In the second step, we asymptotically characterize the similarity between the underlying signal restricted to the estimated support set and the estimated signal given by the sparse spectral initialization method. These results in conjunction provide us with the overall performance of the sparse spectral initialization method for phase retrieval.

Commons Cell Atlas: Developing and Optimizing an Infrastructure to Automate Processing of Single Cell RNA Sequencing Data
Yelim Lee
Mentors: Lior Pachter and Sina Booeshaghi

Single cell RNA sequencing (scRNA-seq) is a new technology that has become popular due to its ability to efficiently identify how cells vary in gene expression to find subpopulations of cells that were previously hidden by bulk RNA analysis. It provides a high-resolution view of cell-to-cell variation (Svensson et al, 2018). RNA-seq data requires computationally intensive pre-processing, since sequences must be aligned to the genome to determine their gene of origin. However, kallisto has revolutionized such analysis. kallisto, developed by the Pachter Lab, performs pseudoalignment to a transcriptome, making it much faster than traditional genome aligners without any loss in accuracy (Bray et al, 2016). The Pachter Lab also introduced the BUS (Barcode UMI Set) file format in order to facilitate preprocessing of single-cell data. Types and number of input files and parameters vary widely among species, sequencing technologies/versions, and types of raw sequence reads files, such that processing different samples with kallisto requires a nontrivial level of manual effort. To eliminate the considerable amount of time spent manually processing various types of data, my project *Commons Cell Atlas* focuses on developing and optimizing an infrastructure to automatically preprocess scRNA-seq data preprocessing, allowing for different sample conditions. In the same run, one could analyze the results of an experiment prepared with the Chromium 10x technology and the results of an experiment prepared with the inDrops technology. The resulting work will allow us to post process multiple single-cell datasets together from various tissue types in order to create a single-cell atlas for a particular species.

Developing Genetic Tools in *D. coriaria* for Understanding the Evolutionary Neurobiology of Social and Symbiotic Behavior
Natali Lelieur
Mentors: Joe Parker, Mina Yousefelahiyeh, and David Miller

In the Staphilinid subfamily Aleocharinae, at least 12 distinct species of beetles have evolved to become myrmecophiles, organisms that integrate into ant colonies. These beetles have evolved body shapes and behaviors that have allowed them to develop parasitic relationships with ants by disguising and integrating themselves into ant societies. The rate at which these different species of beetles have convergently evolved into myrmecophiles is much higher than would be expected within a single family. In order to better understand this evolutionary transition from free-living beetles to myrmecophilic beetles, genetic tools were developed by refining techniques of gene editing in Dalotia coriaria. A transgene was introduced into Dalotia eggs by an injection solution of plasmid DNA with an ie1 promoter sequence driving mCherry with the piggyBac transposon. The transgenic eggs were allowed to hatch into larvae and reach full maturity. The transgenic beetles were bred to develop a transgenic line of Dalotia coriaria. These methods can be used to insert more complex DNA into free-living beetles that will allow for further study of the neurobiology of the evolutionary transition of beetles related to Dalotia.

Colloidal Electronics: Synthetic Cells That Compute
Lexy LeMar
Mentors: Michael Strano, Albert Liu, and John Seinfeld

Synthetic cells, or “syn cells,” are colloidal state machines that range from 10 μm to 250 μm in diameter. Composed of 2-D electronic materials grafted onto colloidal particles, syn cells have the unique capability to be suspended indefinitely in solution, allowing these electronic devices to breach previously inaccessible environments such as gas pipelines or the human digestive tract. One variant of the syn cells was fabricated by electroplating platinum on graphene, printing an array of polystyrene, and capping with a second layer of graphene before lifting off the cells into solution. This project focuses on improvement of device fabrication, understanding the lift-off process, constructing on-board electrical memory arrays, and exploring intercellular interactions. To this end, an electroplating study was conducted to determine the optimal conditions for creating a uniform array of platinum patches. These platinum-coated cells were then placed in a hydrogen peroxide bath. Three series of videos were taken to capture the affect of concentration, salinity, and number of cells on the particle interactions. The attractive surface tension force and the repulsive chemophoresis force cause a breathing behavior that when induced in a large group of syn cells, more complex and powerful attributes could emerge from the ensemble interactions.

Mechanical Behavior of Entangled, Non-Convex Granular Particles: Experimental Analysis of the Angle of Repose
Jade Leong
Mentors: José Andrade, Raj Pal, and Siavash Monfared

Classically, angle of repose testing is achieved using fine granular materials such as sand or soil. With the increasing research in designed granular materials that entangle, there is a greater need for understanding the material’s mechanical behavior. The static angle of repose (AoR) is investigated to understand the mechanical behavior of entangled, non-convex particles. Some of the methods studied are the fixed funnel, hollow cylinder, and wall removal. Performing different methods of the AoR test proves which method works best for entangled non-convex particles. Simulations through the novel Level Set Discrete Element Method (LS-DEM) are performed for the specified AoR method and particle geometry. The simulations are being done in conjunction with the lab testing. Validating the simulation results with the experimental work is of great importance to the advancement of this research.

Documenting Steep Slope Bedrock Erosion on Mars and the Moon
Janette Levin
Mentors: Michael P. Lamb and James Dickson

This project aims to explore the role of dry rockfall in the erosion of the bedrock alcoves of Martian gullies. The role of volatiles in the Martian environment is not well constrained, so we chose the Moon, which is completely dry, as a control environment. We located and analyzed erosional features on steep slopes of fresh Lunar craters in order to better understand the morphology of landforms produced by dry bedrock erosion. Target locations for Lunar erosion were identified using a slope map generated from Kaguya Terrain Camera data to filter locations with slopes between 30-40°. All potential high-resolution stereo pairs that overlap an area of sufficiently steep slope were visually inspected for erosional landforms. High resolution Digital Elevation Models (DEMs) were produced using stereogrammetry for target locations on Mars and the Moon. The morphologies of lunar erosional landforms were analyzed using qualitative observations and quantitative measurements taken from the DEMs, and compared to their Martian analogues. This survey of steep Lunar slopes has led to the discovery of features that resemble terrestrial leveed debris flows, which have not previously been observed in a volatile-free environment.

Automated Thermal Readout and Thermal Studies of the Barrel Timing Layer Sensor Modules for the CMS MIP Timing Detector at the HL-LHC
Sophie Li
Mentors: Maria Spiropulu, Lautaro Narvaez Paredes, Nan Lu, and Adi Bornheim

The MIP Timing Detector (MTD) is a new detector planned for the CMS experiment during the High Luminosity era of the Large Hadron Collider (HL-LHC). In each proton bunch crossing, the HL-LHC will produce over 200 nearly simultaneous pile-up events. The MTD can measure the production time of a minimum ionizing particle (MIP) with a resolution of 30-40ps. This improves the detector's capability to differentiate pile-up events. The Barrel Timing Layer (BTL) is the cylindrical subsection of the MTD and must be maintained at a temperature lower than -30 degrees Celsius. Noise and leakage currents, which increase with temperature, cause time jitter which significantly degrades the time resolution. The temperature of the BTL cooling plate was measured in response to heat generated by resistor arrays. These simulated the expected temperature impact of silicon photomultiplier (SiPM) photon detectors in the BTL. We found a significant temperature gradient both across and through the cooling plate, which was previously unaccounted for. Furthermore, the thermal conditions of various materials and detector setups were analysed. We have developed the BTL cooling plate prototype and thermal readout procedures such that SiPMs can be tested in September.

Neuroscience Meets Electrical Engineering: Neuroscientists Might Be Able to Understand Microprocessors After All
Samuel C. Liebana Garcia
Mentor: Frederick Ducan Eberhardt

In this study we investigate the use of *causal discovery algorithms* as a method to identify causal relations between wires in a transistor-level simulation of the *MOS6507 microprocessor*, as employed in the Atari 2600 video-game console. The overall aim of the study is to validate *causal inference* as a technique to learn more about the networks connecting regions and structures in the brain; the microprocessor model serving as a well-understood *ground truth* to verify the technique's effectiveness. This research was conducted in response to "Could a Neuroscientist Understand a Microprocessor?", a critical paper written by Jonas and Kording in which they dismissed common neuroscience data analysis methods after assessing their ability to describe the MOS6507. The *Fast Greedy Equivalence Search (FGES)* and *Coincidence Analysis (CNA)* causal discovery algorithms were not assessed by Jonas and Kording, hence we test them on the *binary state data* (HIGH/LOW) of 1725 wires recorded from the simulation. The preliminary results show that FGES returns graphs with low *precision* and *recall* values when compared to the known connectome; a finding, we believe, that reflects the challenge of causal inference in *deterministic* data, rather than the accuracy of the method in general. Additionally, we found that CNA, a method for causal discovery from deterministic data, did not scale to the complexity of the microprocessor and yielded results that were difficult to interpret. At this stage it remains unclear whether the deterministic binary nature of the microprocessor data constitutes a useful testbed for inference methods in neuroscience, or whether it only introduces new challenges for structure discovery. Future work involves running FGES on data from a *parcellation* of the microprocessor and assessing to what extent the searches elucidate the causal relations between structural parcels. We also aim to investigate the nature of *equivalence classes* for deterministic causal systems, in an attempt to determine whether the results of FGES on the transistor-level data may actually reflect accurate results for deterministic systems.

Development of Biosensors for R-Ketamine and Radafaxine, Ketamine Class Anti-Depressant Drugs
Elaine Lin
Mentors: Henry A. Lester and Kallol Bera

As depression is a severe set of mental illnesses that affect over 300 million people worldwide, it is important that more efficient anti-depressant drugs are developed. The objective of this project is to evolve biosensor proteins that are able to detect R-Ketamine or Radafaxine ((2S, 3S)-HB), types of anti-depressant molecules. Via site-saturated mutagenesis, fluorescent marker proteins are mutated so they can better bind to drug molecules and thus emit more fluorescence. The fluorescence of the biosensors allows the drug molecules to be imaged in vivo with confocal microscopy. Then, the metabolism of these drug molecules can be studied and better anti-depressant drugs can be developed. An important measure for biosensors is the EC_{50} value, the concentration of the biosensor needed to induce half of the maximum fluorescence response when exposed to the drug molecule. The most effective biosensors for R-Ketamine and Radafaxine currently have EC_{50} values of 10.7 μM and 52.8 μM, respectively. The criteria for a viable biosensor as defined by the Lester Lab is an EC_{50} value of 1 μM. These biosensors must be further mutated so their EC_{50} values drop and they can be used while imaging the drug molecule inside a live cell.

Smoothed Online Convex Optimization
Yiheng Lin
Mentor: Adam Wierman

We study smoothed online convex optimization (SOCO) in a setting where the learner seeks to minimize the sum of a per-round hitting cost and a movement cost which is incurred when changing decisions between rounds. We make three contributions in this work. First, we introduce a new algorithm, R-OBD, which has a competitive ratio that is provably optimal in the setting where the hitting costs are $m-$strongly convex and the movement costs are the squared ℓ_2 norm. R-OBD improves upon the state-of-the-art both in terms of competitive ratio and computational complexity. Second, we show that SOCO with ℓ_2 quadratic movement costs has implications for LQR control and demonstrate the effectiveness of R-OBD in this setting. Well-conditioned hitting cost functions are common in LQR control, and so we prove an improved bound in this setting. Specifically, we prove that when the condition number of the hitting cost functions is k the competitive ratio of R-OBD is bounded above by $1+k$. Third, we show how to use predictions of future costs in the context of R-OBD, introducing a new algorithm, ARFHC, that applies more generally than state-of-the-art algorithms.

Analysis of Variability and Stochasticity in Neural Crest Lineage Using Viral Barcoding With Image Based Readout
Yongjie Lin
Mentors: Michael B. Elowitz and Amjad Askary

The project focuses on applying the viral barcoding based lineage tracing technique to study the variability and stochasticity in the development of neural crest in chick embryo. During the complex process of embryonic development, progenitor cells, even in a seemly homogeneous population, differ in types and number of cells they give rise to. We plan to use a new lineage tracing technique, developed in the Elowitz lab, to address long standing questions about variability in the lineage with dense labeling and high recovery of labeled cells from individual embryos. This new method labels cells with static as well as CRISPR editable viral barcodes and recovers the lineage information by in situ readout of barcodes at the end point. To address the computational challenges of lineage reconstruction using incomplete data, we used simulation to evaluate the feasibility of lineage reconstruction under limitations of current lineage tracing methods. Meanwhile, we are also building a diverse lentiviral combinatorial library that enables us to track the lineage of many neural crest progenitors in the same embryo. We hope to use this lineage tracing method together with our computational framework to analyze the embryo-to-embryo variability in the lineage of neural crest derived cells.

Mixed-Functionalization of Molybdenum Disulfide
Yuying Lin
Mentors: Nathan Lewis and Ellen Yan

An electronic nose is a device designed to identify volatile organic compounds (VOCs) that has attracted research attention due to its applications in disease detection and air quality monitoring. This device consists of an array of chemical sensors that generates a pattern of response upon exposure to VOCs; these patterns are then recognized using machine learning. This project focuses on one particular sensor material, molybdenum disulfide (MoS_2), because of its low toxicity, cost, and high abundance and ease of processing. In the past, studies have been conducted on sensors made with gold nanoparticles upon which functional groups of varying polarities were attached. (sources) Similarly, this project explores the functionalization of MoS_2while mixing the polarities of the functionalizing molecules. Data obtained using X-ray photoelectron spectroscopy demonstrated that functionalizing MoS_2 first with a larger, less reactive molecule and then a smaller, more reactive molecule yields a desirable coverage. Future steps include comparing the performance of mixed-functionalization MoS_2 sensors to sensors made of a heterogenous mixture of MoS_2 functionalized with non-polar and polar molecules separately.

DGNSS-Vision Integration for Spacecraft Navigation
Yvette Lin
Mentors: Soon-Jo Chung and Vincenzo Capuano

Real-time autonomous relative navigation is an important capability for space missions such as on-orbit servicing and formation flying. Global Navigation Satellite System (GNSS)-based navigation is a common solution; however, in high-earth orbit, and in situations of limited computation resources, low number of GNSS satellites, and poor geometry, performance decreases. This project focuses on a novel, highly robust, and accurate real-time navigation architecture that integrates monocular computer vision with GNSS. The chaser and target satellite are each fitted with a GNSS receiver and a camera, and observations from both are used to determine state. The architecture was tested using a set of realistic synthetic images generated according to motion in geostationary orbit, and realistic GNSS measurements corresponding to the same set of positions. We find that the GNSS-vision solution achieves significantly better accuracy than GNSS or vision alone, and robust to situations in which GNSS or vision alone perform poorly. The main focus of my work was image dataset generation, feature detection and pose estimation from camera images, and implementation of the DGNSS-vision fusion batch filter.

Finding High-Redshift Galaxies With JWST
Nora Linzer
Mentor: Charles Steinhardt

One of the primary research goals for the upcoming James Webb Space Telescope (JWST) is to observe the earliest forming galaxies in the universe. Current estimates predict that on average, JWST will find galaxies out to a redshift of 15 in an idealized survey similar to those planned for the first year of operation. The first and most massive galaxies, however, are expected to be tightly clustered together, an effect known as cosmic variance. We calculate cosmic variance at high redshift, concluding that although on average a JWST survey would be able to observe high-redshift galaxies, very few surveys will be close to average. Instead, a survey will find none of these galaxies a majority of the time, while a lucky choice of where to look will instead find many times the average. We then develop alternate strategies to improve the likelihood of finding the first galaxies with JWST, such as parallel surveys or by making use of gravitational lensing.

Spacecraft Simulator Upper Stage
Jamie Littman
Mentors: Soon-Jo Chung and Sorina Lupu

Having the ability to rendezvous and dock in space allows for multiple actions that are beneficial for our next stage in space travel and exploration, including repairs of existing crafts and in-orbit assembly of structures such as telescopes. In order to test these methods, spacecraft simulators are used in the Spacecraft Simulator Facility which allows for frictionless motion. Currently, the craft are built to allow 3 degrees of freedom. However, to have them more accurately represent the environment in space, they need to be updated to allow for up to 5 degrees of freedom. This is done while keeping the structure as light and efficient as possible to minimize energy used by the thrusters. In addition to modifying the structure, an additional mass balancing algorithm needs to be implemented to minimize gravitational torque. This is done through the movement of linear actuator masses and the development of an Extended Kalman Filter to minimize the offset in the z axis.

A Systematic Search for Periodic White Dwarfs in Gaia Data Release 2 Using ZTF Data
Chang Liu
Mentor: Shrinivas R. Kulkarni

The Zwicky Transient Facility (ZTF) is a new optical time-domain survey that uses the Palomar 48-inch Schmidt telescope equipped with a 47-deg^2 CCD camera. It is the first optical survey which will observe the visible part of the Galactic Plane every single night in two colors (g and r bands) to complete the census of all kinds of variable stars. A sample of 81 periodic white dwarfs (WDs) with periods between 1 and 3 hr is selected from a population of 486,641 WDs in the second data release of the Gaia mission (Gaia DR2), by applying Lomb-Scargle periodogram to light curves obtained with ZTF. It contains 16 sources identified in SIMBAD in which there are 4 cataclysmic variables (CVs). Photometric identification of all the periodic sources has been conducted through classification in light curves and analysis in the color-color space with a cross-match between Gaia and PanSTARRS. The most interesting sources still need further spectroscopic identification.

Psychophysical Studies of Human Cognitive Control
Elise Liu
Mentors: Ralph Adolphs and Zhongzheng Brooks Fu

In an ever-changing world, the ability to adapt our thoughts and behaviors is crucial. Cognitive control, which is at the core of human cognition, accounts for such flexibility and is indispensable for goal-directed behaviors. In this project, we investigate the robustness and transferability of cognitive control using a Multi-Source Interference Task (MSIT) with visual feedback. The subject is shown feedback after each trial to see how this information impacts the intensity of behavioral signatures such as the conflict adaptation effect. Adaptive time constraints are set to observe how cognitive control effects scale with response speed. Each block of the MSIT contains transitions between trials with different levels and types of conflict to see whether cognitive control recruited in one trial can resolve a conflict in another. In the future, we plan to design an MSIT reaction time reproduction task to study the effects of conflict on metacognitive abilities.

A Probe Into the Evolution of Quasi Periodic Oscillations Seen by NICER in the 2017/2018 Outburst of MAXI J1535-571
Feiyang Liu
Mentors: Fiona A. Harrison, Javier García, and Matteo Bachetti

Quasi Periodic Oscillations are commonly found in the light curves of Black Hole transients. Their shape and oscillation frequency changes as transient systems evolve over time. And they are believed to be generated from the inner accretion region of Black Holes, which makes them a potential Rosetta stone for deciphering physical processes in the vicinity of accreting Black Holes. MAXI J1535-571 is a Black Hole transient that entered into outburst in September 2017 and was subsequently monitored extensively by the NICER in the X-ray band. Using data from these observations. We analyzed the power density spectrum and energy spectrum of over 136 0.7ks-long observations and find a certain type of Quasi Periodic Oscillations whose frequencies increase over a certain time. By comparing the Oscillation frequency with the corresponding spectrum, we identified a very prominent correlation between spectra's hardness and Quasi Periodic Oscillations' frequencies. Our results suggest that Quasi Periodic Oscillations come from coronae which dominate the hard spectrum part.

Sweet Taste 2D-QSAR Prediction and Activation Mechanism of the G Protein-Coupled Sweet Receptor Heterodimer (TAS1R2/1R3)
Gaoyuan Liu
Mentor: William A. Goddard III

The sweet taste in humans is mediated by the heterodimer TAS1R2/1R3 G protein-coupled receptor (GPCR). In experiment studies, a wide variety of sugars and artificial sugars bind to the TAS1R2/1R3 heterodimer receptor. We build a sweet taste 2D-QSAR prediction model, which can be used for testing unknown sweeteners, by 21 cases training sets and using interaction energy between sweeteners and critical residue, helixes of transmembrane domains (TMDs) changing during Molecular Dynamics (MD) and free energy of activation as descriptors. We carry out 100 nanoseconds MD with membrane and 0.15mol/L NaCL solution for TAS1R2/1R3 with Rebaudioside M, we notice that the salt bridge in TM3-6 of TAS1R3 breaks and the salt bridge between Venus flytrap domains (VFDs) forms at the same time. We align the G-protein (GP) to opening TM3-6 of TAS1R3 and get the stable anchors between intercellular loops and G-protein by 30ns MD. We carry out Metadynamics for RebM-TAS1R2/1R3 with G-protein to open the salt bridge in TM3-6 of TAS1R2 to look at free energy profile and we observe the opening form has lower free energy in this case.

Characterization of Hermaphroditic Cues for Mate Recognition in *Caenorhabditis elegans*
Hongrui Liu
Mentors: Paul W. Sternberg and Chun-Hao Chen

Precise mate recognition is essential to faithfully transmit genetic materials for phenotypic plasticity during evolution. In our previous study, we show that *C. elegans* males utilize physical contact to verify the potential mates through unknown cues in the short distance. In this project, we aim to identify contact-dependent cues on hermaphrodites for mate recognition. To this end, we exploit the natural diversity of *C. elegans* wild-type isolates by analyzing 12 intraspecific strains from different geographical locations. We find that *C. elegans* males are able to distinguish those intraspecific wild-type isolates with different genetic background, providing a genetic foundation of mate recognition during evolution. Future work will focus on genome-wise association (GWA) mapping to identify hermaphroditic contact-dependent cues and study the neural mechanism of mate recognition in *C. elegans* males.

A Modular Workflow for Processing inDrops Sequencing Data
Lauren Liu
Mentors: Lior Pachter and A. Sina Booeshaghi

Single-cell RNA sequencing (scRNA-seq) provides information about the RNA content of individuals cells. However, the various parts involved in processing the results of an scRNA-seq experiment—choosing the sequencing technology, performing error correction and assignment, and quantifying transcript or gene expression—are often packaged together into a single opaque workflow. The kallisto | bustools workflow leverages the BUS (Barcode, UMI, Set) file format to separate single-cell RNA sequencing technology preprocessing from the gene- or transcript-level analysis of the data. We develop a suite of tools, collectively referred to as BUStools. With these new tools, and small modifications to kallisto, we can now process scRNA-seq data from almost any sequencing technology. To show this, we process an existing scRNA-seq dataset, produced using the inDrops technology, using the kallisto | bustools workflow and demonstrate results comparable to those obtained using the standard inDrops workflow.

Enantioselective Polycyclic β-Lactam Synthesis Using Engineered Hemeproteins
Qianhe Liu
Mentors: Frances H. Arnold and Inha Cho

β-Lactam-based structures are heavily represented in complex pharmaceuticals, especially antibiotics such as penicillins that can efficiently treat bacterial infections by inhibiting growth of bacterial walls. However, continued exposure to these β-lactam antibiotics allows bacteria to evolve defense systems such as β-lactamases to be resistant to β-lactams. Thus, novel β-lactam antibiotics foreign to existing bacterial defense systems are in high demand. Polycyclic β-lactams have shown potential to disable bacterial β-lactamase, but their synthesis is challenged by the need for the precise control over stereocenters. Recently, the Arnold group has identified a variant of the truncated hemeprotein cytochrome P411 BM3, harbored by *E. coli*, that has demonstrated the ability to synthesize a model polycyclic β-lactam by mediating intramolecular C–H amination using an amide precursor.

Through rounds of site-saturation mutagenesis, we can improve the yield and enantioselectivity for this model reaction. Furthermore, using additional amide precursors with different functional groups, we can produce a wide scope of polycyclic β-lactams that can be used as the basis for β-lactamase resistant antibiotics.

Statistical Analysis of Rewards-Based Crowdfunding Platforms
Sarina Liu
Mentors: Agostino Capponi and Animashree Anandkumar

This project empirically compares successful and failed campaigns on the two most popular rewards-based crowdfunding platforms, Kickstarter and Indiegogo. Even though crowdfunding is a relatively new field, over the past decade, project creators have improved the quality signal from their products based on trends in target goal, pledged amount, campaign duration, and creator reputation. Despite the All-Or-Nothing funding format on Kickstarter and the Keep-It-All funding format on Indiegogo, only limited differences are observed on the creator's side when comparing those aforementioned factors that affect probability of success. However, on the funder's side, there is greater trust in All-Or-Nothing campaigns. A major focus here is also the significant effect of intraplatform competition on project design, which is an important new area of research as the popularity of fintech increases. Finally, an economic model is constructed from these empirical findings.

Study of the Insulating States in Magic-Angle Twisted Bilayer Graphene
Xiaoling Liu
Mentors: Jason Alicea and Alex Thomson

Twisted bilayer graphene (TBG) is constructed by stacking and twisting two layers of graphene relative to each other. Near the magic twist angle of 1.1 degrees, the electronic structure of TBG features flat bands that, when partially filled, yield correlated insulating states as observed in numerous experiments. To shed light on experiments, we simulate an effective free-electron model for magic-angle TBG with uniaxial strain and map out properties including band structure and local density of states. We further introduce long-range Coulomb interactions, derive an effective Hamiltonian for the flat-band subspace and perform a Hartree-Fock mean field analysis which is expected to capture the observed correlated insulators.

Developing Quantitative Methods for Characterizing Gene Expression in *Pseudomonas aeruginosa* Biofilms
J Livingston
Mentors: Dianne Newman and Melanie Spero

Understanding the behavior of bacteria in chronic bacterial infections is essential for the development of effective treatments. Hybridization chain reaction (HCR) is a technique that provides *in situ* molecular signal magnification enabling simultaneous mapping of multiple target RNAs. To develop this method we have designed and validated new probes for future use to visualize gene expression. We verified the specificity of various HCR probes for mRNA and rRNA targets and verified the quantitative nature of the probes by comparing HCR results to qRT-PCR (*q*uantitative *R*everse *T*ranscription *P*olymerase *C*hain *R*eaction) gene expression data. We hypothesized that characteristic expression levels of a range key metabolic genes in *Pseudomonas aeruginosa* would correspond to different metabolic states that could be detected using HCR. Our probes were specific to their intended targets and could be used to quantitatively determine gene expression levels, indicating that we can use them to look at gene expression patterns *in situ*. Future work will use this method to identify different metabolic states in *Pseudomonas aeruginosa* biofilms.

FPGA Accelerated 2nd-Order Coherence (g^2) Measurements
Aron Lloyd
Mentors: Oskar Painter and Vinicius Ferreira

Orders of Coherence are the normalized auto-correlations; which roughly translate to 'ability of a signal to interfere with itself'. They reveal information regarding statistical distribution in frequency space. Arguably more interesting though, the g^2 of a quantum signal distinctly contrasts that of classical due to the discrete nature of photons. This makes it a popular 'indication of Quantumness'. Problem with quantum signals in the microwave regime (with which we are concerned) is that they are small, and require profuse repeated averaging to achieve proper Signal-to-Noise, on the order of 1,000,000 repetitions. With signal processing involved, this task becomes a day-long event on a conventional computer, even with powerful GPU/CPUs. This is the context where FPGA's prove invaluable tools. A Field Programmable Gate Array device can be 'configured', using typed Hardware Description Language, into a highly optimized, nearly direct implementation of a high-speed circuit. In our case, we want to calculate the g^2 of a photon after driving/emitting from a Transmon qubit. In terms of digital processing, we do 4 operations: Mean Subtraction, Demodulation of Carrier Frequency, application of FIR lowpass filter, & calculation of correlation functions. If averaged over 1,000,000 runs, an FPGA cuts the total processing/averaging time from roughly 14 hours —> 30 minutes.

Using GEANT4 to Model CsI Crystals in the Mu2e Calorimeter
Victoria Lloyd
Mentor: Bertrand Echenard

The Mu2e experiment will search for charged lepton flavor violating neutrino-less conversion from a negative muon into an electron in the field of a nucleus. This reaction is extremely suppressed in the Standard Model of particle physics and an observation would be a clear sign of new physics. Mu2e plans to improve the current sensitivity on mu-to-e conversion by four orders of magnitude. The experiment relies on a crystal calorimeter to separate electrons from muons to reduce background. Using the Geant4 framework, we model the transit time taken by optical photons to reach the photomultiplier as a function of their origin for different crystal geometries. By cataloging these distributions, my project will improve the accuracy of the simulated time-of-flight data used to create the particle identification algorithms used in the experiment.

Integration of Bond Types in Molecular-Orbital Based Machine Learning
Beau Lobodin
Mentors: Thomas Miller III and Tamara Husch

Molecular orbital-based machine learning methods have been shown to accurately predict post-Hartree-Fock correlation energies within a mean absolute error of 2 mhartree on molecules from within the QM7b-T dataset, thus providing a cheaper, more transferable means by which solutions to the Schrodinger equation can be obtained. It was during such experiments that particular Fock, Coulomb, and exchange matrix elements composing the training vectors were seen to display distinct local structures related to individual bond types. Adding bond-assignment functionality to *entos*, the principal quantum chemical software package used in this research, we are able to apply this new knowledge to separate our regression problem into parts. Using results from the incurred post-Hartee-Fock and localization calculations, we assign bond types to MOLPRO generated training sets beforehand such that supervised molecular orbital based machine learning methods may be employed. Qualitatively, we have observed increased performance on sets of simpler molecules, and we anticipate increased success with more advanced tests.

Gravitational Wave Models of Eccentric Binary Blackhole Systems
Jackie Lodman
Mentors: Yanbei Chen and Vijay Varma

Numerical relativity (NR) simulations are extremely computationally expensive, but remain the only *ab initio* method to accurately predict the gravitational waveforms produced by binary black hole mergers. Surrogate models are models produced through the interpolation of pre-existing NR simulations, and are as accurate as NR simulations at a fraction of the computation cost. Models of this type play a crucial role in extracting the signals from the data from gravitational wave detectors. Currently, binaries simulated in these models are assumed to be in quasicircular orbits, as any starting eccentricity would be radiated away before the signal falls into the LIGO band. This assumption, however, may not always hold, as dynamical interactions could lead to binaries with nonzero eccentricity in the LIGO band. Therefore, it is important to include eccentricity in our models to fully understand the signals seen by our detectors. In this project, we develop the first surrogate model for eccentric binary black holes. To begin, we restrict ourselves to equal-mass, non-spinning, binary black holes with nonzero eccentricity. We find that we can build an accurate model for eccentricities of up to 0.2.

Rapid Discharge Calorimetry and Viscometry of Metallic Glasses in the Supercooled Liquid Region
Christopher Long
Mentors: Brent Fultz and Stefan Lohaus

Continuous heating through the glass transition temperature causes solid metallic glasses to decrease in viscosity by over 12 orders of magnitude and enter a supercooled liquid (SCL) region. Due to rapid crystallization, no experimental data exists in the SCL region, preventing the validation of a theoretical model for it. Rapid discharge calorimetry and viscometry are experimental methods for crossing the glass transition temperature while outpacing crystallization. They work by firing a high-current pulse through metallic glasses, heating them from room temperature to 500°C in five milliseconds. This provides a window to gather information about the behavior of metallic glasses in their supercooled liquid phase. By using high-speed instruments, we measured temperature, voltage, and current in order to calculate the enthalpy, entropy, and heat capacity of the metallic glass NCPB239 ($Ni_{68.17}Cr_{8.65}Nb_{2.98}P_{16.42}B_{3.28}Si_{0.5}$). Furthermore, the apparatus compresses the samples to deform them while they are hot and measures the required force, allowing for the determination of their viscosity. We have refined our instrumentation to yield accurate measurements, and our calculations of enthalpy and heat capacity align with existing literature. Our measured viscosity bridges a data gap in the SCL region, which will help to evaluate the validity of theoretical models.

Stimuli-Induced Secondary Structure Response of a Cephalopod Reflectin Protein
Alejandro López
Mentors: Alon Gorodetsky, Mikhail Shapiro, and Preeta Pratakshya

Abstract withheld from publication at mentor's request.

The Search for Kilonovae
Tegan Loveridge
Mentors: Mansi Kasliwal and Igor Andreoni

Kilonovae, extragalactic transients that are powered by the radioactive decay of heavy elements created in the ejecta from compact object mergers, are still somewhat of a mystery to us. From the single well-studied example we have observed, we know that they can follow neutron star – neutron star mergers and suspect that they could follow other gravitational wave events such as black hole – neutron star mergers. Due to their potential relationship with these important events as well as the probe they offer into rapid neutron capture nucleosynthesis, learning more about these transients is vital.
The Zwicky Transient Facility (ZTF) database has been the primary source of transient data for this project. Using constraints on the distance and timescale based on the kilonova associated with the gravitational wave event in 2017, lists of candidates were obtained by querying the ZTF database. The images and light curves of these objects have so far not revealed any kilonovae, though further examination with forced photometry is needed to confidently classify some candidates. More optimized queries that focus specifically on searching areas near potential host galaxies will also be performed.

Optimizing MRI Scan Times With Reinforcement Learning and Deploying Deep Learning Models Onto MRI Scanners for Real-Time Decision Making
Grace Lu
Mentors: Shreyas Vasanawala, Elizabeth Cole, and Adam Blank

Magnetic resonance imaging (MRI) is a medical imaging technique for imaging soft body tissues. It samples data in the Fourier domain along multiple trajectories to reconstruct images. We aim to optimize Cartesian sampling, in which different rows of the Cartesian matrix are sampled until all rows have been sampled and an image can be created from the data. Unfortunately, sampling all of the rows is time-consuming, costly, and inefficient for both the patient and hospital. Undersampling the data with compressed sensing can still generate high-quality images while shortening scan times by leveraging the physical and spatial qualities of the data. The optimal undersampling pattern for sampling trajectories has been found to favor sampling the origin of the Fourier domain first, as that is where the majority of the energy is. With reinforcement learning, we can continuously infer the next best sampling trajectory as we acquire data. We experimented with different image reconstruction techniques and reward functions to produce the best perceptual image quality while still minimizing scanning times. We also worked on deploying trained deep learning models onto Heartvista, an MRI scanning software, so scanners can make real-time decisions to scan the inferred next best sampling trajectory.

Tidal Distortions of Hot Jupiters Characterized With Numerical Methods
Tiger Lu
Mentors: Burkhard Militzer, Sean Wahl, and James Fuller

The shape of a hot Jupiter responds nonlinearly to the gravitational field of its host star. We study this distortion with the Concentric Maclaurin Spheroid (CMS) method, which finds an equilibrium shape and gravity field of a rotating, liquid planet with a prescribed internal structure; as well as tidal interactions with a perturber. The model already has been used to great effect in the computation of the gravitational fields of Jupiter and Saturn under the gravitational influence of a satellite. We present a series of scaling relations to predict the tidal love number k2 and flattening for an exoplanet within a viable range of observational parameters (mass, radius, equilibrium temperature). We also benchmark the CMS method to determine limits of convergence for calculations in cases of extreme tidal distortion. Our computed k_2 has real applications and has been measured for a few exoplanets, as we know from Batygin (2009) and Sz. Csizmadia, H. Hellard, and A. M. S. Smith, A&A 623, A45 (2019).

Assessment of the Standard k-ε Turbulence Model
Moya Ly
Mentor: Guillaume Blanquart

Reynolds-averaged Navier-Stokes (RANS) equations allow modeling of turbulence in fluids with a larger domain and lower computational cost than is possible through direct numerical simulation (DNS), but in less detail. In ANSYS Fluent, simulations were run using a 2-D axisymmetric model of a turbulent, incompressible, round jet to match the experimental conditions of Hussein, Capp, and George (1994). k-ω, Spallart-Allmaras, and standard, RNG, and realizable k-ε RANS models produced expected velocity trends for a turbulent jet. However, the k-ω simulation gave a higher centerline velocity and lower turbulent kinetic energy (k) value, while the other simulations gave lower centerline velocity and higher k (if applicable) as compared to experimental data. Future work will analyze the accuracy of a standard k-ε model with the injection of a passive scalar into the jet and combine the k-ε model with DNS to optimize accuracy, resolution and speed of simulations.

Automatic Detection of Motion Artifacts in Magnetic Resonance Imaging
Jeffrey Ma
Mentors: Shreyas Vasanawala, Ukash Nakarmi, and Julian Tyszka

Magnetic resonance imaging (MRI) is a non-invasive imaging modality where detailed images of anatomy, tissue structures and physiological processes of the body can be visualized using magnetic fields and radio waves. Unfortunately, MRI requires lengthy data acquisition times and complex scanning parameters and protocols, and patient discomfort and movement during scanning often result in motion artifacts, poor image quality, and even misdiagnosis, especially with pediatric patients. Current solutions are suboptimal, and artifacts commonly go unrecognized despite the extensive training of MR scanner technicians. In many centers, patients are simply asked to return for a repeat scan, wasting valuable time and resources. To solve this issue, this work uses deep learning techniques to develop an automatic machine learning pipeline for detecting motion artifacts from scanned images and assessing the diagnostic quality of MR images. Our network architecture identifies motion errors immediately after the scanning process, automatically flags images by providing an automatic image diagnostic score based on the presence of motion artifacts, and advises the technician to repeat a scan while the patient is still in the scanner, thus streamlining and increasing the reliability of MRIs for pediatric patients.

***Ab initio* Investigations Into Electron Dynamics: Spin-Defect Relaxation Times Due to Spin-Orbit Coupling**
Shreshth Malik
Mentors: Marco Bernardi and I-Te Lu

The utility of spintronic devices relies on preserving spin information during transport, which can be lost at momentum scattering events via a spin-flip relaxation mechanism called the Elliot-Yafet (EY) mechanism. The EY mechanism involves the interactions between electrons and the environment, e.g., lattice vibrations and atomic defects. While lattice vibrations dominate at room temperature, the interactions between electrons and defects can control spin relaxation processes at low temperatures and in highly doped or disordered materials. The characteristic time to lose spin polarisation – the spin relaxation time (SRT) – is the figure of merit for spintronic materials. SRTs can be investigated without any empirical parameters using *ab initio* calculations. However, first principles calculations for spin-defect interactions are hindered by expensive matrix element calculations. Here, we develop an efficient numerical approach for spin-flip matrix elements and hence SRTs, applying the approach to study electrons/holes scattering off neutral defects in silicon. The method developed in this work can be used to predict SRTs due to impurity scattering in a wide range of materials, providing fundamental insights into spin-flip processes to facilitate the discovery and development of effective spintronic devices.

Separation of Cosmic Microwave Background From Foreground Signals for the BICEP Collaboration
Ananth Malladi
Mentors: Sergi Hildebrandt Rafels and Jamie Bock

According to the theory of Cosmic Inflation, the gravitational waves from the inflationary period would leave an imprint on the B-mode polarization of the Cosmic Microwave Background (CMB). The goal of the BICEP collaboration is to use data from the BICEP/Keck telescopes to examine the possibility of detecting this signal. However, this is a nontrivial task due to the presence of synchrotron and dust emissions (which emit polarized light in the same regime as the CMB). In this project, I attempt at separating the CMB signal from dust and synchrotron radiation by using a Constrained Least Squares fit to the data from the BICEP/KECK telescopes, and the Planck space mission. Following published results from other experiments, we assume that synchrotron radiation follows a power law, and that dust follows a modified black body. The code to perform this task was written in Python.
As of now, the code shows promising results on artificially generated data. Currently, tests are being conducted on the code to show that (1) integration over bandpass responses of the detectors is necessary, (2) constrained least squares is an effective method (as compared to Python's built-in libraries), and (3) component separation is feasible even when there are few observing frequencies and several model parameters. Further studies may investigate the usage of masks to more effectively filter out the contributions of dust and synchrotron from the galaxy and may attempt a similar procedure on data from the Planck satellite.

Improving Power Conversion Efficiency in Vertical Schottky-Junction Transition Metal Dichalcogenide (TMD) Solar Cells
Morgaine Mandigo-Stoba
Mentors: Harry Atwater and Cora Went

Transition metal dichalcogenides are a fairly recently discovered class of semiconductors with a variety of appealing qualities. They have ultra-high absorption per unit thickness, around one order of magnitude larger than other new photovoltaic materials like Gallium Arsenide and two orders of magnitude larger than traditional photovoltaic materials like Silicon. This allows for fabrication of thin, flexible cells with the potential to greatly expand applications of solar power to transportation, spacecraft, and more. Additionally, TMD solar cells use far less material than traditional Silicon solar cells and have the potential to greatly reduce fabrication costs. This project aims to improve the power conversion efficiency (PCE) of TMD solar cells above 1% by optimizing metal contacts in vertical Schottky-junction solar cells. Lumerical device is used to identify promising device configurations which reach simulated PCEs of over 6%, and which will be fabricated using template stripping, exfoliation, and a combination of kinematically controlled transfer printing and temperature dependent transfer to produce exceptionally clean device interfaces free from Fermi-level pinning.

Calibration and Optimization of Phased Array Transmitters
Mohith Manohara
Mentors: Ali Hajimiri, Austin Fikes, and Matan Gal Katziri

Phased array systems are useful in many applications for their ability to steer electromagnetic beams without requiring moving parts. However, it is necessary to calibrate the array phases to optimize the directivity of the beam to a particular receiver. In addition, the bent surface on flexible arrays changes the phase centers of each element, and this can negatively impact the farfield beam pattern. To optimize the phases, an algorithm was written to adjust the phases to maximize the power at a receiver. This initial algorithm was written and tested on an array. Further improvements to the algorithm for speed and effectiveness are being investigated. Additionally, we collected phase data between different elements of a flexible array to determine the effect of shape on the beam pattern and element coupling. A relationship was identified between the local curvature of the array and the phase coupling between elements, and this information can eventually be used to capture the shape information of an array by measuring the mutual coupling between elements.

Assessing the Efficiency of Different Strategies for Guide RNA Multiplexing in Cas9-Driven Genome Engineering
Zeping Mao
Mentor: Kaihang Wang

The use of CRISPR-Cas nucleases has become a central part of biological research. Due to increased needs for precise and efficient targeting of multiple genomic sites, guide RNA (gRNA) multiplexing has emerged as a core component of the CRISPR-Cas toolkit. There are several different strategies to build gRNA multiplexing systems, those of which include: (i) multiple single gRNA expression cassettes, and (ii) gRNA polycistronic cassettes. The multiple single gRNA expression cassette consists of placing individual promoters upstream of each single gRNA. In contrast, the gRNA polycistronic cassette is comprised of multiple single gRNAs driven by a single promoter, but separated by several linkers that get processed post-transcriptionally. However, although both of the aforementioned gRNA multiplexing systems have been individually characterized, their efficiencies have never been extensively cross-compared in prokaryotes. Because there is an intrinsic need for more efficient gRNA multiplexing systems in the context of genome engineering, in this study we perform a thorough comparison across a wide assortment of gRNA multiplexing strategies using *Escherichia coli* MDS42 as a model. In our system, we implement an array of robust, screenable phenotypes - such as change in luminescence and gain or loss of antibiotic resistance - to quantify prospective gRNA multiplexing efficiency. Colonies are further assessed using conventional genotyping approaches. Identification of the most reliable gRNA multiplexing system would allow for increased performance in genome engineering tasks that could otherwise not be performed, such as the splitting and shuffling of large genomic segments.

Quantum Scar States
Daniel Mark
Mentors: Olexei I. Motrunich and Cheng-Ju Lin

Many-body quantum scarring is a recently discovered phenomenon, where some energy states in a many-body quantum system do not obey the strong Eigenstate Thermalization Hypothesis (ETH). Quantum scar states thus allow us to refine our understanding of the ETH, and thermalization in quantum systems in general. In particular, scar states were observed experimentally and theoretically in the 'PXP model'. In this project we study the PXP model and related models. In particular, we have found two exact states in a related model known as the Lesanovsky model. We study these and other findings and their possible relation to scar states.

Investigating the Role of HMGA1 in Neural Crest Specification and Migration
Krystyna R. Maruszko
Mentors: Marianne Bronner and Shashank Gandhi

The neural crest is a vertebrate-specific, multipotent population of cells that originates at the neural plate border, undergoes EMT, and then migrates to distant locations in the embryo. These cells then differentiate into their diverse derivatives in the adult, some of which include melanocytes and the craniofacial structures. In a single-cell RNA-seq study done by my mentor, Shashank Gandhi, it was discovered that HMGA1 is highly expressed in neural crest cells. We know from previous studies that HMGA1, and the other proteins in the family High Mobility Group A, participate in a wide array of nuclear functions such as binding DNA, modifying protein structure, and assisting in gene expression. However, its role in neural crest development has not yet been described. We have worked towards identifying the role of HMGA1 in neural crest development using three approaches: in situ hybridization/Hybridization Chain Reaction to determine when and where HMGA1 mRNA transcripts are first detected; CRISPR-Cas9 to knock-out HMGA1 in neural crest progenitors in chick embryos, and transient overexpression of HMGA1 in neural crest cells. We show that HMGA1 first appears in the neural plate and the neural plate border, the region where neural crest progenitors reside. Eventually, the expression of this gene is retained in migratory neural crest cells, suggesting that this gene may play multiple roles during the specification and migration of neural crest cells. Additionally, we also show that a loss of HMGA1 results in the reduction of neural crest specifier genes such as FoxD3 and Tfap2b and neural crest migratory genes such as Sox10 and HNK1.

On Variants of Erdös' Distinct Distances Problem
Surya Mathialagan
Mentors: Adam Sheffer and Polona Durcik

Given n points in the plane, what is the minimum number of distinct distances $D(n)$ determined by these points? When Erdös posed this problem in 1946, he also provided an upper bound of $O(n/\sqrt{\log n})$, and conjectured that this was tight. Recently, Guth and Katz showed an almost matching lower bound of $\Omega(n/\log n)$, nearly settling the problem. Many variants of the distinct distances problem still remain wide open, and we consider two such problems in this project.

In the bipartite variant of this problem, we consider the quantity $D(m, n)$ - the minimum number of distances determined by two sets in R^2 of sizes m and n respectively, where $m \leq n$. Elekes showed that $D(m, n) = O(\sqrt{mn})$ when $m \leq n^{1/3}$, and the classical distances problem implies that $D(m, n) = O(n/\sqrt{\log n})$, when $m \geq n^{1/3}$. In this project, we show that Elekes' construction is tight for $m \leq n^{1/3}$. We also extend the Guth-Katz analysis to the bipartite setting to obtain $D(m, n) = \Omega(\sqrt{mn}/\log n)$ when $m \geq n^{1/3}$, leading to the current best known lower bound for this problem.

Another variant that we consider is the case where a set of n points on an algebraic surface in R^3. Sharir and Solomon showed that such a set of points must span $\Omega(n^{7/9-\varepsilon})$, which is much larger than the conjectured bound of $\Omega(n^{2/3})$ for general point sets in R^3. In this project, we improve this bound to $\Omega(n^{0.82-\varepsilon})$ using graph-theoretic techniques and Elekes-Rónyai-Szabó type results.

Analyzing Cesium Iodide Scintillating Crystals for Installation in the Mu2e Experiment
Sudhi Mathur
Mentors: Frank Porter and David Hitlin

Charged leptons with different quantum numbers are grouped into three flavors, electrons, muons and tau particles. Although charged lepton flavor violation (CLFV) has never been experimentally observed, a potentially observable CLFV conversion is the neutrino-less, coherent conversion of muons to electrons $\mu^- N \rightarrow e^- N$. The experimental signature of this CLFV conversion is a single, monochromatic electron with energy approximately equal to the muon rest mass energy. A single event sensitivity of 3×10^{-17} is needed to suppress background noise and obtain results, which would be four orders of magnitude better than the previous attempt to detect the muon-to-electron CLFV conversion. Cesium Iodide (CSI) scintillating crystals can be used to accurately measure the incoming electron's kinetic energy and, thus, are crucial for a muon-to-electron conversion detector to reach such a high sensitivity. The muon-to-electron experiment is under construction at the Fermi National Accelerator Laboratory. The CSI scintillating crystals that can be used to detect the conversion must be assessed for suitability. Our objective is to analyze and select the optimal CSI scintillating crystals capable of detecting the conversion. We analyze the light yield, longitudinal uniformity response and fast to total ratio of the CSI scintillating crystals by irradiating them with a radioactive ^{22}Na source. Our analysis of the light yield of CSI scintillating crystals as a function of time and humidity provides insights to aging of the scintillators and their usable lifetime.

Information Theoretic Bounds on Generalization Error for Deep Neural Networks
Jack Maxfield
Mentor: Yaser Abu-Mostafa

Deep neural networks have been successfully applied to many real-world problems. Yet it remains poorly understood why these models generalize well out-of-sample, even with limited training data. For example, results from PAC learning theory predict far more training samples are necessary to achieve good generalization than what is typically needed in practice. Recent work relates generalization performance of networks to information theoretic quantities between its input, output, and hidden layers, but only holds when the input distribution is a product of independent, identically distributed (i.i.d.) random variables. We extended these results to arbitrary distributions and ran experiments testing how well the analysis holds up in the absence of the independence assumption.

Assured Positioning, Navigation, and Timing (PNT) of Aerial Vehicles
Austin McCoy
Mentors: Soon-Jo Cheung and Anthony Fragoso

There are currently no effective methods for aerial vehicles to acquire absolute position without GPS. One approach to this problem is a custom ResNet-50 CNN designed to extract and geographically classify structural, illumination-invariant features from aerial terrain imagery. Such a system offers a compact, reliable method to classify ascertain absolute location for aerial vehicles with available on-board IR or near-IR aerial imagery. This project focused on verifying said model correctly learns salient, illumination-invariant features. In particular, a smaller version trained on Rhode Island was examined, using visualization techniques such as heat maps to spatially represent different modalities of activation levels as well as Deep Dreaming to represent particular classes and filters by training input to maximize their respective activation levels. Combined, these two analysis techniques indicated the network indeed learned desirable features, in particular structural blobs mimicking features learned in SIFT feature recognition algorithms.

Dynamics of Whistler Waves and Resonance Cones in Relation to Density Perturbations
Daniel McLoughlin
Mentors: Paul M. Bellan and Young Dae Yoon

Whistler waves are low frequency ($\omega << \omega_{pe}$, $\omega << \omega_{ce}$) plasma waves that are common in space and in the laboratory. Under certain regimes, whistler waves conform to spatial structures called “resonance cones.” It has been previously demonstrated analytically and experimentally that these structures become modulated in the presence of long-wavelength density perturbations. In this study, the existence and modulation of whistler resonance cones are demonstrated numerically using a class of plasma simulation called the “particle-in-cell” simulation. The code can successfully produce whistler resonance cones and simulate the same periodic, lens-like focusing of the resonance cone from density perturbations. A more comprehensive analysis that yields the exact analytical solution for whistler waves is also presented.

EPI-Hi Electron Instrument Response Simulation Using GEANT4
Isaac McMahon
Mentor: Mark Wiedenbeck

EPI-Hi is a collection of three solid-state detector telescopes on the Parker Solar Probe, designed to observe particles with energies above 1 MeV per nucleon. For particles and ions with the mass of a proton and above, it is simple to deduce their incident energies using the instrument’s signature response to each particle. Electrons, however, scatter wildly due to their small mass, and therefore produce an unclear response in the instrument. The goal of this project is to simulate the response of the instrument to electrons using Monte-Carlo techniques in order to create a method to deduce the incident electron intensity spectrum from the instrument observations using linear regression. This will allow previous electron intensity spectrum predictions to be verified using data from the Parker Solar Probe.

Characterizing Microwave Cavities Through a Time-Resolved Ringdown Technique
Hayward Melton
Mentors: Thomas Rosenbaum and Daniel Silevitch

The dynamics of microwave resonant cavities offer a new tool for probing experimental condensed matter physics. Current techniques use vector network analysis to determine cavity parameters such as the resonant frequency and quality factor, but require a hundred milliseconds or more per measurement, too slow for studying the dynamics of many interesting physical systems. An adaptation of a time-resolved microwave cavity measurement technique similar to pulsed NMR is explored which allows for measurements on the order of microseconds, thus enabling characterization of the dynamics of driven magnetic materials. This technique utilizes the natural ringdown of a microwave cavity as it is abruptly deenergized after being pumped with microwave energy detuned from the resonant frequency. Using time-resolved measurements allows for fast characterization of materials inside such cavities while preserving precision and accuracy.

Utilizing Nanoscale Lithography of Metal–Organic Resist Materials for Device Fabrication
Varun Menon
Mentors: Matthew Hunt and Axel Scherer

The ability to fabricate structures with increasingly higher resolution and spatial density in semiconductor materials is critical to the continued development of nanoscale field effect transistors (FETs) that scale in accordance with Moore’s law. The traditional approach – implementing ever-smaller wavelength photon sources during the photolithographic fabrication process – is now yielding diminishing returns because resolution has become limited by the resist materials that are patterned via lithography, and no longer by the wavelength of energy used to perform the lithography. There is thus a need to develop and study novel, higher-resolution resist materials such as the family of negative tone, metal–organic resists synthesized by our collaborators at the University of

Manchester. While previous studies with this resist at Caltech have demonstrated sub-10 nm resolution when deployed with extreme thinness (sub-5 nm), this project aimed to characterize and utilize the resist in thicker configurations (10s of nm), where it can be more practically used for device fabrication. We began by characterizing the resolution and spatial density achievable with 40 nm thick resist using two different sub-nm lithography probes, that of a 35 keV helium ion beam and a 200 keV electron beam. After demonstrating an ability to place nanoscale features less than 20 nm apart using the more practical helium ion beam lithography technique, we applied this capability to the fabrication of a novel, field-emission device. The device, which leverages controlled plasmonic resonance across two tightly spaced gold nanoparticles, is described here in theory and explored via simulation with the COMSOL Multiphysics platform.

Mechanical and Physical Characterization of Poly(ethylene glycol) Diacrylate Hydrogel Swelling
Rebecca Mikofsky
Mentors: Julia Greer and Max Saccone

Hydrogels, hydrophilic polymer structures, are used in industries including beauty, medicine, agriculture, and food due to their low cost, biodegradability, durability and ability to swell to much larger sizes. This work aims to characterize the change in the mechanical and physical properties of 3D printed poly(ethylene glycol) diacrylate hydrogels due to swelling with aqueous ionic solutions. Hydrogel samples were created by digital light processing stereolithography using custom-formula resins, enabling the fabrication of a variety of shapes including architected materials like lattices. The photoreactive resin was characterized by fitting measurements to the working curve equation to determine curing ability (thickness formed from a specific amount of light energy). The printed hydrogels were swelled in salt solutions with variable ionic charge, swelling time, and drying time after swelling. Mechanical tests were done using a nanoindenter. Berkovich nanoindentation was used to determine hardness and stiffness. Loss and storage moduli were measured using dynamical mechanical analysis with a 10 μm flat punch over ten frequencies between 1 and 45 Hz.

Electronic Structures of the d^8 Group 10 Tetracyanometallates
Jayce Miller
Mentors: Harry Gray and Brendon McNicholas

The electronic structure of tetracyanonickelate(II) has puzzled ligand field theorists for decades. Its structure has recently been revisited using a combination of *ab initio* computational methods and experimental data. This analysis is scrutinized and extended to tetracyanopalladate(II) and tetracyanoplatinate(II). While there is strong evidence for a $d_{xy} < d_{yz,xz} < d_{z2} < \pi^*/p_z < d_{x2-y2}$ one-electron orbital ordering for all three complexes and the computational data allow several more bands of $Pt(CN)_4^{2-}$ to be assigned, the term assignments found for $Pd(CN)_4^{2-}$ remain uncertain and there is still some ambiguity about the ordering of the orbitally forbidden singlet terms of $Ni(CN)_4^{2-}$.

A Method for Detecting Gravitational Wave Events in Radio With ASKAP
Emma Mirizio
Mentor: Tara Murphy

The gravitational wave event GW170817 was historic in that it was the first neutron star merger to be detected not only by the Laser Interferometer Gravitational-Wave Observatory (LIGO), but in multiple electromagnetic wavelengths including radio. Recently, LIGO moved into its third observing run and has seen an influx of detections. Thus, it is important to develop a reliable method to search for radio signals following these transients. In this project, we utilized the capabilities of the Australian Square Kilometre Array Pathfinder (ASKAP) to search for the possible neutron star merger S190510g using images from ASKAP surrounding the detection of the candidate event. ASKAP has the sensitivity necessary to detect events such as GW170817, and the image collected following the event covered a large portion of LIGO's sky localization for S190510g. By cross matching candidate optical galaxies with sources found in the radio images, we narrowed the analysis in the ASKAP field to 75 galaxies on the basis that radio sources without an optical counterpart are at too high a redshift to be detectable by LIGO. This method will be employed for future gravitational wave events that are poorly localized by LIGO to discover radio counterparts to neutron star mergers.

Feasibility of In-Situ Flow-Energy Harvesting in Enceladus' Vents
Prinesh Mistry
Mentors: Timothy Colonius, Luís Phillipe Costa Ferreira Tosi, and Benedikt Dorschner

Enceladus, a prime candidate for habitability in the solar system and the venue for an inevitable robotic mission, has a saltwater ocean underneath its icy crust which supplies jets of vapor and ice through cracks in the south pole, ejecting into Saturn's E ring. Due to planetary protection concerns, a robotic mission to Enceladus might forego bringing a radioisotope thermonuclear generator, necessitating alternate forms of energy generation. The flow from the vents is a potential constant source of energy. In this project we investigate whether a flextensional flow energy harvester (FEH), a low efficiency but high reliability device, could generate energy based the vent flow characteristics. We use a MATLAB model to sweep the nondimensionalized parameter space of the vents and the

FEH to determine at what point the device would generate energy. The data can be used to improve the functional range of the device.

Rapid Deployment of Origami Structures Using Hinge-Focused Bistability
Paromita Mitchell
Mentors: Chiara Daraio and Connor McMahan

Bistable structures are becoming increasingly important in new technologies. In some applications, restrictions in transportation require small, narrow structures that can be deployed into a designed structure, such as solar sails in spacecraft, sustainable energy, or in medical applications. However, current technologies require large activation mechanisms to translate the structure from one state to another. In this project, we focus on producing simple to fabricate, origami structures that require a small amount of activation, with stability in one state. The project mainly consisted of prototyping a 3D printed structure with bistable hinges, and optimizing the energy gradient of the system such that one state is favored, using rigid body structures in order to investigate potential issues that may arise. Some such issues included rigid body origami folding, hinge collisions, and preventing tertiary folding states. Developments resulted in a Miura Ori structure with a flat unfolded structure that collapses to a nearly closed structure, suggesting that bistable origami structures can be fabricated given certain conditions are satisfied for the fold and structure of the rigid plates.

Perceptual Straightening Task to Test Predictive Coding Theory of Autism
Elizabeth Moar
Mentors: Ralph Adolphs and Zhongzheng Fu

The predictive coding theory of autism proposes that an autistic person's perceptual experience is based more heavily on the actual sensory input than the brain's prediction model. This project aims to test this theory and better understand the root causes for differences in those with autism. A recent study by Hénaff, Goris, & Simoncelli demonstrated that humans perceptually straighten natural videos. Thus, given a natural video with a curvature based on each frame's pixel-intensity, when judging between consecutive frames we estimate a smaller difference due to the predictability of the frame pair. Thus, our ability to straighten a curve is equivalent to our ability to predict the sequence. This project will use this task to compare the degree of straightening between a control group and an autism group. The hypothesis is that the autism group will straighten the curves less than the control group due to the greater reliance on sensory information rather than prediction derived from the predictive coding theory of autism. After extensive preparations, data collection has begun and we aim to analyze our data to test this hypothesis.

Verifying Maeda's Conjecture for Hecke Operator T_2
Christopher Moon
Mentor: Ashay Burungale

Ghitza and McAndrew describe a computational approach to verify Maeda's conjecture for the Hecke operator T_2 on the space of cusp forms of level one. Such an approach relies on the existence of generators of the Galois group of the characteristic polynomial that correspond to certain cycle pattern decompositions of the polynomial in Z_p for a prime p. We explore the question of whether the primes in which we see decompositions corresponding to more specific generators of the permutation group Sn for a characteristic polynomial of degree n is more efficient, thereby possibly increasing the current standing upper bounds for valid weights on which the Hecke operator T_2 satisfies Maeda's conjecture.

Analyzing the Significance of Cell Surface Molecules at Wiring the Nervous System
Joshua Morales
Mentors: Kai Zinn and Shuwa Xu

Neurons must make correct synaptic connections with other neurons for the nervous system to function properly. Many studies have shown that cell surface proteins are responsible for guiding neurons to their final destination. The Zinn Lab has identified two classes of interacting cell surface proteins, known as defective proboscis extension response proteins (Dprs) and Dpr-interacting proteins (DIPs), that function in neuronal targeting in the CNS and neuromuscular junction (NMJ) of *Drosophila melanogaster*. We sought to understand the significance of these interactions in neuronal development through CRISPR/Cas9 technology to modify the genome sequence of *D. melanogaster* to generate mutants of these affinity variants. These flies will be subject to phenotype analysis on synaptic targeting of both the CNS and NMJ.

There are interactions between DIP and Dpr proteins that exhibit different affinities and function on other aspects of wiring the nervous system. It is of interest to know whether these interactions require different affinities. I examined their expression patterns during embryonic development by using Dpr-Gal4 to drive the expression of a UAS-reporter gene. By comparing 4 markers, we chose the one that had the best expression in neurons and muscles and will examine the remaining 17 Dpr and 9 DIPs.

Previous studies have established that DIP-α and its interacting protein Dpr6 and Dpr10 are important regulators of neuronal specificity in the visual system. In collaboration with the Shapiro lab at Columbia University, we identified several DIP-α mutants that increase or decrease its affinity to Dpr6 and Dpr10 at different scales. Over-expressing these mutants have different effects on neuronal development in animals than over-expressing WT proteins.

Utilizing Deep Neural Networks to Extend the Discovery Reach of Higgs Self-Coupling Signatures With the CMS Experiment at the Large Hadron Collider
Eric A. Moreno
Mentors: Harvey B. Newman and Jean-Roch Valery Vlimant

The goal of this project is to use deep neural networks to improve the efficiency and/or better suppress the backgrounds in signatures involving Higgs boson decays to b-quark jets at the Large Hadron Collider. This could improve the precision of the CMS experiment's measurements of Higgs boson properties and extend its sensitivity to Beyond the Standard Model physics. The project involves designing new neural network architectures to better tag b-quark jets in events with ever-increasing background pileup and applying these b-taggers to analyses of the production of a pair of Higgs bosons (di-Higgs). With the help of an Interaction Network, a neural network designed for predicting the evolution of physical systems by learning the interactions between nodes in a graph, we advanced the b-tagging efficiency for networks with per-constituent jet features. The motivation behind the interaction paradigm arises from the need to predict the influence of particle flow candidates and their parent vertices upon ideal b-jets. When combining the Interaction Network with existing per-jet feature taggers, we create a new deep neural network with the best b-tagging efficiency we've witnessed yet. This assists in increasing the statistical significance for the decay pathway of two coupled Higgs Bosons to jets from heavy b quarks (b-jets) and jets from the decay of W bosons which carry the weak interaction (W-jets), furthering the search for beyond the Standard Model physics.

Center of Gravity and Velocity Estimation of Unknown Orbiting Objects From Optical Flow
Muhammad Moughal
Mentors: Soon-Jo Chung and Vincenzo Capuano

In spacecraft proximity operations and missions, such as on-orbit servicing, formation flying, and small bodies exploration, on-board vision based techniques are required for autonomous relative navigation of a chaser spacecraft with respect to a target object because ground-based communication is inefficient due to delays and lack of coverage. These techniques are grouped under the general problem of spacecraft pose estimation. Successful pose estimation provides the relative position and orientation of a target object with respect to the chaser spacecraft. In this project, we improved upon a portion of the monocular based pose estimation system for such targets with the idea that monocular based systems offer a solution with low mass, volume, and power consumption. We developed an Extended Kalman Filter based algorithm that utilizes an alternative derivation of optical flow to estimate the center of gravity and the relative velocity of a moving target with respect to a moving chaser. These values form a part of the overall pose of the target as required by the goal of spacecraft pose estimation.

Entrapment of Hyper-Volatiles in Interstellar and Cometary CO_2 Ice Analogs
Isabelle Muise
Mentors: Karin Öberg and Geoffrey Blake

Hyper-volatile atoms and molecules desorb off icy grains at very low temperatures found 20 AU from the sun, but have been detected in the atmospheres and surfaces of planets much closer to the sun such as Earth. This is due to hyper-volatile entrapment within a less volatile ice matrix such as H_2O or CO_2. CO_2 entrapment has not been known to play an important role in hyper-volatile transport, but a recent study shows an elevated entrapment efficiency for the hyper-volatile CO in CO_2 compared to H_2O (Simon et al. 2018, ApJ). This series of experiments compares entrapment efficiencies of hyper-volatiles N_2, CH_4 and Ar within H_2O and CO_2 matrices by depositing a layer of ice on a substrate within a chamber cryocooled to 23K and then ramping the temperature up linearly at a rate of 1K per minute, all while measuring the concentration of gas phase molecules in the chamber using a mass spectrometer. By comparing the integral of the initial low-temperature hyper-volatile desorption peak and the integral of the higher-temperature desorption peak of entrapped hyper-volatiles, the entrapment efficiency of the ice can be calculated and compared for different hyper-volatiles and ice matrices at different gas mixing ratios and ice thicknesses.

Phase Transitions of the Ising Model on Bruhat–Tits Trees Under Non-Trivial Boundary Conditions
Aru Mukherjea
Mentor: Sarthak Parikh

An important tool in physics is the AdS/CFT duality, a correspondence between theories of quantum gravity in anti-de Sitter space in $n+1$ dimensions and conformal field theories in n dimensions. A discrete model in which this duality may arise is the Ising model on the Bruhat–Tits tree, which can be constructed as a quotient of projective linear groups, $H_p = PGL_2(\mathbb{Q}_p)/PGL_2(\mathbb{Z}_p)$, with the boundary of the tree forming the projective line over the p-adic numbers. One can form quotients of the tree by considering H_p/Γ for a Schottky group $\Gamma \leq PGL_2(\mathbb{Q}_p)$. These quotients will contain exactly one cycle, acting as discrete models of BTZ black holes. As the system shows scale invariance as the critical temperature is approached, investigating the phase transitions that occur under this model provides further insight into the AdS/CFT duality and BTZ black holes within AdS/CFT, as well as other problems in the same universality class. The aim of the project is to compare the phase transitions of the Bruhat–Tits tree and its quotients, particularly the effect of taking the quotient on the critical temperatures and the phases that exist in the system, as well as the effect of non-trivial boundary conditions on the existence of phase transitions. To do this, we exploit the local similarity of the tree and its quotients to generalise methods devised for the tree such as those developed by Thompson and Eggarter to its quotients, as well as the algebraic structure of the p-adic numbers.

Time Dependence in Dubgrid Stellar Evolution Models for GIZMO
Dhruv A. Muley
Mentor: Philip Hopkins

Historically, the Feedback In Realistic Environments (FIRE) project has used a stellar-evolution prescription where supernova yields are averaged both in the IMF and in time. This gives reasonable results for mass resolution scales and dynamical times far exceeding the masses and lifetimes of massive stars, but in situations in which this is not the case—e. g., in a dwarf galaxy—this averaging procedure would limit the realism of the simulated stellar feedback. To remedy this problem, I use the NuGrid stellar-evolution data to obtain time-dependent elemental yields and supernova rates for stellar populations, taking into account changes in their composition over time. I incorporate these changes into the GIZMO hydrodynamical code, and run a test suite of simulations to measure the effects of the new prescription.

Failure of Power Networks, Linear Dynamics
Maya Mutic
Mentors: Andrew Stuart, Bamdad Hosseini, Alessandro Zocca, and Alfredo Garbuno-Inigio

With the growing threat of climate change, many are looking to renewable energy as an alternative source of energy to fossil fuels. However, with a rise in renewable energy usage comes a higher potential instability in the power grid. This instability is caused by increased variations in the frequencies of power systems, which occur since renewable energy is generally less stable than more traditional sources such as fossil fuel generators. This project simulated power network dynamics and calculated the probability of grid failure due to frequency violations. We modeled the dynamics of power grids using the Kuramoto equations, which simulate the behavior of coupled oscillators. To improve computation time, a Karhunen-Loève expansion was used to solve a linear approximation of the Kuramoto equations. Grid failure in this scenario was attributed to two reasons: that the change in frequency of the oscillators was too great, or that the rate of change of frequency (RoCoF) was too great. When compared to the non-linear model, the failure rates given both factors was significantly higher in the non-linear model than the linear.

Characterizing the Natural Olfactory Space of *Drosophila*
Brian Nguyen
Mentors: Elizabeth J. Hong and Thomas O'Connell

Using vinegar fly *Drosophila melanogaster* as our model, we explored how complex, natural scents produced by fermenting kiwi are processed and represented in the fly brain. To distinguish the natural olfactory space's features, we tested how neural representations of natural odor mixtures contrast from those of unnatural ones. We used solid phase microextraction (SPME) coupled to gas chromatography/mass spectrometry (GC-MS) to identify five key odorants, and their corresponding concentrations, found in kiwi fermented with bacteria *Acetobacter pomorum*, yeast, and more. With a defined molecular space, we created five, single-component odor mixtures and a naturalistic, multi-component mixture equivalent to kiwi. Presenting these mixtures to the fly and measuring electroantennography (EAG) activity at various sites in the antenna, we produced analogous odor mixtures that act as controls, mimicking their natural counterparts's EAG responses. We continue to search for distinctive features of the natural olfactory space in the linearity of EAG responses to tailored odor statistics, in behavioral results, and in the fly mushroom body's responses captured with two-photon imaging.

Imaging Antiferromagnetic Domain Reorientation in Sr_2IrO_4 After Ultrafast Optical Excitation
Mai Nguyen
Mentors: David Hsieh and Kyle Seyler

The ultrafast optical manipulation of magnetic order is a promising area for nonequilibrium physics and future spintronic technologies. Within this field, an emerging interest is to understand the influence of ultrafast optical excitation on antiferromagnetic Mott insulators, where the magnetic order is strongly correlated with the electronic degrees of freedom. In Sr_2IrO_4, a Mott insulator in which antiferromagnetism sets in below the Néel temperature of 240 K, the optical second-harmonic generation couples to the antiferromagnetic order and can resolve different antiferromagnetic domains. In this work, we build a second-harmonic generation imaging setup to visualize and study the evolution of antiferromagnetic domains in Sr_2IrO_4 after intense ultrafast optical excitation. Future work will explore the fluence, wavelength, and polarization dependence of ultrafast excitation on the antiferromagnetic domain structure.

Synthesis and Characterization of Homoleptic Borane Adducts of Hexacyanomanganate
Cherish Nie
Mentors: Harry Gray and Brendon McNicholas

Using tris(pentafluorophenyl)borane and tris(2,4,6-fluorophenyl)borane, we have obtained full characterization of Mn(III) and partial characterization of Mn(II) oxidation states of boronated hexacyanomanganate. Binding of highly soluble Lewis acids such as borane with stable redox active cores has been shown to lower the electron density of the central metal atom while preserving the substitutional stability and electrochemical reversibility. Relative Lewis acidities of boranes match the observed shifts in formal potential for the manganate redox couples. The formal potential is shifted anodically by approximately 360 mV per $B(C_6F_5)_3$, approximately 290 mV per $B(Ph)_3$, and approximately 190 mV per $B(C_6F_3H_2)_3$. Shifts in infrared, ultraviolet, and visible transitions are consistent with previous work on boronated cyanometalates.

Fiber Error and Optical Aberration Modeling for the Prime Focus Spectrograph
AJ Nielsen
Mentors: Dan Reiley and Evan Kirby

The Prime Focus Spectrograph (PFS) is an optical and near-infared spectrograph that is being planned as an instrument for the Subaru Telescope, to be added on by 2021. PFS itself consists of 2394 individual optical fibers which can be individually positioned, allowing for data from up to 1.2 square degrees of sky to be captured simultaneously. However, due to its complexity and the sheer number of moving parts, the optical systems within PFS are imperfect, and contain many sources of error due to mechanical limitations and inherent optical flaws in the lenses. Of these many error sources, the two of greatest significance are fiber positioning errors (since positioning the fibers absolutely precisely is impossible) and focal ratio degradation, or FRD (which occurs due to irregularities in the optical fibers' reflective surfaces). In this project, we utilize optical models of the Subaru Telescope and the PFS to examine the link between fiber positioning errors and FRD errors to the efficiency of a specific fiber's optical output, as well as examining the optical outputs, errors, and efficiencies for specific field positions of both the telescope and the spectrograph.

ERT: An Enhanced Reality for Teaching
Alison Noyes
Mentors: George Djorgovski and Santiago Lombeyda

A virtual reality classroom provides unique advantages over regular classrooms such as removing negative social pressures preventing students from asking questions or indicating confusion and such as allowing direct interaction with labs which would normally be too difficult, expensive, or dangerous to perform in real life. The classroom has been built in the Unity game engine written in the language C# using the packages SteamVR and Photon Unity Networking (PUN). This summer ERT has been updated to the newest version of Unity, SteamVR, and PUN in order to ensure future functionality. Updates included improvements to the previous movement, drawing, and communication features. ERT has also been adapted to allow users to easily integrate their own labs in the classroom space, and two example labs have been developed, a planetary simulation and a MATLAB calculator. These labs use socket communication in order to sync information with ERT through a concierge which handles both continuous updates (in the planetary simulation) and large packets of information (MATLAB calculator). Our changes increase the usability of ERT and improve the experience of both students and teachers.

Playing Games on Graphs: Ramsey, Paper, Scissors
Will Overman
Mentors: Sang-il Oum and Leonard Schulman

Fox, He, and Wigderson recently introduced a game they called "Ramsey, Paper, Scissors." This game is played on a graph on n vertices that initially begins with no edges. There are two players named Proposer and Decider. On each turn, Proposer picks a valid pair of vertices and Decider simultaneously picks either YES or NO. If he picks YES an edge is created between these vertices, and if he picks NO then it is not. A pair of vertices is valid if it hasn't been yet proposed and if a YES answer by Decider would not create a certain forbidden subgraph. Proposer wins if at the end of the game there is an independent set of target size s, and Decider wins otherwise. The paper by Fox, He, and Wigderson considered the case when the forbidden graph is a triangle and analyzed the values of s for which Proposer and Decider can win with high probability. In our project we consider this game for other forbidden graphs beyond triangles.

Timescales and Efficiencies of Star Formation in the Small Magellanic Cloud
Kayla A. Owens
Mentors: Barry Madore and Lynne Hillenbrand

The so-called Schmidt Law refers to a power law relationship between the gas density and the rate of star formation in a galaxy. We present a timescale ratio motivated approach to this determination by invoking two distinct timescales: τ_c for the cloud cooling and collapse timescale and τ_s for the massive stellar main sequence lifetime. The MS lifetime is well-constrained by stellar evolution models, but the cloud collapse timescale has not been determined. By correlating the relative areal frequencies of regions with and without stars to gas densities, we determine the ratio of these timescales, and thus an absolute timescale by knowing the massive stellar lifetimes. We apply this to the nearby Small Magellanic Cloud using publicly available MCPS photometry and ATCA neutral hydrogen maps. Our preliminary results indicate a timescale ratio to gas density dependence of $\frac{\tau_s}{\tau_s+\tau_c} = 0.46\frac{N}{10^{22}cm^{-2}} + 0.03$ where N is the column density of a given cell. Assuming a massive star lifetime of 100 Myr, corresponding to the least massive main sequence stars included in our sample, we obtain the relation $\tau_s + \tau_c = 217$ Myr $\frac{N}{10^{22}cm^{-2}}$.

Developing Motion Planning Algorithms for Energy-Efficient Autonomous Hybrid Locomotion
Luis Pabon
Mentor: Joel Burdick

Hybrid locomotion refers to a robot's capability for both aerial and terrestrial locomotion. Combining the two forms of locomotion allows one to overcome the energy concerns of flying and the spatial constraints of driving. A robot capable of hybrid locomotion (drive-o-copter) was developed and improved upon to take advantage of both locomotion modes. There is a need to develop motion planning algorithms that can plan energy-efficient paths for robots capable of hybrid locomotion. A working solution using the A* algorithm was developed and implemented in MATLAB. We demonstrate that the algorithm is able to plan energy-efficient paths that take advantage of both locomotion methods. Future work will develop and compare with other hybrid locomotion planning methods relying on sampling-based or optimization-based algorithms

Analysing Broadband Instrumental Polarization to Improve the WIRC+Pol Data-Reduction-Pipeline
Skyler Palatnick
Mentors: Dimitri Mawet and Max Millar-Blanchaer

The WIRC+Pol instrument on the Hale Telescope at Palomar Observatory has been recording spectropolarimetric measurements in the near-infrared of brown dwarfs since 2017. Brown dwarfs, objects too small to be considered stars and too large to be considered planets, are intriguing subjects of study because they give a broader understanding of star formation and they also have strong similarities to large, gaseous exoplanets in terms of mass, radius, and temperature. Spectropolarimetry, or the measurement of polarization of light as a function of wavelength, can reveal various aspects of the atmospheric composition and cloud coverage of brown dwarfs. Prior to the installation of a half-wave plate on WIRC+Pol in March 2019, instrument systematics correlated with telescope pointing had created major obstacles preventing the accurate calibration of WIRC+Pol data. The half-wave plate solved these issues, but dozens of data sets from before its installation remain uncalibrated. With the overall objective of successfully calibrating all of this data, I used mathematical models to compute and examine the broadband instrumental polarization of WIRC+Pol to better understand the nature of the systematics and how best to deal with them during data calibration.

Restricting Integral Length Scale Growth in Triply Periodic Turbulence Simulations
Limbert Palomino
Mentors: Guillaume Blanquart, Chandru Dhandapani, and Kyupaeck Jeff Rah

The 3D periodic box is an essential tool for studying turbulence. It is both an apposite canonical configuration for homogeneous isotropic turbulence and a computationally efficient configuration to simulate. Unfortunately, without an active mean of generating turbulence, the turbulent kinetic energy decays over time due to viscous dissipation. Through the years, various methods of forcing the Navier-Stokes have been proposed to maintain this statistically stationary turbulence, including spectral and linear forcing. Although linear forcing schemes fully capture the physics of turbulence, as the simulation evolves in time, the largest eddies in the simulation grow to the order of the computational domain size. The current study characterizes this growth in terms of both the integral length scale and the corresponding energy spectra. Furthermore, we propose a modified linear forcing technique that is analogous to a re-scaling of the computational domain at each time step. This provides more active control over the integral length scale and eddy growth in the simulations.

Opinion Formation on Networks
Alex Pan
Mentors: Franca Hoffmann, Mason Porter, and Heather Brooks

Media has always influenced public opinion. With the rise of extremism in society, it is especially important to understand how media outlets cause polarization of ideologies. Mathematical models can give us new insight into these opinion formation dynamics. One popular type of opinion model is a bounded-confidence model. In this model, agents are given opinions and evolve their opinion by interacting with other agents whose opinion is similar to their own. A recent extension of the model captures the impact of media on opinions through a network; the network mathematically characterizes the population by representing both individuals and media outlets and the information channels between them. Over time, individual opinions will converge to a steady state. Currently, little is known about the distribution of opinions at steady state and how the media influences this distribution. We examine bounded-confidence models on synthetic networks with various levels of media influence. In a complete network, we observe numerically that there is a phase transition, indicating a sudden change in qualitative behavior, from a single opinion group to several opinion groups. In ongoing research, we are working on a characterization and rigorous proof of the observed bifurcation and analyzing variations of the model.

Developing a Python-Based Polarization Model for Imaging Polarimetry of Exoplanets With the Keck Telescope
Emily Park
Mentors: Dimitri Mawet and Max Millar-Blanchaer

Currently, scientists working at the Keck Observatory use imaging and spectroscopy to characterize exoplanets, brown dwarfs, the galactic center, and other astronomical objects. However, this analysis relies only on the intensity of light as a function of wavelength and time, which limits the amount of information that can be gathered. Analysis via polarimetry, a different technique that takes advantage of the full vectorial nature of light, can allow us to deduce additional information, such as the structure and composition of planetary atmospheres of exoplanets. As such, polarimetry is a crucial technique for characterizing exoplanets and other astronomical bodies. To implement this at the Keck Observatory, several new components must be installed on the Near Infra-Red Camera 2 imager. However, polarization due to the instruments can affect the necessary results. I developed a Python-based polarization model and calibration plan to filter out the instrumental polarization and derive the original on-sky polarization to help implement polarimetry on this instrument.

Engineering a Dynamically Switchable Conjugation System
Lillian Parr
Mentors: Richard Murray and John Marken

In synthetic biology, the ultimate goal is to engineer living systems capable of performing useful tasks. As these tasks grow in complexity, there is an increasing need for multi-cell systems in which cells can interact and communicate. As such, we propose using plasmid conjugation as a method of intercellular communication. Because conjugation allows for spatially defined transfer of entire genetic circuits, a high volume of information can be transferred cell to cell. To improve external control over conjugation, we constructed an inducible circuit encoding the master transcription factor required for plasmid mobilization. We demonstrated that the presence of this circuit increases conjugation rates over natural levels. Additionally, we built an inducible circuit coding for an entry exclusion protein and demonstrated that the presence of this circuit decreases plasmid receipt at high induction levels. We are currently engineering a conjugative plasmid to allow switchable conjugation: unless inducer is added to the system, minimal plasmid transfer occurs. This modified conjugative plasmid will be a valuable addition to the synthetic biology toolbox, enabling dynamic control of high-dimensional information transmission between cells.

Scalable Fabrication of Nano-Architected Materials Using 3D Interference Lithography With Metasurfaces at Visible Wavelengths
Phillippe Pearson
Mentors: Andrei Faraon, Julia Greer, and Farzaneh Afshinmanesh

3D nano-architected materials have potential applications in areas such as photonic crystals, microfluidic devices, and impact-absorption. There are currently several additive manufacturing techniques that allow for precise fabrication of 3D structured materials including two-photon lithography and stereolithography. However, neither provide high-throughput nanoscale patterning over areas on the order of 10 cm^2 or greater. Interference lithography using a metasurface optical element to generate a 3D interference pattern affords rapid large-area patterning with nanoscale resolution. By exposing a photosensitive polymer (SU-8) to the metasurface interference pattern followed by baking and development steps, a crosslinked 3D nano-architected material has been fabricated. To target impact-absorption applications, the patterned polymer is then pyrolyzed at 900°C, during which organics are volatilized and a stiff, carbon-based 3D nano-architected material is realized. To scale this process, several laser exposures of SU-8 are tiled by scanning XY translation stages in a raster pattern such that the size of the patterned area is limited only by the range of the stages. Pyrolyzed structures have been fabricated in SU-8 films that are 20 µm thick over a 7x7 mm^2 area, and work is being done to scale this by an order of magnitude. Impact testing with velocities on the order of km/s with micron-scale silica spheres will be conducted on these materials to evaluate their feasibility for impact-absorption applications.

Determining Host Factors That Influence Bacteriophage Lambda's Lysis-Lysogeny Decision
Toussaint M. Pegues
Mentors: David Ashley Van Valen and Edward Pao

Bacteriophage infections have two options when they infect bacteria. They can either replicate themselves and kill the host (lysis) or integrate its genome into that of the host (lysogeny). The bacteriophage lambda lysis/lysogeny decision has been studied extensively; there are textbooks written about it. The process is well known, but the mechanism isn't completely understood. To discover the mechanism behind it, two engineered fluorescent phage strains were used to screen the Keio collection of *E. coli* knockouts to determine which genes, or lack of which genes, influence the decision towards lysis or lysogeny. If the phage ended up going down the path to lysis, the bacteria would fluoresce green or blue depending on the phage strain, if lysogenic, it would fluoresce red. This fluorescence allows single cell readings of bacterial populations. Genes relating to metabolism and membrane potential have been observed to effect the lysis/lysogeny decision, but the specific mechanism has not been elucidated.

Linking Protein Structure and Function Through Exhaustive Mutagenesis
Shih Wei (Daniel) Peng
Mentors: Alison Ondrus and Rahul Purohit

Abstract withheld from publication at mentor's request.

Autonomous Flying Ambulance: The Design and Prototyping of an Oblique Wing and Gimballed Rotors for Fixed Wing VTOL Drones
Isaac Perrin
Mentors: Soon-Jo Chung and Ellande Tang

The Autonomous Flying Ambulance is an active project being developed for rescue applications where the range of a fixed wing aircraft is needed, but the ability to vertically land in a confined area is essential. The aircraft's unique configuration is an important platform for further development in autonomous system for transitional aircraft and for rotor failure control systems. To improve upon the current prototype, a new method for extending the wings for fixed wing flight was designed and prototyped using a low-mounted oblique wing design. Additionally, a method for gimballing the rotors was designed and prototyped for integration into future builds of the autonomous flying ambulance. The oblique wing and gimballed prototypes together drastically decrease the aircrafts drag, increase the maneuverability, and increase the structural efficiency.

Improving Raman Mineral Identification by Implementation of a Neural Network
Karen Pham
Mentor: George R. Rossman

Raman spectroscopy is a powerful, non-destructive analytical technique for identifying minerals with wide applications in geoscience and materials science research. Various machine learning methods have been shown to improve mineral classification by a Raman spectrometer; however, many methods in the literature train on a small subset of minerals (<2000) and/or rely on preprocessing such as baseline correction. In this project, a convolutional neural network (CNN) was trained to identify a range of baseline-corrected and non-baseline-corrected spectra, demonstrating lack of need for preprocessing steps. Spectra were obtained from the RRUFF database. For minerals that had a low number of spectra in the database, artificial spectra were created to train the model by adding Gaussian noise to existing data.

Creating an Infrastructure for the Application of the Tri-Signature Through X-Ray Differential Phase Contrast Imaging
Gaurav Phanse
Mentors: Lambertus Hesselink, Max Yuen, and Glen George

Traditional absorption-based X-ray imaging systems have allowed for the detection of many hazardous materials through specific signatures, but are unable to accurately differentiate between various hazardous and nonhazardous materials. The X-ray Differential Phase Contrast (DPC) imaging system is a three-grating imaging system that provides three imaging signatures: attenuation, visibility, and the dark-field. This project focuses on building an infrastructure in which all three of these signatures are obtained for specific materials commonly found in airport luggage and are then plotted in a 3D grid to form a tri-signature. Obtaining the tri-signature of multiple samples of the same material allows for the creation of a data cluster that characterizes that material. These clusters are more unique to their respective materials than an individual signature would be. This uniqueness would make materials with similar attenuation values much more distinguishable. To further this research, the infrastructure could be implemented into an X-ray system that is able to image and output, in real-time, what each material is and what different materials are present in the same image.

Examining the Effects of Temperature on the Physical Properties of Magnetic Topological Insulator Cr-Doped $(Bi_xSb_{(1-x)})_2Te_3$
Bannhat Phat
Mentor: Nai-Chang Yeh

Introducing magnetism into topological insulators holds potential for practical applications including spintronics and quantum computing. This study is concerned with the relationship of magnetism and its effect on the surface electronic states of Cr-doped $(Bi_xSb_{1-x})_2Te_3$. Moreover, the study will be concerned with measuring the resulting changes in the magnetic landscape for a Cr-doped $(Bi_xSb_{1-x})_2Te_3$ surface as a function of temperature. By measuring the spatially-resolved, magnetism-induced spectroscopic gap in the tunneling spectra, we can develop an understanding of how magnetism manifests itself in the Cr-Doped $(Bi_xSb_{(1-x)})_2Te_3$ topological insulator.

Biogenic Magnetite Arrays and Their Interaction With Weak Radio Waves
Samuel L Piascik
Mentors: Joseph Lynn Kirschvink and Isaac Avram Hilburn

Many migrating and homing animals stop responding to geomagnetic directional cues in the presence of weak, radiofrequency (RF) noise in the 0.2 - 10 MHz band, a response which has yet to be explained biophysically. Our previous work has focused on the possibility that the radio waves interact with the magnetic moment of large numbers of single-domain magnetite nanoparticles (magnetosomes) in specialized, massively-magnetic magnetoreceptor cells; this mechanism is known to dissipate the energy of the radio wave as ultrasound via the magnetoacoustic effect. Propagation of ultrasound to mechanosensitive ion channels in the magnetosome membranes could then provide a pathway for connecting the radio waves to the nervous system. We now investigate the energy transmission associated with RF applied to biogenic magnetite crystals using micromagnetic modeling techniques to obtain numerical solutions to problems involving thousands of crystal structures. Finally, we use our numerical models to simulate the effects of attempted pulse-remagnetization of these crystalline arrays and compare the simulation results to our experimental observations of the effects of both continuous-wave, weak RF and isolated electromagnetic pulses on various animal subjects.

Altered Brain States in Video Games: Inducing a Choke State
Anthony Pineci
Mentors: Shinsuke Shimojo and Mohammad Shehata

Most well-known examples of choking occur when someone is in a state of flow, a mental state where the task being performed is challenging and requires high effort but is also intrinsically rewarding. Although some causes of entering a choke state are known, the relation between the flow and choke state is not well explored despite being the close relationship between the two states. To further understand the relationship between these two states, it is necessary to create a behavior paradigm where the participant will choke following a state of flow. To create this paradigm, modifications to a music rhythm game have been made to introduce mechanisms which are hypothesized to break the participant out of a flow into a choke state. The first mechanism uses forced errors to manipulate the brain's conflict monitoring system. The second mechanism uses feedback manipulation then hence the loss aversion system. Different criteria for creating forced errors were tested while participants' performance was analyzed. No clear trend on performance was found for this mechanism. Results indicate that it will be necessary to further refine the criteria, explore feedback manipulation or a combination of both mechanisms to induce a choke state during flow.

Next Generation In-Vivo Biomedical Devices Operated Through 3D Magnetic Localization and Analog AI Networks Learning on Hardware Noise
Nikhil Poole
Mentor: Azita Emami

With low-power, implantable biomedical devices saturating the market, novel methods of measurement and integration must be developed in order to enhance the current standard of performance. The method of 3D magnetic localization relies upon coil-induced magnetic field gradients that exhibit a bijective mapping with spatial coordinates to precisely determine the location of the device. A capsule-sized PCB is designed and assembled in order to transmit all measured magnetic field data via Bluetooth Low Energy to an external client device. Optimized power consumption and RF network matching, multi-agent server connections, and user-actuated measurements are attained in the final construction of the ingestible capsule device. This project proceeds to explore the development of next generation autonomous biomedical devices operated on low-power, fully analog, and reconfigurable neural networks. Learning on the noise inherent in analog hardware, a 65nm CMOS design simulating any arbitrary multi-layer neural network is proposed. Simulations of the dot-product architecture demonstrate high linearity and easily-modeled Gaussian noise distributions in the subthreshold regime. Such results validate the potential for autonomous *in vivo* devices designed around a precise network of analog cores and absent any high-power digital blocks.

Imaging the Effects of Laser Irradiation on Amyloid-β Protein Aggregates in Super Resolution
Tara S. Porter
Mentors: Matthew Lew, Tianben Ding, and Rebecca Voorhees

Amyloid-β protein aggregates occur at abnormally high concentrations in the Alzheimer's brain, and are thought to be toxic to neurons. It is of particular interest to study the dynamic processes of growth and change of the protein structures to understand how the disease may be treated. The response of preformed amyloid fibrils to laser irradiation at 405 and 445 nanometer wavelengths is studied using the super-resolution technique of transient amyloid binding imaging with the fluorescent dye molecules Nile red and Nile blue. This project aims to quantify the differences between the two types of dye molecules for imaging fibrils of the amyloid-β 42 protein. Furthermore, it explores how laser irradiation damages fibrils alone and in conjunction with Thioflavin-T and monomers. Using the molecular orientation of the dye molecules along the fibrils, we will explore how the relative disorder of different regions of the structure relates to the tendency of that fibril region to grow or decay.

Laplace-Domain Frequency-Time Hybrid Solvers for the Wave Equation
Sridhar Prabhu
Mentors: Oscar Bruno and Thomas Anderson

Wave scattering in domains exterior to complicated scatterers has been an important and challenging problem with applications in diverse areas of science and engineering, including communications, defense, and energy exploration. Much work in wave scattering has been done in the context of the time-harmonic regime, where the fields are assumed periodic. This is well-justified due to the limiting-amplitude principle stating that the time-harmonic regime is the steady-state of wave propagation. Still, transients can be important to simulate. Recent work at Caltech in the Bruno group has focused on transient (sometimes referred to as "time domain") simulation using a Fourier hybrid approach, relying on well-studied frequency domain numerical methods as building blocks. This project will extend the methods to Laplace-domain, allowing the treatment of initial value problems. A successful Laplace-domain solver will be able to complement the Fourier Hybrid Approach by being able to handle arbitrary initial conditions. In other words, the main question is whether one can understand a book simply by reading the first page. We think so!

Quantifying Active Cholesterol Metabolites in Hedgehog Signaling
Sarida Pratuangtham
Mentor: Alison Ondrus

Abstract withheld from publication at mentor's request.

Furthering the FORC Technique to Analyze Massively Magnetic Cells
Randall Pulido
Mentors: Joseph Kirschvink and Isaac Hilburn

Many experiments in biomagnetism, as well as rock magnetism, rely on the generation of First Order Reversal Curves (FORCs) to place important constraints on the concentration and distribution of single-domain magnetite crystals (e.g., Chen et al., 2007). Although the vibrating-sample magnetometers (VSM's) that are routinely used for this type of measurement require fairly strong samples (e.g. volcanic or intrusive rocks), a special type of FORC, termed a remanence-FORC or rem-FORC, can be done in principle on the superconducting moment magnetometers that are used routinely in paleomagnetic laboratories around the globe. This rem-FORC method exposes samples to precise, scaleable DC magnetic field pulses. In particular, the RAPID sample handler SQUID magnetometer systems described by Kirschvink et al. (2008) can be used to screen bulk tissue samples for the presence of biogenic magnetite and massively magnetic animal cells using rem-FORC. Once biogenic magnetite bearing bulk tissue samples have been screened with rem-FORC, subsequent, more detailed and time consuming experiments can be run on the samples in an attempt to find where the massively magnetic cells are located in the tissues and then to extract and image them. Locating, extracting and imaging Massively Magnetic Cells (MMC) is one of the primary goals of the Kirschvink Laboratory DARPA RadioBio grant project. Finishing the implementation of the rem-FORC technique is a necessary step towards completing this larger goal. We have been constructing a system to allow for the Lowenstam 2G Magnetometer to run frozen tissue samples and are developing a method to acquire rem-FORC data using nonlinear DC magnetic field pulse level step sizes. Furthermore, we have started to run and analyze frozen beef tissue samples.

Realizing Chiral Anomaly in One-Dimensional, Quasi-Periodically Driven Systems
Zihao Qi
Mentors: Gil Refael and Yang Peng

It was shown that d-dimensional systems subjected to n mutually irrational quasi-periodic drives can exhibit behaviors that occur in (d+n)-dimensional systems. Conversely, topological responses in higher dimensional systems can be simulated in systems with lower dimensions subjected to external drives, which often are manifested by energy or charge pumping. In this project, we explore whether chiral anomaly, a three-dimensional phenomenon characterized by chiral charge non-conservation, can be realized in one-dimensional systems subjected to two external drives by engineering electromagnetic fields in the synthetic dimensions. We analytically affirmed this possibility. Numerically, using a cubic lattice model for Weyl semimetals, we simulated the charge pumped in the adiabatic limit for various conditions – including boundary conditions, magnetic field strength, and drive frequencies. Future work will include simulations on the energy pumping between the two drives and potential experimental implementations in which chiral currents can be observed, should we discover such effects numerically.

Elucidating the Molecular Mechanism of a Mutation's Block on hSRP Function
Ruilin Qian
Mentors: Shu-ou Shan and Jae Ho Lee

Signal recognition particle (SRP) is responsible for the targeted delivery of approximately 30% of the newly synthesized proteome to the eukaryotic endoplasmic reticulum. SRP54 is one of the subunits of human SRP and plays a central role in SRP function, by interacting with its receptor, SR. Previous research showed that a mutation G226E on SRP54 could block SRP function, causing Shwachman-Diamond syndrome, an inherited bone marrow failure syndrome. However, indirect measurement of the interaction between mutant SRP and SR showed no defect compared to wild-type SRP. To elucidate the mechanism of the block, we first plan to use fluorescence-based techniques to directly monitor SRP-SR interaction both in real-time and at equilibrium. Furthermore, we plan to monitor the conformations of SRP-SR complex at single-molecule level to determine whether the mutation causes defect in the necessary conformational changes for SRP function. Understanding the mechanistic details of G226E mutation would further elucidate how SRP pathway is regulated, and potentially lead to reversing the effect of the mutation to restore SRP function and cure the disease.

Acoustic Levitation for Terahertz Spectroscopy: Optimization, Implementation, and Application
Haoye Qin
Mentors: Scott Cushing, Jonathan Michelsen, and William Denman

Conventionally, terahertz spectroscopy for liquid and solid samples suffers from the involvement of either capillary tube or glass substrate to hold these samples, which will result in an unwanted interference from these containers. Therefore, in this project we employ acoustic levitation to levitate liquid droplet or solid-state materials in the air for obtaining their terahertz spectroscopy, which avoids the contaminant and interaction from the container wall. An acoustic levitator is demonstrated in simulation, optimized for its geometric parameters via genetic algorithm and implemented for levitation experiments. Liquid droplets and air bubbles are successfully levitated stably and spectroscopy of target material is obtained. This technique also provides a potential platform for studying air-liquid interface and phase transition, and has promising application in XUV spectroscopy.

Deep Learning for Predicting Significant Wave Height From Synthetic Aperture Radar
Brandon Quach
Mentors: Peter Sadowski and Anima Anadkumar

The Sentinel-1 space mission provides synthetic aperture radar (SAR) imagery of the entire world's oceans every six days. We investigate the use of deep learning to predict significant wave height from SAR wave spectra, using colocations with altimeter satellites for training. While previous models have relied on hand-engineered intermediate features, our approach extracts additional information from the high-dimensional wave spectra, reducing the root mean squared error from 0.40 meters to 0.35 meters. Furthermore, we explore the benefits of combining cross spectrum, intermediate features, and geographic information to inform predictions, particularly in extremely high and low significant wave height regions.

Interferent Blocking and Target Detection for Nano-Scaled Electrochemical Neural Probes
Eleanor Rackoff
Mentors: Michael Roukes and Jessica Arlett

Neurological disorders are correlated to irregularities in neurotransmitter and neuromodulator release. However, existing technology doesn't allow neuroscientists to easily explore chemical irregularities, meaning that experimental neuroscientists typically focus on electrophysiology studies. For this reason, we aim to develop implantable neural probes to assist in concurrent electrophysiological and neurochemical measurements. In the development of these probes, we must modify the sensors so that they block interferents while measuring chemicals of interest. In order to block unwanted chemicals from generating confounding signals, we have developed a protocol to electrodeposit a layer of m-phenylenediamine (PPD) on the electrochemical pads. With this protocol, we have achieved a target to interferent signal ratio of 27 for high concentrations of dopamine, and a ratio of 226 for ascorbic acid, both of which are common interferents. For detecting target chemicals, we use a microplotter to dispense a target-specific enzyme on the electrochemical pad. So far, we have had success in measuring glucose on pads that are larger than those on the actual probes using glucose oxidase as the enzymatic layer. Moving forward, we plan to demonstrate simultaneous interferent blocking and target detection on the correct pad size, which will lead us to *in vivo* experimentation.

Optimizing the Search for Electromagnetic Counterparts (EM) to Gravitational Wave (GW) Events With the Liverpool Telescope (LT)
Priyadarshini Rajkumar
Mentors: Chris Copperwheat and Daniel Perley

Our understanding of gravitational wave (GW) events is greatly enhanced by identifying and studying their electromagnetic (EM) counterparts. For nearby GW events with a small localization uncertainty, an effective strategy is to search for new transient sources in previously catalogued galaxies, whose properties are consistent with the GW data. Even with a limited field of view, such as that of the Liverpool Telescope (LT), it is plausible to discover the EM counterparts using an efficient observational strategy. But because many galaxies must be observed and the EM counterparts are faint and fade rapidly, a reliable automatic procedure is crucial to schedule observations efficiently. Therefore, we designed an algorithm in Python that uses a catalogue of nearby galaxies and the three-dimensional GW localization map to create a prioritized list of galaxies based on GW error-map probability, observability, and absolute magnitude. We tested our algorithm with past GW events and, within a few minutes, obtained consistent results with previous observations. For example, NGC 4993, host galaxy of GW170817, was in 3rd place in our observing schedule. Thus, this algorithm can swiftly assist in the formulation of effective follow-up plans which should increase the probability of localizing EM counterparts.

Fabrication and Analysis of Lithium Niobate-Based Microwave to Optical Transducer
Hamza Raniwala
Mentors: Oskar Painter and Jash Banker

Silicon-based, superconducting qubits represent a practical method of producing quantum computing architecture but face a major limitation in information transfer due to the lossy nature of microwave photons. Microwave-to-optical (M2O) transduction is a promising method of upconverting the microwave photons found on-chip in superconducting qubits, to optical photons that are transferrable through low-loss fiber optics. In this paper, we explore the design, fabrication, simulation and testing of a novel scheme of M2O transduction by coupling two resonator components. We investigate the use of a lithium niobate ($LiNbO_3$)-based, piezoelectric resonator that allows conversion between microwave modes and mechanical modes; and a one-dimensional optomechanical crystal (OMC)-based optomechanical resonator that facilitates conversion between mechanical modes and optical modes. By combining these components, we hope to construct a robust prototype M2O transducer that will provide the building blocks necessary for high-fidelity, cross-qubit information transfer and, therefore, a feasible quantum network.

Level Set - Discrete Element Method to Study the Behaviour of a Load-Bearing Column Designed From S-Shaped Particles
Animesh Rastogi
Mentors: Jose E. Andrade, Raj K. Pal, Siavash Monfared, and Robert Buarque de Macedo

Aleatory structures are made up of loose and custom-designed granular materials. Custom - designing the grains opens up intriguing possibilities to attain a wide range of mechanical behaviour of aleatory structures. In this study, we used Level Set - Discrete Element Method to pluviate the “S” - shaped particles into a container. We observed entanglement among the particles. This entanglement shows the possibility of the structure to resist tensile forces. The next step is to apply compressive and tensile forces on the pluviated particles and observe its behaviour. The results from the simulations will be helpful in two ways. Firstly, it will help in understanding the response of the structure under various loads. Secondly, this will guide the experimental studies to build and analyse a free-standing load bearing column made out of “S”- shaped particles.

Approximating 3D Curvatures Using Non-Periodic Tessellations of Twisting Unit Cells
Aditya Rathi
Mentors: Chiara Daraio and Connor McMahan

Flat structures are easier to manufacture and can be packed more efficiently than curved geometries. These abilities make flat-fabricated structures well suited to applications where it is essential to minimize volume and mass. However, many applications require 3D geometries. Our study aims to bridge this gap by providing a method to approximate the desired 3D geometry from initially flat sheets using non-periodic tessellations of “square twist” origami unit cells. To design these tessellations, we first characterize the behavior of individual square twists with varying geometric parameters by simulating their folding behavior and recording their post-folded curvatures and in-plane strains. Interpolating this data allows us to predict the curvature of any square twist with parameters within the parameter range of our simulations. This data proves that a square twist with the correct parameters is globally curved when folded while being flat in its unfolded state. Furthermore, we can easily tune its curvature through minor variations in the geometric parameters. Next, we characterize the interactions of these square twists in tessellations. Through careful selection of parameters we can generate 3D geometries with a global curvature. A future goal of this research is to inversely design tessellations that approximate arbitrary 3D geometries.

Characterizing the Effects of Composition and Structure on the Optical Properties of Electrochemically Deposited Nickel Phosphide Films
Jillian Reed
Mentors: Nathan Lewis and Paul Kempler

Solar-driven water splitting devices use sunlight to generate hydrogen fuel from water, thereby addressing a problem in energy storage inherent to an intermittent energy resource. Catalysts are needed to obtain rates of fuel formation which match the rate of solar power absorption. Nickel phosphide can serve as an effective hydrogen evolution catalyst in 0.50 M H_2SO_4, but films thicker than 50 nm reflect approximately 90% of visible light, which directly limits device efficiency. When catalyst films are nanostructured such that regions of catalyst are smaller than the wavelengths of the solar spectrum, we can subvert the traditional tradeoff between increased loadings of the catalyst and reduced collection of light by preferential transmission of light through the voids in the film. The effects of deposition temperature on the elemental composition and microstructure of electrochemically deposited Ni-P films, before and after selective etching in acid, was measured via ellipsometry, profilometry, and energy dispersive X-ray spectroscopy in order to determine the optimal conditions for obtaining nanostructures exhibiting optical transparency. Optically transparent and electrochemically stable Ni-P films would improve the long term performance of solar-driven water-splitting devices.

Real Dynamic System Simulation Platform for Reinforcement Learning
Qibing Ren
Mentors: Anima Anandkumar and Anqi Liu

Reinforcement learning (RL) combined with Deep learning (DL) sheds light on solving series of continuous control applications especially robotics. With growing complexity of dynamic systems from the inverted pendulum to Cassie, my project is to stabilize these systems by RL and find pain points where RL fails to work. We would develop such a platform that constitutes dynamical systems that simulate real environments and fine-tuned algorithms that serve to facilitate reproducible and accessible research on RL and ultimately the design of the superior learning algorithms. Through this project I can get insights into how to properly design, analyze and certify learning systems that safely and reliably interact with complex and uncertain environments and how to combine tools from control and learning to approach those challenges.

Cellular Circuits Involving Sterol Metabolites
Amrita Rhoads
Mentor: Alison Ondrus

Abstract withheld from publication at mentor’s request.

Tensile Behavior of Entangled Non-Convex Granular Particles
Sydney Richardson
Mentors: José Andrade and Siavash Khosh Sokhan Monfared

Concrete among other permanent materials belong to a non recyclable family of construction media. Once materials belonging to this category are formed and hardened in a specific shape, the substance becomes stuck in a highly rigid form. Deconstruction is possible, but time and labor intensive. My research involves designing “smart” particles which have the ability to form load-bearing structures without the glue-like properties of concrete. By looking at different particle shapes, such as staples and “s” shaped, a better understanding of these materials as a whole rather than individual parts becomes apparent. Various tests performed such as finding the angle of repose, compression testing of freestanding columns, three point bend tests of freestanding beams, and shake testing reveal material properties such as resistance of movement, material behavior under a load, Young’s modulus of the material, and resistance to horizontal and vertical motion, respectively. Simulations developed with the LS-DEM code allows for the creation of virtual experiments. 3D printing our own particles allows for shape based testing and the customization of shape. This gives us the ability to test any desired particle shape in both experiments and simulations.

Designing Segmented Linear Actuator Thigh Holster for Novel Ankle Exoskeleton
Paulina Ridland
Mentors: Aaron Ames, Claudia Kann, and Maegan Tucker

The study of bipedal walking, the primary focus of the AMBER lab, has many applications towards assistive devices. Assistive devices, primarily exoskeletons, have the power to enhance or even restore mobility. Ankle exoskeletons specifically provide partial assistance to able bodies for locomotion, making it easier to walk (in the case of metabolic reduction) or do more while walking (carry a larger load or walk farther). The research presented involves two different ankle exoskeletons that provide partial assistance for their users, and describes in detail the mechanical design of one specifically. The first design is based on an existing device at MIT that uses a rotary motor, and the second, the main focus of this report, has a new design that incorporates linear motors instead. This new device has been designed to produce a greater ankle torque to provide increased assistance, and have a lower profile to feel more like a tall boot than an external gadget. It features an original thigh-mounted linking linear actuator holster, which has a lower profile and allows for scalable maximum torque. These two devices will be used by the AMBER lab to further research nonlinear control theory and iterative-based learning algorithms applied to human assistance.

Characterizing CZT Detectors for X-Ray Astronomy
Milan S. Roberson
Mentors: Fiona Harrison and Sean Pike

X-ray astronomy studies some of the hottest, most energetic and violent events in the universe. The basic data product of many modern X-ray observatories is a list of photons that interacted with the detector, their energy and position. *NuSTAR*, the first hard x-ray focusing space telescope, uses Cadmium Zinc Telluride (CZT) crystals as part of its focal plane detectors. The CZT detectors aboard *NuSTAR* are 2mm thick and were manufactured by eV Products, but SRL currently has new 3mm thick CZT detectors made by Redlen Technologies that need to be characterized. We characterized one Redlen detector, taking measurements of its interpixel conductance, leakage current, and electronic readout noise. We found that edge pixels became noisier after cooling the detector, but we were able to correct for the pixels with non-normal noise spectra at room temperature. Finally, we characterized the spectral performance of the detector after irradiating it with ^{241}Am and ^{155}Eu samples and found its energy resolution (FWHM) at 86 keV was 20% lower than that of the detectors aboard *NuSTAR*.

Free Standing Force Balance System Development for CAST
Zoe Rock
Mentors: Soon-Jo Chung and Ellande Tang

In vertical takeoff and landing (VTOL) aircraft the forces that interact between their wings and propellers have been mostly unstudied. The goal of this project is to create an instrument that will be able to analyze these forces in many different wing/propeller setups. In order to create this instrument, we will look at the designs of commercial instruments that have the same purpose and modify the designs to fit our needs. CAD software is used to design and model the instrument, while FEA software is used to make sure that the instrument will not break or deform under the stresses it will experience while in use. The instrument is a cost effective, easily reproducible, and can handle multiple wings and propellers unlike commercial instruments of its kind. This instrument will allow us to better collect data on and understand the forces that occur between wings and propellers in VTOL aircraft. The data collected can then be used to design better and more efficient VTOL aircraft in the future.

Accretion Disk Modeling of FU Ori Stars
Antonio Rodriguez
Mentor: Lynne Hillenbrand

FU Ori stars are a class of young stellar object (YSO) that mysteriously undergo episodic outbursts in optical brightness on the order of four to five magnitudes. In regards to the astrophysical processes at play in these curious objects, it has been generally accepted for a few decades that accretion disks surrounding a central young star are likely responsible for their behavior. Models suggest that the observed outbursts are caused by rapid accretion at rates three to four orders of magnitude greater than those of quiescent-state T Tauri (young) stars. In turn, during the century-long outburst, the disk outshines the central star by factors of 100-1000 as observed in the lightcurves of FU Ori stars, leading to accepted models of the radiation from them in outburst as being purely due to a rotating accretion disk. We present new observations along with corresponding models of the newest FU Ori candidates (Gaia 17bpi and HBC 722), and discuss the successes and limitations of the conventional model. While the cause of the outbursts is still a subject of significant debate, further observational and theoretical exploration of FU Ori stars shows promise in adding to our current astrophysical picture of stellar formation.

Assessing the Conformational Profile of an HIV-1 Transmitted Founder Envelope Using DEER Spectroscopy
Sam Sacco
Mentors: Pamela Bjorkman and Kim Dam

Viral HIV-1 strains responsible for establishing infection in new hosts are thought to differ from chronic strains due to a rigorous selection process associated with transmission across mucosal barriers. One unstudied aspect of transmitted founder (T/F) strains is the conformational profile of their envelope protein (Env), a molecular machine which mediates host recognition and viral fusion. Here we characterize the conformational profile of Env in T/F strain A4146, a virus which was isolated from a patient shortly after infection via intravenous drug use. The unique phenotype of this transmitted founder, including its resistance to CD4 (host receptor) binding site targeting antibodies, its cold sensitivity, and its reactivity to the patients serum indicate that A4146 adopts more heterogenous Env conformations relative to chronic strains. Using Double Electron-Electron Resonance (DEER) spectroscopy we characterize the conformational profile of T/F A4-146 Env and compare it to conformational profiles of Env observed in chronic strains.

Light Curve Classification With Recurrent Neural Networks
Vinu Sankar Sadasivan
Mentors: Ashish Mahabal and Matthew J. Graham

The Zwicky Transient Facility (ZTF) camera, with a 47-degree field of view, can image the entire northern sky every few days to collect more than a terabyte of data per day. The ZTF observes around a billion objects in the space, and it detects transient and variable events at a rate of about 100,000 alerts per night. The process of transient detection is automated, but classifying and characterizing them will help us understand them better. Recurrent neural networks (RNNs) are observed to learn features from time-series data and are state-of-the-art in speech classification tasks. Our research attempts to address the challenges in using RNNs for classifying light curves with irregular temporal gaps and widely varying lengths. Our model has an impressive 380x parameter memory reduction when compared to the state-of-the-art convolutional neural network (CNN) mode, with an accuracy of over 98% in classifying long period variables against objects from other classes in Catalina Real-Time Transient Survey (CRTS). The model when tested on ZTF data using transfer learning gives a classification accuracy of 62%. Training with ZTF data and fine tuning could make the model perform better for classifying ZTF light curves.

Neoproterozoic Tectonics of the Bayankhongor Ophiolite, Central Asian Orogenic Belt (Mongolia)
Anar-Erdene Saikhan-Erdene
Mentors: Claire E. Bucholz and James R. Worthington

The amalgamation of the Central Asian Orogenic Belt (CAOB) in central Mongolia is represented by tectono-magmatic processes that accompanied Neoproterozoic ocean-basin closure and collision between the Khangai and Baidrag continents along the ophiolitic Bayankhongor suture zone. The suture includes a northeast-vergent thrust stack of (meta)sedimentary-matrix mélange units that bound a central ophiolite unit. Middle Paleozoic volcano-sedimentary and late Paleozoic sedimentary strata are in unconformable sedimentary or fault contact with the suture. The NW–SE-trending Bayankhongor ophiolite is 150–270 km long and ≤7 km wide and discontinuously exposes a complete pseudostratigraphic section including altered ultramafic rocks, layered and isotropic gabbros,sheeted dikes, pillow basalts, and pelagic sedimentary rocks. Previous researchers interpreted these rock associations to reflect oceanic lithosphere generated in a mid-ocean-ridge, supra-subduction-zone, or mantle plume. Zircon U/Pb geochronology for a plagiogranite intrusion from the ophiolite dates its crystallization at ~650 Ma. Detrital-zircon-crystallization-age spectra for mélange units reflect terrane provenance for the Khangai and Baidrag continents; youngest-age populations young from south to north, possibly reflecting progressive terrane accretion. Ongoing mineral chemistry, whole-rock chemistry, and igneous-zircon geochronology for the Bayankhongor ophiolite will elucidate the tectonic setting of its formation, improving regional-tectonic models for the CAOB.

A Supramolecular Hydrogel Platform for Thermal Stabilization of Biopharmaceuticals
Erika Salzman
Mentors: Eric Appel, Catie Meis, and Julia Greer

Hydrogels have emerged as promising materials for a variety of biomedical applications, including as platforms for sustained drug delivery due to their tunable, tissue-like mechanical properties. In particular, supramolecular hydrogels take advantage of transient, reversible bonds that allow for injectability and self-healing, making them a minimally-invasive delivery method for biopharmaceuticals with the potential to treat a vast number of pervasive diseases. Many biopharmaceuticals suffer from thermal instability and short half-lives in *in vivo* delivery depots, and hydrogels have shown potential as stabilizing excipients for these drugs, allowing them to withstand elevated temperatures that they may experience during transport and *in vivo*. In this study, a cellulose-based supramolecular hydrogel utilizing polymer-nanoparticle (PNP) interactions developed in the Appel lab has been loaded with model cargo including insulin and β-galactosidase and subjected to rapid aging conditions, including heating and shaking, for periods of up to 30 days. The ability of this hydrogel system to stabilize drug cargo under harsh conditions for extended periods of time suggests its potential as a dual-purpose, biocompatible material that can act as both a sustained-release drug delivery platform and a stabilizing agent for sensitive drugs, reducing the need for a costly cold chain system.

Optical Coherence Tomography in Silicon Photonics
Julian Sanders
Mentors: Ali Hajimiri, Craig Ives, and Aroutin Khachaturian

Optical Coherence Tomography (OCT) provides soft tissue imaging at micron-scale resolutions and millimeter depths for informing clinical diagnoses, but OCT systems are bulky, expensive, and require mechanical beam scanning. Integrating an OCT system on a silicon photonic integrated circuit using a scalable fabrication process for silicon photonics could address these issues. Our project would involve integrating a large portion of an OCT system on a chip. A significant challenge to integrating OCT is designing photonic components for broadband operation. Also, integrating a multi-component system can lead to a large chip if one isn't careful, especially with a spectrometer and an optical antenna being two highly-desirable but potentially area-consuming components for an on-chip OCT system. Meeting these challenges requires investigating various possibilities for implementing components, simulating their broadband function at the various wavelengths that an OCT system can operate at (ranging from visible to near-infrared) and applying them to a chosen fabrication process.

Identification and Estimation in a Linear Panel Data Model Allowing Random Coefficients to be Correlated With Regressors Within and Across Time Periods
Rafael Santiago
Mentor: Robert P. Sherman

Current panel data models only allow for random coefficients to be correlated with regressors within or across time periods but not both. The model proposed in this study allows coefficients to be correlated with regressors within and across different time periods. This new model addresses the situation where regressors have potential influences in future time periods. The current study aims to estimate and simulate the causal effects in various types of models to determine whether the proposed estimator is accurate and efficient in different settings. Furthermore, the study aims to determine the significance of the marginal means on the regressand obtained through different types of simulations.

Predicting Intelligence From Structural MRI Data
Louis Santos
Mentors: Ralph Adolphs and Julien Dubois

Numerous studies have been conducted to investigate the neurological underpinnings of inter-individual variations in psychological traits, intelligence being one of great significance. Two tools increasingly used to examine brain variation in an effort to understand differences in cognitive ability are functional MRI (fMRI) and structural MRI. fMRI measures regional brain function using blood oxygenation as a proxy for neural activity, while structural MRI examines the brain's anatomical structure. Both methods have started to contribute to our understanding of what makes a brain more intelligent than another. A recent fMRI study was able to explain ~20% of inter-individual variation in general intelligence (Spearman's g), with data collected from resting subjects. That study did not account for variation in brain structure. Here I investigated whether morphometric features extracted from structural MRI data--such as cortical thickness and surface area--can explain variance in cognitive ability, independently of functional data. I find that structural data alone can explain ~12% of the variance in general intelligence in the Human Connectome Project dataset (N=1000). Moreover, combining structural and functional data, we found that each contributed both independent and overlapping information to the prediction. This brings us ever closer to an understanding of the neuroarchitecture of cognition.

Design of Sample Chamber and Electrochemical Cell for In-Situ Characterization of Iodine Vacancies in Hybrid Organic-Halide Perovskites
Miranda Schwacke
Mentors: Michael Toney, Nick Weadock, Rachel Beal, and Brent Fultz

Highly efficient hybrid organic-halide perovskite solar cells are known to be tolerant to defects. Yet, there is still significant disagreement in the field about the nature of defects in these perovskites. Recently, it has been demonstrated that there is a lattice contraction in halide perovskites when they are exposed to iodine vapor, indicating a high concentration of halide vacancies in these films. We have designed a new sample chamber containing an electrochemical cell which allows for accurate quantification of defects. The sample chamber allows for iodine vapor to be introduced over perovskite films during X-ray diffraction experiments. The electrochemical cell contains a silver anode, a silver iodide solid electrolyte, and a carbon felt/iodine cathode. By measuring the potential created by the reaction of iodine vapor and silver to form silver iodide, we can calculate the partial pressure of iodine gas in the sample chamber. Design choices for the cell were made considering that it must be small, accurate, work at T=45°C, and allow minimal diffusion of iodine vapor through the cell. Measuring the partial pressure of iodine in parallel with lattice contractions in halide perovskites will allow us to calculate the concentration of and energetics associated with halide vacancies.

Failure and Stability of Power Networks: Nonlinear Dynamics
Anish Senapati
Mentors: Andrew Stuart, Bamdad Hosseini, Alfredo Garbuno-Inigio, and Alessandro Zocca

The stability of power networks is of vital importance since deviations outside an operational range may lead to failure of generators and power outages. The second order Kuramoto model is a popular tool for modelling networks of oscillators such as power networks. We analyzed the first and second order Kuramato models to understand the evolution of θ_j and $\dot{\theta}_j$ for random initial conditions. The transient stage of the Kuramoto equations was studied and statistics for the failure of networks were computed, defined as when θ_j or $\dot{\theta}_j$ exceed certain thresholds.

Using Monte Carlo simulations, the effects of variations in the initial parameters and failure thresholds on the network was studied. Particularly, the effect of parameters within the variance of the initial conditions on the mean and variance of θ_j and $\dot{\theta}_j$ was measured. Similarly, the effect of the failure threshold on the failure probability and exit time. During the analysis, differences between the linear and nonlinear variations of the Kuramoto model were found and studied. This analysis gave insight as to the disadvantages of the linear model in comparison to the more accurate nonlinear model.

Knots With Prism Manifold Surgeries
Zhengyuan Shang
Mentor: Yi Ni

Ballinger et al. have determined the list of all prism manifolds P(p, q) that are possibly realizable by Dehn surgeries on knots in S^3. In this paper, we explicitly find braid words of primitive/Seifert-fibered knots on which surface slope surgeries yield all the prism manifolds listed above. This completes the prism manifold realization problem.

Identification of Cancer Stem Cells in Glioblastoma Multiforme
Varun Shanker
Mentors: Stephen Skirboll and Jehoshua Bruck

With much of current cancer research currently focusing on molecular biology, little has been understood regarding the cells that actually drive the formation and recurrence of these potent tumors. Glioblastoma Multiforme(GBM) is the most malignant form of brain tumor in humans, and remains incurable. The presence of a subpopulation of self renewing cells capable of multi-lineage differentiation within the tumor propagating tumorigenesis, or cancer stem cells(CSC), has been implicated in the cancer's resistance to chemotherapy and radiation and recurrence. In this project we identify candidate cancer stem cell markers using fluorescence-activated cell sorting of a single cell suspension derived from GBM surgical specimens. Tumor subpopulations, as screened by positive expression of the candidate cell-surface marker, are thus isolated and cultured *in vitro* for evaluation of tumor sphere forming enrichment to identify cancer stem cell phenotypes.

Real/Bogus Classification for the Palomar Gattini-IR Telescope Using Deep Learning
Manasi Sharma
Mentor: Mansi Kasliwal

Palomar Gattini-IR is a new, wide-field infrared survey telescope that is accomplishing the first all-sky time domain survey of the dynamic infrared sky in J-band. The survey produces tens of thousands of alerts each night for transients such as variable stars, dwarf novae and supernovae; however, numerous false positive, or bogus, detections often appear due to issues such as poor subtraction in the image analysis pipeline or defects in the detector, which reduce efficiency for the researchers who must manually classify these sources. Thus, we present a deep-learning, real/bogus classifier that separates bonafide transients from the false candidates through deep learning on a training sample. We first describe the software used by the GROWTH collaboration for classification and labeling of the transients, as well as the set-up of a Zooniverse classification scheme to build our training sample. We then describe the neural network architecture, which is a two-layer Convolutional Neural Network, implemented using the high-level Keras API and TensorFlow. We describe the results of performance tests which show a 99.77% classification accuracy from K-fold Cross Validation. A sub-sample of these classified real transients were followed up with infrared spectroscopy at Palomar Observatory, including a confirmed supernova and a flaring brown dwarf. We compare this classifier to the performance of braai, the RB deep learning classifier for the Zwicky Transient Facility (ZTF).

Rotation Periods of Potential Exoplanet Host Stars
Ilya Sherstyuk
Mentors: Rachel Akeson and BJ Fulton

The APF-50 exoplanet survey contains 51 stars with 9 total candidate exoplanets that would be discoveries. Rotational modulation of starspots on the surfaces of stars can mimic the signatures of orbiting planets. The orbital periods of the candidate planets must be compared to the rotation periods of the host stars to check that they do not match. We developed a method for finding the rotation periods of the stars by processing photometry and spectral measurements that track magnetic activity. This method involves bandpass filtering the data and then searching for significant peaks in Lomb-Scargle periodograms, accounting for potential aliases which occur from sampling frequencies present in the data. We perform a Gaussian process fit using the Python package RadVel to quantify the quasi-periodic structure in the stellar rotation signal and measure uncertainties using Markov-Chain Monte Carlo. Using data from the APF and HIRES instruments, we found the rotation periods of the majority of the stars in the sample which allows us to confirm the presence of several new planetary companions.

Après moi le déluge: **How to Make a Millisecond Pulsar With a Red Giant Companion**
Tzarina Shippee
Mentor: Sterl E. Phinney

Recycled neutron stars (millisecond pulsars, or MSPs) with white dwarf companions have very small orbital eccentricities, (e), following the eccentricity-orbital period relation (e-Pb) predicted by Phinney (1992). Recently, however, an intriguing gap has become clear in the orbital distribution around 20-40 days. Even more recently, five pulsars of high eccentricity have been discovered with periods in this gap (Stovall et al. (2019)). One possible explanation for the origin of such systems involves connecting high eccentricity pulsar binaries to red giant-neutron star systems with pulsar-enhanced accretion shutdown. Systems very similar to those expected of the low mass X-ray binary progenitors of the numerous binary millisecond pulsars orbited by helium white dwarfs have just recently been discovered (eg. 2FGL J0846.0+2820 in Swihart et al. (2017) and PSR J1417-4402 in Camilo et al. (2016), Strader et al. (2015), and more recently in Swihart et al. (2018)) and require further understanding before we can hope to possibly use them to explain the gap in MSP eccentricities. As such, I have endeavored to discover what initial conditions result in accretion shutdown during MSP formation.

Rearrangement of the Olfactory Circuit After Loss of Projection Neurons in the Olfactory Bulb to Retain Function
Eyvindur Árni Sigurðarson
Mentors: Carlos Lois and Luis Oscar Sanchez Guardado

The brain has limited ability to regenerate compared to other organs of the body. This makes recovery or restoration of function after an injury or neurodegenerative disease very limited. Regardless of its recovery limitation, the brain has the ability to learn new information by making new connections. To study the brain's ability to restore neuronal activity function, we used transgenic mice to specifically ablate the projection neurons in the olfactory bulb (OB) at three different times during maturation and neuronal assembly of the olfactory circuit. These times were P4, when the connections between neurons start to be functional; P30, when the organization of the olfactory system is complete but not fully mature; and at P60 when the connections of the olfactory system are organized and stable. Then, we analyzed the structural organization of the OBs, and their ability to smell (detect and distinguish between odors). There seems to be a time specific window where the brain is plastic enough to make up for a massive loss of neurons in such a way that it can retain the former function of those lost neurons. Our result showed a temporal window where the OB has the ability to rearrange to be functional.

Frustrated Domes: Pop-Up Gridshells Deployed in Tension
Olivine Silier
Mentors: Chiara Daraio and Paolo Celli

Shape morphing structures are increasingly being used for mechanical and civil engineering applications. The Daraio group has recently explored a strategy to morph initially flat, rubbery sheets into three dimensional surfaces by leveraging the kinematic frustration induced by non-periodic patterns of cuts. The goal of this project is to develop large-scale structures from analogous mechanics principles. In particular, we create pin-jointed gridshells that mimic the out-of-plane morphing behavior of the architected sheet. Additionally, pinning together couples of free boundary nodes allows the structures to retain their shape while developing a state of pre-stress that enhances their structural behavior. Via experiments on meter-scale domes and numerical models, we study how the geometrical parameters of these systems affect their deployed shape and structural response.

Gut-Brain Interactions in Parkinson's Disease: A Role for Mitochondrial Bioenergetics
Gabriel Tofani Sousa e Silva
Mentors: Sarkis Mazmanian and Livia Hecke Morais

It is known that the intestinal microbiome impacts the host's health, development, and behavior. The relation between the microbiota and neurodegenerative diseases has been already established. However, the link of these microorganisms with specific physiological alterations in neurological disorders remains unknown. Neuropathological hallmarks of Parkinson's disease include the formation of α-synuclein (αSyn) protein aggregates in various regions of the central and enteric nervous system, and altered mitochondrial function. Using mice that overexpress human aSyn, we accessed mitochondrial bioenergetics in isolated mitochondria from the gut and specific regions of the brain using different approaches including enzyme activity assays, ATP detection assays, western blots for proteins markers of neuronal death. Here we report that the lack of microbiome may alter some aspects of mitochondrial bioenergetics. These findings contribute to the hypothesis that the gut microbiome plays a role in PD.

Deconvolution of Astronomical Images
Shubhranshu Singh
Mentors: Ashish Mahabal and Dmitry Duev

The images obtained from ground-based telescopes suffer from blurring due to the presence of the earth's atmosphere. The images contain objects that are not point-like which they would have been if observed from a space-based telescope. To undo the effect of the blur, deconvolution has to be performed on these images. This is particularly useful to separate star profiles in a crowded field, where the profiles of stars overlap with each other. We are using data from the Hubble Space Telescope and convolving it manually to generate image pairs for training a convolutional neural network (CNN). Also, to check the model's performance on isolated sources, simulated data was generated with few sources. We get a peak signal-to-noise ratio (PSNR) of 51.74 dB on the simulated data and the convolved images have a PSNR of 44 dB. The final goal is to make the algorithm work on the data from the Zwicky Transient Facility(ZTF) survey.

Using Computational Based Modeling to Predict HIV-1 Strain Resistance
Tarini Singh
Mentors: Pamela Bjorkman and Anthony West

Broadly neutralizing antibodies (bNAbs), produced by only a small proportion of HIV-1-infected individuals, can neutralize up to 90% of HIV-1 strains worldwide, and prove to be promising in fighting and eradicating HIV infection. But, they are still prone to HIV-1 resistance through escape mutations in the gene encoding the HIV-1 envelope protein. Thus, we propose creating and testing a model to characterize escape by using computational analyses to determine how sequences and residues in specific bNAbs and HIV-1 strains can predict resistance and escape in those strains.

Using two Rosetta protocols, an older protocol previously used in the lab and adopted from the Crowe lab at Vanderbilt as well as the flex_ddG protocol developed by the Kortemme lab at UCSF, we can computationally model the binding affinity of bNAb 3BNC117 to a variety of HIV-1 strains, varying strain specific features such as notable mutations or the V5 loop sequence. From there, we can correlate the resulting ΔΔG values to binding affinity, correlated with known IC50 values. Further research can look into specific residues that may explain resistant strains and also determine why significant Ab/strain outliers are unable to be predicted by the model. This will eventually be useful in determining how to best engineer antibodies in order to avoid causing or to remain potent against the resistant mutations.

Mapping the Chemodynamics of the X-Shaped Bulge Over Time
Tawny Sit
Mentors: Melissa Ness and Evan Kirby

The Milky Way has been observed to have an X-shaped structure within its bulge, but empirical characteristics of this structure such as its chemical composition, age distribution, and how far it extends have not yet been determined. We use the data-driven code *The Cannon* to measure abundances and ages of 25367 stars in the X-shaped bulge using spectra from APOGEE DR14, training on a set of 5591 APOGEE stars whose ages have been determined independently with Kepler astroseismology. This data was divided into low- and high-α subsets due to observed differences in abundance-age correlations between the two groups and run through *The Cannon* separately. We examine the metallicity and age distributions of stars within 3.5 kpc of the galactic center and two specially targeted fields in the X-shaped bulge and find that the fields have similar age distributions but different metallicity distributions. We also find that the X-shaped bulge appears to end between the latitudes of these fields. Additional analysis will more closely examine the abundance distributions and dynamics of this area.

Alternative Electrolyte Solutions for Use in Mg-Metal Batteries
Julia Sloan
Mentors: Kimberly See and Sarah Bevilacqua

Lithium ion batteries are widely used today but are quickly reaching their theoretical capacity limit, motivating the development of next-generation energy storage systems, such as magnesium batteries, as an alternative with high capacity and low cost. However, magnesium is very reactive with many commonly used electrolytes, preventing the reversible electrochemistry that is required for battery function. To control reactivity at the magnesium surface, an electronically insulating and ionically conducting thin film was designed to protect the Mg. Here, we test the behavior of this protected magnesium in various electrolytes. Carbonates are known to be highly reactive and passivate both magnesium and protected magnesium. The all-phenyl complex (APC) in THF provides an electrolyte feasible for use in these batteries, showing reversible electrochemistry over many cycles and decreased reactivity with the protected magnesium.

THE1 Regulation of Cell Division in *Arabidopsis* Roots
Whitney Sloneker
Mentors: Elliot Meyerorwitz and Hanako Yashiro

Receptor-like kinase THESEUS1 (THE1) has been connected to dividing cells in the shoot apical meristem. However, its role in dividing cells of the root has not been elucidated. To this end, we used *the1-1* and *the1-4* alleles to test if THE1 functions in root development. First, we analyzed root morphology in *the1* mutants. We observed root lengths, number of lateral roots, and root structure of the wild type. Next, we observed where *THE1* was expressed in the root by using the pTHE1-3xVenus reporter. To test if THE1 regulated cell division, we used the CYCB1;1-GFP reporter to indicate which cells were dividing. Preliminary results suggest that the mutations give rise to longer roots than the wild type and THE1 works differently in the root than the meristem. While expressed more commonly in the epidermis in the shoot apical meristem, *THE1* is expressed in the root stele instead of at the root epidermis.

M-Dwarf Flare Stars and Implications for the Habitability of Orbiting Exoplanets
Nathaniel I. Smith
Mentor: Wen Ping Chen

The increasing breadth and depth of information about exoplanets and exoplanet-forming systems enables the testing of increasingly sophisticated hypotheses concerning the conditions that impact planetary formation and evolution. One interesting case is that of exoplanets orbiting M-dwarf flare stars. Through convection these stars are highly magnetically active and as such experience frequent flaring activity on the minute timescale, releasing flares with properties that differ from those of the more-studied solar flares. Here, we investigate the characteristics of M-dwarf flare star systems and attempt to model the time profile of empirical flare events, with a goal towards relating the model both to the underlying physics and to the current understanding of solar flares. We find that flaring behavior in M-dwarves diverges qualitatively and quantitatively from solar flaring behavior, producing flares with a differing radiation profile over a wider range of energies and timescales. We also relate flaring behavior to observed planetary formation in these systems using data from groups such as the EDEN project. As the habitable zones of M-dwarfs are closer to the star than for larger star types, issues such as tidal locking depress prospects for habitability. The intense X-ray and UV fluxes of flare stars depress the likelihood of life further, both directly, and through evaporation and photodissociation of water.

Reaction Mechanism for the Hydrogen Evolution Reaction on the Basal Plane Sulfur Vacancy Site of WSe2 and WTe2 Using Grand Canonical Potential Kinetics
Jie Song
Mentors: William Goddard and Soonho Kwon

We use the Grand Canonical Potential to study the reaction mechanism of the hydrogen evolution reaction in transition metal dichalcogenides (TMDCs). Our work focuses on the 1T phase and the 2H phase of WSe2 and WTe2. We will use VASP to calculate the free energy of different reaction intermediate and transition states under different numbers of electrons, and then fit the energy to the number of electrons. Using the obtained fitting parameters, the expression of GCP(n;U) is obtained. Then use the energy data under different conditions, such as different pH, potential, to compare and judge the catalytic performance of different materials under different conditions.

Optimal Design of Experiments in Atmospheric Source Inversion
Yanke Song
Mentor: Andrew Stuart, Bamdad Hosseini, Krithika Manohar, and Melike Sirlanci Tuysuzoglu

Atmospheric source inversion is the problem of estimating the rate of pollutant emissions from indirect measurements of concentration. In this project we model the dispersion process in steady state as an advection-diffusion elliptic partial differential equation (PDE). Then source inversion coincides with the problem of inferring the source term of the PDE from point values of the solution. To solve this ill-posed inverse problem, we employ the Bayesian approach that combines measurements with prior knowledge about the source to give a stable and accurate estimate of the unknown. We discuss novel choices of the prior distribution to inject geometric information about the location of the sources. Next we consider the optimal experimental design problem of choosing the best sensor locations to obtain the best estimate of the source term. We present a new method based on principle component analysis that considers the structure of the PDE and our choice of the prior distribution on the source. We demonstrate the effectiveness of our methods with extensive numerical experiments.

Simulating the SuperTIGER Instrument
Carlos H. Sosa
Mentor: Mark E. Wiedenbeck

The SuperTIGER instrument was created to record cosmic rays. It flew in Antarctica for 55 days and collected data on the elemental cosmic rays it detected. A simulation of the SuperTIGER's response to cosmic rays was created using Geant4, a software package developed by CERN to simulate the passage of particles through matter. Using this simulation, data was collected on the elements from Magnesium to Cobalt, which will be used to calibrate the actual instrument response.

Determining How Transcription Factors Regulate the *brinker* Promoter Proximal Element in *Drosophila melanogaster*
Mohamed Soufi
Mentor: Angelike Stathopoulos

Multicellular organisms regulate many genes using complex and precise combinations of cis-regulatory modules (CRMs) and transcription factors. The *brinker* gene in the fruit fly *Drosophila melanogaster* has multiple CRMS that regulated brinker expression and research has shown that the promoter proximal element (PPE), a DNA sequence just upstream of *brinker*, is required for the CRMs to function properly. The goal of this project is to better understand the molecular mechanism behind the PPE and its interactions with the CRMs. A previous study performed a yeast one-hybrid screen against a library of *Drosophila* transcription factors to identify proteins capable of binding to the PPE. Using RNAi in fly embryos, we will knockdown the proteins found to bind to the PPE to see if they have an effect on *brinker* expression. We expect the knockdown of some proteisn found in the yeast one-hybrid screen to alter *brinker* expression in flies. A better understanding of gene regulation mechanics would allow future research to develop cures to people who suffer genetic diseases involving altered CRM interactions.

High Strain Rate Behavior of 3D Printed Al 6061 T6 Alloy:
Shreyas Sreeram
Mentors: Guruswami Ravichandran and Suraj Ravindran

Aluminum alloys are widely used in aerospace applications due to its high strength to weight ratio. These materials are typically manufactured using metal forming operations. Recently, additive manufacturing (3D printing) is evolving as a major manufacturing process to make metallic alloys which has a potential to replace the conventional manufacturing processes. The material behavior of the traditionally manufactured aluminum is relatively well-known, whereas, the characterization of the 3D printed aluminum alloys are very limited. In this study, an experimental investigation is performed to characterize the conventionally manufactured aluminum-6061-T6 and the 3D printed counterpart of aluminum-6061-T6. This study focuses on analyzing the high rate behavior using a Split Hopkinson Pressure Bar(SHPB) setup. The stress-strain behavior of the 3D printed alloy was studied, and its microstructural mechanisms were analyzed and compared with those of the conventionally manufactured Al 6061.

Simplifying Real-Time Analysis of Sounds
Deepak Narayanan Sridharan
Mentors: K. Mani Chandy and Julian Bunn

Data streams are ubiquitous in today's world of big data. An acoustic signal is usually recorded as a stream of 64 bit floating point numbers, and are a natural source of data streams today. We would like to come up with plug-and-play platform that enables the creation of a variety of acoustic applications using IoTPy, a software built in-house at Caltech to build modular applications that process streams of data collected from various sources. We would also like to enable users to plug together components of open-source software to build useful applications that process sounds, and the creation of new acoustic applications. For the same, we look at the fundamentals of digital signal processing, concurrent and parallel programming and machine learning and use them for our various applications.

Data Analysis in Virtual Reality
Spiro Stameson
Mentor: George Djorgovski

The complexity and magnitude of modern data sets poses an increasing challenge in interpreting information, creating a barrier between knowledge and understanding. To solve this problem, effective data visualization methods must be developed to bridge the gap between quantitative content and human intuition that enables scientific discovery. The key challenge in the era of big data is not acquisition, but rather the discovery of meaningful patterns hidden in the data. Immersive virtual reality (VR) platforms have the potential to enable effective scientific data visualization across many disciplines. Traditional methods involving the projection of hyper-dimensional data sets onto a 2-dimensional plot can destroy information by obscuring important structures hidden in the data, preventing the development of key intuitions. New developments in VR increase the number of dimensions we can visualize, leading to a higher probability of recognizing interesting patterns, correlations, or outliers. To quantify the benefits of using VR to represent data, we created visualizations utilizing software from Caltech startup Virtualitics, and are holding trials where one group of participants performs analysis using 3D/VR graphs, while another used 2D visualizations. Through comparison of the relative performance, we hope to show the effectiveness of VR as a visualization interface for data professionals.

Explaining Past High Heat Fluxes of Miranda and Ariel Using “Resonance Locking”
Sarah C. Steele
Mentors: Francis Nimmo and James Fuller

Moons orbiting large bodies evolve outwards with time, but the details of their migration histories are poorly understood. Pairs of moons sometimes get caught in mean-motion resonances (MMRs), in which their mutual orbital interactions cause tidal distortions of the moons, thereby generating heat. Since the tidal heat fluxes produced depend on how quickly moons are moving through those resonances, the migration rates of the Uranian moons Miranda and Ariel can potentially be constrained by heat flux estimates generated from topography obtained during the Voyager flyby [1] [2]. However, existing models of orbital evolution are unable to explain the inferred heat fluxes [2]. Our work attempts to determine whether the inferred heat fluxes can be accounted for by “resonance locking” [3], which occurs when a moon becomes trapped in resonance with an oscillation mode of the planet and thus migrates outwards on the timescale over which that mode evolves. A consequence is that, when moons become trapped in mean-motion resonances (MMRs), this mechanism can produce tidal heating in the moons that is much larger than would be possible without “resonance locking”. Work so far suggests that “resonance locking” is capable of producing heat fluxes within the inferred ranges for Miranda and Ariel, which suggests that the migration histories of these moons indeed depend closely on the interior evolution of the planet. Future work will attempt to apply the inferences made about the moons’ migrations in this framework to better understand the interior evolution of Uranus.

Low Cost Etching of GaAs Microstructures for Thin-Film Solar Cells
Ariel Stiber
Mentors: Harry Atwater and Phillip Jahelka

GaAs thin films are a compelling replacement for silicon as the most common photoabsorber used in photovoltaic cells. GaAs has a high absorption coefficient permitting cells to be one-hundredth the thickness of a silicon cell. This allows more devices to be created per wafer, offsetting the environmental cost of manufacturing them much more quickly than silicon cells. Additionally, by distributing the wafer capital over a large number of devices, the solar cells are more economically scalable. However, the normal techniques to fabricate GaAs devices are costly and energy intensive. We investigated low-cost methods of fabricating GaAs thin films by etching microstructures into a wafer and then exfoliating them, allowing for wafer reuse. Our principal discovery is that etching a 110 GaAs wafer parallel to the 110 planes in a refrigerated solution of citric acid and hydrogen peroxide results in crystallographic etching with minimal mask undercutting. By combining this with traditional isotropic etchants we anticipate being able to produce high-aspect ratio microstructures for photovoltaic applications.

Synthesis and Characterization of Bulk Aluminum-Doped Graphitic Carbon
Grace Suenram
Mentors: Nicholas Stadie and Brent Fultz

Heteroatom doping of graphite is a common chemical method to tailor carbon’s intrinsic properties. Boron and nitrogen are standard choices for substitutional chemical dopants, while this project aimed to extend the direct synthetic route of high heteroatom content materials to aluminum as a dopant. Aluminum-doped graphitic carbon was obtained herein through direct reaction of a liquid phase mixture of an aluminum precursor (aluminum chloride) and a carbon precursor (benzene) in a closed system at high temperature. Characterization of structure was carried out through X-ray powder diffraction and Raman spectroscopy. Bulk composition was analyzed via energy dispersive X-ray spectroscopy. Metastable graphitic phases containing higher than the 0.01% equilibrium solubility of Al in graphite may have interesting applications in catalysis and energy storage.

The Impact of Action Set Structure on Submodular Maximization
Haoyuan Sun
Mentors: Jason Marden and Adam Wierman

In the submodular maximization problem, a network of agents each equipped with local actions is trying to maximize a global objective intuitively exhibits property of "diminishing return." It has been shown that a simple greedy algorithm guarantees solutions at least 1/2 of the optimal. In the greedy algorithm, agents sequentially make decisions that are the best given only the decisions by all previous agents. In this paper, we explore the performance of the greedy algorithm when given certain constraints on the local action sets of the agents. We show a lower bound on the performance of the greedy algorithm when there is little redundancy between actions of different agents, as measured by the marginal gain of one action with respect the other. We additionally extend this setting to when the access to decisions rendered by previous agents is limited.

Robotics Simulation of Multiple Degree-of-Freedom (DOF) Spacecraft Testbeds
Jennifer Sun
Mentors: Soon-Jo Chung, Rebecca Foust, and Wolfgang Hoenig

Spacecraft testbeds are useful tools in developing and validating algorithms for motion planning, state estimation, and control. At the Caltech Aerospace Robotics Control Lab (ARCL), spacecraft testbeds, otherwise known as the Multi-Spacecraft Testbed for Autonomy Research (M-STAR), are modelled as a 3-D pendulum on a floating platform with sixteen thrusters and four reaction wheels as on-board actuators. M-STAR is designed to be modular and can accommodate 3-DOF, 5-DOF, and 6-DOF operations. We design a virtual environment that can be utilized in pure simulation and Mixed Reality experiments to help simplify validation of higher-level algorithms. This method is preferred over placing physical objects in the ARCL workspace as it is laborious and dangerous to the experimental workspace and testbeds. Our approach mainly utilizes the Robot Operating System (ROS) framework and Gazebo, a 3D rigid body simulator, to design a simulation environment. A virtual replication of the ARCL spaceroom and spacecraft testbeds are loaded into Gazebo. Movement of the spacecraft testbeds is then simulated by applying vectorized force trajectories at each relative thruster location. The position and orientation, or pose, of the spacecraft testbeds in the simulation is compared with real experimental data to test the accuracy of the robotic simulations.

Search for Neutral Long-Lived Particles Decaying in the CMS Muon System
Nathan T. Suri
Mentors: Maria Spiropulu, Cristian Pena Herrera, Christina Wang, and Si Xie

To isolate experimental signals for the twin glueball pair production with a single delayed di-b-jet decay process, we will be motivating the development of a firmware filter known as a Level 1 trigger to identify signature hadronic final states in the CMS muon system through an offline study for Run 3 of the LHC. As the delayed jets indicative of neutral LLP decays travel longer than normal SM-background jets, the large volume of the muon system provides a better opportunity at detecting the long-lived particle's final state than the inner detector or calorimeter levels. The offline study showed support for the development of a Level 1 muon region of interest trigger by demonstrating that the events exhibiting the target low transverse momentum final states contain clusters of hits in the muon system endcap, not being able to penetrate the steel yokes, while background processes are mainly stopped in the calorimeters yielding low number of muon system hits. On account of the promising signal to background discrimination uncovered in the offline study, an Run 2 analysis has been initiated to more closely explore the value in using the muon system to detect the decays of long-lived particles.

Using Graviton Effective Field Theory to Compute Gravitational Potentials for Black Hole Inspirals
Bethany Suter
Mentors: Clifford Cheung and Mikhail Solon

This year, the LIGO detectors entered their third observing run and have been detecting black hole interactions with increasing precision and sensitivity. These detections have opened up a new way to compare the predictions of Einsteinian gravity with more exotic models. One of these models, massive gravity, is a concrete toy to use in testing these predictions. This project uses ideas from Effective Field Theory and standard techniques from Quantum Field Theory to calculate scattering amplitudes for scalar particles interacting via gravitons. We first calculated amplitudes up to the 1-loop level assuming the standard massless graviton and then assuming a massive graviton. We then mapped these amplitudes to gravitational potentials for black holes. We also explored a means of simplifying the calculations using the color-kinematics duality between gluons and gravitons. Future work will include looking at the different predictions of these two theories (massless and massive gravitons), and comparing them to black hole inspiral data to determine if the massive graviton theory could be a legitimate contender as a model for gravity.

Modelling Heat Flows Behind a Shockwave in O_2
Matthew Szedlock
Mentor: Guillaume Blanquart

Modelling heat flows behind a shockwave is an essential component of designing spacecraft, specifically with regard to their heat shields which protect scientific payloads when entering atmospheres at hypersonic speeds. Behind the shockwave that is formed, there can be increases in temperature that can reach up to around 10,000 Kelvin. At such high temperatures, gases begin to display largely unpredictable non-equilibrium phenomena with their vibrational energy mode before relaxing towards a Boltzmann Distribution. The goal of this project was to review past literature on previous experiments and models to determine their assumptions and scientific reasoning and then utilize this information to design a model that could robustly predict these flows and do so efficiently. By taking a simple molecule, O_2, and then mapping its energy states as Boltzmann Distributions, the predictions of past models could be compared to the results of simulations, run with FlameMaster, to determine which models came closer to accurately predicting these hypersonic flows. In the future, these models could then be synthesized into something that does better at modelling non-equilibrium phenomena and improving heat shield designs for spacecraft.

Identification of the Domain-Domain Interaction Between Two Cell Surface Proteins, Ptp10D and Sas, in *Drosophila melanogaster*
Sriharsha Talapaneni
Mentors: Kai Zinn and Peter Hyung-Kook Lee

Receptor tyrosine phosphatases (RPTPs) are proteins that reverse the reactions catalyzed by tyrosine Kinases (TKs). Ptp10D is one of the six RPTPs in *Drosophila*, and it is known to have a physical interaction with Stranded at Second (Sas), a cell surface protein (Lee *et al.*, 2013). The interaction between Ptp10D and Sas regulates axon guidance and the organization of longitudinal glial cells in the embryonic CNS. In this project we are investigating the physical interaction of the extracellular domains (XCDs) of these two proteins using the *Drosophila* S2 cells and the 3rd instar larvae. To study this, we made XCD variations of Sas and Ptp10D: each of the constructs missing one of the primary XCDs such as FN3 or vWC. We then transfected *Drosophila* S2 cells with these Sas and Ptp10D constructs and have started to perform Western blot and Co-immunoprecipitation assays on the cell lysates and supernatants.By investigating the interactions between these variations, we will be able to find out specific domains involved in the physical binding between these two proteins. This study will provide a better understanding of the roles of Ptp10D and Sas in cell-cell communication.

Quantum Teleportation Using Time-Bin Entangled Photons
Yuchen Tang
Mentors: Maria Spiropulu, Cristian Pena, Si Xie, and Neil Sinclair

Quantum teleportation is the transfer of quantum information between various locations using classical communications and quantum entanglement. This project is part of the Fermilab Quantum NETwork (FQNET) project which uses optical fibers to transmit time-bin photonic qubits over long distances by entanglement. An entanglement source setup has been completed at Fermilab. The 1536 nm photons are converted to 768 nm photons with a second harmonic generator (SHG) and down converted to 1536 nm through a spontaneous parametric down conversion process (SPDC) before getting detected by superconducting nanowire single photon detectors (SNSPDs). We investigated the long-term behavior of the interferometer and the intensity modulator of the setup at Fermilab. We then built an entanglement source at Caltech based on the setup at Fermilab and managed to get photon pairs. We characterized various devices in our experiment to reduce noise and to prepare an interferometer setup to demonstrate entanglement. Subsequent work will be done to commission the 1536.49 nm narrowband filters in the network and to precisely control the temperature in the interferometer.

3D Printable Polyelectrolyte Complexes With Versatile Mechanical, Responsive, and Healing Properties
Zane Taylor
Mentors: Julia R. Greer and Daryl Yee

Polyelectrolyte complexes (PECs) are a class of supramolecular polymers that are mechanically compliant, and exhibit stimuli-responsive, and self-healing behavior. These materials have found applications in soft robotics, recyclable materials, and reparable systems. In this work, we developed a versatile PEC system for 3D printing using *in situ* polymerization of acrylic acid in the presence of trivalent metal-cation crosslinkers such as iron (III) and aluminum salts. This system was developed and tuned for projection micro-stereolithography printing, resulting in a compliant material displaying upwards of ~300% strain and ~4MPa stress, as determined using ASTM D638 Standard V tensile testing. 3D printed architectures of this material were shown to exhibit self-healing capabilities and were also selectively soluble, with properties being easily modified by the choice of metal cation crosslinking species. The versatility of this system introduces a large parameter space for facile 3D printing of self-healable and responsive systems with tunable mechanical properties.

Parallelized Ocean Modelling Using Strang Splitting and Sound Waves
Gianmarco Guin Terrones
Mentor: Jörn Callies

Traditional ocean models frequently make the justifiable assumption that the ocean is incompressible. But the incompressible fluid equations necessitate the solution of an elliptic boundary value problem every time step to obtain the pressure field, which makes parallelization challenging. A recently proposed approach that instead includes (slowed down) sound waves obviates this repeated solution for the pressure field and can more readily make use of the massive parallelism of modern computing architectures. In this work, a Julia implementation of this approach, which treats the sound waves as one of a few Strang splits, was tested in various oceanographic flow regimes. This model's output was compared to either analytical solutions or to solutions obtained with conventional incompressible models. Initial results show that the model accurately captures the response of an idealized ocean to wind stress, displaying Ekman and stratified spin-up dynamics in one, two, and three-dimensional configurations. The model has also been found capable of simulating baroclinic eddies. Requirements for different model parameters, such as grid spacing and the adjustable sound speed, were quantified.

Developing Mounts and Image Slicers for the ROSIE Integral Field Spectrograph on the Magellan Baade Telescope
Jasmine Terrone
Mentors: Rosalie Cushman McGurk and Evan Kirby

An integral field spectrograph is an optical tool which allows scientists to obtain the spectra of an entire field at once, making it more time and cost efficient than long slit spectroscopy to understand the dynamics and compositions of extended objects such as galaxies. An image slicer integral field unit is composed of multiple mirrors located at the focal plane of the telescope that divide a field into multiple slices and reposition those slices so that they can be dispersed without overlap by the following spectrograph. This project centers on the designing and manufacturing of the integral field unit (IFU) for the IMACS wide-field imaging spectrograph on the Magellan Baade Telescope at Las Campanas Observatory, named the Reformatting Optically-Sensitive IMACS Enhancing IFU, or ROSIE IFU. The ROSIE IFU is comprised of multiple different optics including an image slicer, which is a stack of thin quartz mirrors that slice the original image; a pupil optic that refocuses the slice; and a slit mirror that directs the slit onto the spectrograph. The goal of this project was to aid with the development of the mounts for these optics. Specifically, a focus was made on analyzing the structural integrity of the mounts as deformations of any kind could result in a loss of data. Additionally, prototypes of the image slicer were developed. The constituent elements of this instrument, the delicate quartz mirrors, must be held in two configurations: one "block" configuration for polishing the stacked slices into the correct curvature, and one "fanned" configuration for positioning the mirror slices at precise angles. To achieve this task, two sets of holes must be manufactured on each slice: stationary holes, which are in the same position for each mirror, and fanning holes, whose positions are unique to each slice and are calculated by rotating the holes about the optical axis. When dowels are inserted into these fanning holes, each slice is held at a unique angle, resulting in the final configuration that will be used in the ROSE IFU. The resulting drawings will be sent to optics manufacturers to be machined. Finally, the mounts, clamps, and image slicer prototypes were 3D printed to practice aligning the optics.

Vacuscribe: Hermetically Sealed Apparatus for Two Photon Lithography With Custom Photoresins
Vincent Tieu
Mentors: Julia Greer, Amylynn Chen, and Andrey Vyatskikh

The Nanoscribe Photonic Professional GT is a 3D microfabrication printer that uses two-photon lithography to create structures with sub-micron precision. The existing setup involves writing the nanostructures in a photoresist sandwiched between a silicon wafer and 170 um glass slide, all of which is directly exposed to the lab environment. While this is sufficient for commercial photoresists, it is sub-optimal for custom resins that are air/humidity sensitive, resulting in decreased write quality or even failed prints. In addition, solvents released into the lab environment can pose a health hazard. We developed the Vacuscribe through a deterministic design methodology to contain the custom resin sample in an inert environment for the duration of the print, minimizing its exposure to the outside environment. We will conduct test prints with custom resins to examine the effectiveness of the apparatus for improving print quality, and compile a manual detailing proper operation. This will allow researchers to work with custom resins and take advantage of their unique properties in nanomaterials.

Analysis of Dural Lymphatics in Pathological Situations
Anna Tifrea
Mentors: Jefferson Chen and Nathan Lewis

Recently discovered, dural lymphatics are a vessel network in the dura matter of the brain whose confirmation disproved the previously held concept that the central nervous system (CNS) lacked a lymphatic drainage system. Dural lymphatics represent one of the ways that cerebral interstitial fluid (ISF) gets filtered, as well as how fluid and macromolecules are drained from the brain. This project focuses on exploring a possible link between the abnormal functioning of dural lymphatics and Alzheimer's disease, a neurodegenerative disease. We are conducting immunohistochemical (IHC) staining on paraffin embedded archival material with podoplanin (D2-40), an antibody that marks lymphatic endothelium, to quantify and compare the abundance of lymphatics in Alzheimer and normal control patient brain tissues. We also performed a dual stain with beta amyloid, a peptide detected in Alzheimer's disease, to try and associate the status of the patient with the number of lymphatics present. Our preliminary data presents a slight increase in lymphatics from negative control patients to Alzheimer patients, showing a possible linkage between an abnormal number of dural lymphatics and Alzheimer's disease.

Construction of a Magneto Optical Trap
Alicia Tirone
Mentor: Nicholas Hutzler

Magneto Optical traps have been widely used in the field of Atomic Molecular Optics as a robust way to laser cool and trap atoms. The goal of this project is to build a magneto-optical trap to study atomic and molecular generation methods for Ytterbium and Ytterbium Oxide using a moglabs diode laser to cool on the 399 Ytterbium transition. Atomic generation through thermal heating of a target with a commercial diode was investigated and found to be unsuccessful; however, an ablation-loaded MOT may be possible, despite the high temperatures of the initial atomic cloud.

High-Dimensional Deconvolution of Noisy Datasets With Applications to Cosmology
Megan Tjandrasuwita
Mentor: Peter Capak

Deriving the physical properties of galaxies, such as their distance, from astronomical imaging is a non-linear problem. For cosmology measurements, such as dark energy studies, it is crucial to maintain a high level of overall accuracy when estimating these properties even when individual measurements are noisy or incomplete. Traditional model-fitting methods or machine learning methods have struggled to meet the requirements of cosmology studies. We have re-cast the problem as a mapping between data space and physical parameter space, which turns the problem of accuracy into a high-dimensional deconvolution problem. We solve this problem using a combination of machine learning techniques. First a Growing Neural Gas (GNG) learns the noisy data distribution and represents it as a set of vectors. Next, we use these vectors as the starting point for the extreme deconvolution method, which represents the data as a Gaussian Mixture Model (GMM). The combination of these two techniques allows us to find the underlying distribution of a 4D simulated photometry dataset in a reasonable amount of compute time. Applying this technique to even more complex, higher-dimensionality datasets will provide a new way of making cosmological measurements and understanding galaxy evolution.

Development of a Calibration Technique to Characterize the Drag Reducing Capabilities of Megasupramolecules in Turbulent Pipe Flow
Anika Todt
Mentors: Beverley McKeon and Ryan McMullen

The addition of polymers to turbulent flow can result in drag reduction. However, these polymers are susceptible to shear degradation. In 2015, Wei et al. synthesized novel self-reassembling megasupramolecules, which have the potential to resist decreases in efficiency that would otherwise be caused by shear-degradation. Particle image velocimetry (PIV) will be used to characterize the drag-reducing capabilities of the megasupramolecules in turbulent pipe flow. However, the image distortions caused by the refractive index mismatch and curvature of the pipe need to be accounted for to obtain accurate measurements. To this end, a Matlab program capable of dewarping PIV images is developed. The dewarping program is validated through the assembly and imaging of a custom calibration section and target.

Developing a Python Kiosk That Facilitates the Deployment of Clusters for Machine Learning
Andy Tong
Mentors: David Van Valen, Dylan Bannon, William Graf, and Erick Moen

Machine learning is a relatively new development in biology. Often, biology labs don't have the powerful computers necessary to process large amounts of data or the experience to set up cloud computing. To remedy that, the kiosk will help ease the process of deploying a cluster on the cloud. A cluster is a group of machines, in this case from Google or Amazon, that pool their computing power together. Clusters are used in tandem with Kubernetes to do all the computing and organizing of applications in terms of management, deployment, and scaling. What the kiosk does is it takes in user inputs for areas such as minimum GPU nodes, giving default options when possible, and it checks certain inputs for their validity. The kiosk is written python in order to make future editing much easier. The potential applications of machine learning in biology are endless, from predicting protein structure and function to identifying cell types in live-cell imaging. The kiosk should make it easier for labs without the proper setup or background to get into machine learning and hopefully will expand the use of machine learning in biology.

Large Area Patterning of Three-Dimensional Nano-Architected Metamaterials via Metasurface Mask Interference Lithography
Thomas Tran
Mentors: Julia Greer, Ryan Ng, and Phillippe Pearson

Both ultra-strong and lightweight, materials architected on the nanoscale exhibit phenomenal mechanical properties. They promise multifunctionality, offering solutions to many engineering problems, but their feasibility is limited by the lack of a scalable fabrication method. Currently, high aspect ratio 3D nanostructures possessing periodic sub-micron features can be made using metasurface mask interference lithography. By exposing a photoresist material to a 3D interference pattern formed by a metasurface, structures of areas on the order of 1 cm^2 can be made in a single exposure step, demonstrating processing time improvements over serial methods like two-photon lithography. To further upscale this process and produce larger area specimens of at least 20 cm^2, we propose two methods. Continuous scanning of a laser over a fixed metasurface mask can generate sample sizes limited by the mask size, while raster patterning discrete exposures by moving the laser and mask can generate larger samples with stitch lines. Initial experiments demonstrate the consistency of the patterns generated by continuous scanning, while the discretized exposure of two adjacent regions resulted in regions of solid, overexposed resist. Once a defect-free raster pattern can be formed on larger substrates, automation of the experimental setup can expose large area samples with little oversight.

Improving the Expanding Photosphere Method
Kyle Tregoning
Mentors: G.C. Anupama and Avinash Singh

The expanding photosphere method (EPM) is a geometric technique used to derive distances to type II-P supernovae. Sources of error in the EPM arise from dereddening techniques used to correct for host galaxy extinction, and ambiguities in the coefficients used to calculate dilution factors to correct for the pseudo-blackbody flux emission of the photosphere. With seven type II-P supernovae consistent with zero host galaxy reddening, we derive the average color evolution of type II-P supernovae, finding intrinsic color excesses of $(B\text{-}V)_0 = 1.189 \pm 0.010$ mag and $(V\text{-}I)_0 = 0.751 \pm 0.013$ mag at 30 days before the middle of the transition phase. Using six type II-P supernovae with distances independent of the EPM, we optimize coefficients used to calculate dilution factors in the {BVI}, {BV}, and {VI} filter sets, and search for correlations between optimal coefficients and underlying supernovae properties.

Engineering of Standalone Trpb Catalyst for Abiological Enolate Based C-C Bond Formation via Directed Evolution
Soma Turi
Mentors: Frances Arnold and Ella Watkins-Dulaney

Enzyme catalyzed synthesis has become a favorable approach for the preparation of novel compounds as enzymes are highly selective, can easily be obtained and engineered to increase efficiency or alter the substrate/reaction scope. However, many synthetic transformations lack natural analogues, which severely limits the applicability of enzymes. Herein, we report the engineering of a tryptophan synthase β-subunit from *Thermotoga maritima* (*Tm*TrpB) using directed evolution to catalyze enolate-based C–C bond formation in aqueous medium. Although a mainstay technique for synthetic chemists, enolate chemistry has only modest precedence in nature. Previously, the Arnold lab engineered TrpB to accept derivatized indole nucleophiles and serine as electrophile. We discovered that an engineered TrpB variant, Tm9D8*, can accept ketones, including propiophenone, whose enolate form can react as nucleophiles. Mass-spectrometric analysis revealed that the product spontaneously cyclizes to give valuable unsaturated N-heterocycles. Using directed evolution, we sought to improve the activity of Tm9D8* with propiophenone by performing random and iterative site saturation mutagenesis. Additionally, by performing reaction optimization experiments, we found a 1.5-fold activity increase upon increasing the temperature from 37 °C to 55 °C. Finally, substrate scope exploration revealed that the enzyme accepts 1-indanone and isophtalide and shows trace activity with aldehydes as well.

The Representation of Molecular Wavefunctions Using Plane Wave Bases
Shu Fay Ung
Mentors: John Preskill and Peter Love

Quantum simulation offers a potential solution to the electronic structure problem, which encompasses the determination of molecular ground state wavefunctions and their corresponding energies. Most quantum algorithms encode the wavefunction using a set of N Gaussian basis functions which lead to Hamiltonians with (N^4) second-quantized terms. This is problematic because many algorithms for time evolution and energy estimation have costs which scale explicitly with the number of terms. Recently, Babbush *et. al*. proposed the "plane wave dual basis" (PWDB) which give rise to Hamiltonians with $\mathcal{O}(N^2)$ terms. We developed code implementing PWDB Hamiltonians for non-periodic and 2D systems. We also investigated the feasibility of classical simulation in the PWDB and find that the problem scales too quickly for a classical computer to handle. Furthermore, we applied the technique of unitary partitioning to the PWDB Hamiltonians transformed under a qubit mapping and find only a constant factor reduction in the number of terms. This suggests that the PWDB gives an optimal number of terms in the qubit Hamiltonian.

Supplemental Education and Educational Outcomes in the California Public School System
Luka Valencic
Mentor: D. Roderick Kiewiet

With the education students receive in public schools increasingly seen as inadequate, there is an increasing tendency to look at various forms of education outside schools to supplement the education students receive in schools. This study aims to determine the prevalence of the various forms of supplemental education students in the California public school system utilize, their distribution in relation to various districtwide demographic, social, and economic characteristics, and the effect of participating in the various forms of supplemental education on postsecondary educational outcomes. The data on the utilization of various forms of supplemental education as well as postsecondary educational outcomes was collected through a survey which was sent out to 1050 people who attended a California public school within the last 12 years. Additional data on districtwide characteristics of schools was acquired from the National Center for Education Statistics. Various tests were conducted on the data to determine the relationship between different forms of supplemental education, districtwide characteristics, and postsecondary educational outcomes. The forms of supplemental education with the strongest correlations with other variables are private tutoring, test preparation, and academic competition. More work should be done to determine why those forms of supplemental education have the strongest correlations.

Magnetic Field Mapping Around the nEDM Experiment Cryostat
Tine Valencic
Mentors: Bradley Filippone and Wanchun Wei

The neutron electric dipole moment (nEDM) experiment under development at the Kellogg Radiation Laboratory will search for an nEDM by detecting small changes in the precession frequency of neutrons. To do so, the gradients of the magnetic field must be minimized. I mapped the magnetic field on the floor of the synchrotron and located an apparent dipole. However, a finite-difference model indicated that this dipole's effects on the magnetic field at the center of the cryostat are negligible. Further mapping of the field took place inside the cryostat. The significant gradients detected at the center of the cryostat were surmised to possibly come from the imperfect degaussing of an adjacent mu-metal shield. Additional work was done on the cryogenic pumping system, in particular on the control of the gate valve isolating the turbo pump.

Influence of Substrates on the Nucleation of Phototropic Se-Te Nanostructures
Lorenzo X. Van Munoz
Mentors: Nathan S. Lewis and Ethan D. Simonoff

Photoelectrochemically deposited Se-Te films display periodic nanostructures whose pattern can be controlled by the wavelength, polarization, and phase of the illumination source and whose fidelity is influenced by energetics of the Se-Te/substrate junction. We show that the applied deposition potential affects the pattern period and fidelity of lamellar Se-Te nanostructures due to its effect on nucleation density and Se-Te stoichiometry for substrates including p+ Si, n+ Si, Au, and Ti. The nucleation mechanism was studied for Se-Te films grown potentiostatically on each substrate at ambient temperature under nominally uniform, linearly polarized, incoherent, near-IR illumination by depositing charge densities corresponding to 0.1%, 0.5%, 5%, 10%, and 100% of -750 mC/cm^2. Stoichiometric data were collected using energy dispersive X-ray spectroscopy (EDS), while large area images of the Se-Te films were obtained with a scanning-electron microscope (SEM) and their Fourier transforms (FT) were analyzed by peak fitting the frequency spectrum to obtain the nucleation density, pattern period, and fidelity. The films were observed to improve in fidelity and reduce in period at more negative deposition potentials on some substrates. Additionally, we report results for pattern formation from a thin film on other substrates. The importance of nucleation morphology to the main spectral features of these photoactive films is also being explored by artificially inducing nucleation density in stepped potential experiments.

Mechanics of LEONARDO—a Bipedal Quadcopter
Saskia van Nieuwstadt
Mentors: Soon-Jo Chung, Kyunam Kim, Patrick Spieler, and Sorina Lupu

With the ultimate objective of extreme mobility for the robot LEONARDO (LEg ON Aerial Robotic DrOne), this project contributes a mechanical upgrade and analysis of the robot's legs. Energy-efficient mobility for the robot, such as walking, hopping, and running, is being developed. By coordinating the actuation of its propellers and legs, LEONARDO can have versatile maneuverability. A literature survey of existing legged robots provided a background for the leg design. Forward and inverse kinematics models for a parallel mechanism are developed to predict end-effector foot position and hip actuator angles, respectively. The derived equations are coded in Python and will assist in leg positioning during motion. New CAD models for the joints are made, with an emphasis on increased thickness and carbon fiber reinforcement to strengthen the legs. Fabrication includes 3D printing and simple assembly. This work is integrated with other students' simulation and control system for testing and iteration to develop LEONARDO's mobility. Intended results include standing and walking, and in the future more advanced mobility such as walking on a tightrope, jumping hurdles, and walking on extremely rough terrain.

Harvesting Energy on Enceladus
Polina A. Verkhovodova
Mentors: Tim Colonius and Philipe Tosi

NASA's Cassini mission revealed that there are complex organic molecules spraying from hydrothermal vents on the south pole of Saturn's small, icy moon Enceladus. The data suggests that the conditions on Enceladus can sustain life. As such, the exploration and sampling of Enceladus' vents and subsurface ocean is likely to be a robotic mission in the future. One of the criteria that the robot has to satisfy is its power requirement. One solution is to harvest energy from the mechanical flow of the hydrothermal vents using technologies such as turbines or a piezoelectric flow energy harvester. This project performs a systems-level engineering analysis to determine whether turbines or the piezoelectric flow energy harvester will satisfy the power requirement for the robot and can survive in the conditions of the hydrothermal vents and subsurface ocean on Enceladus.

Motion Simulation of a Bipedal Robot With Propellers
Yasmin Veys
Mentors: Soon-Jo Chung and Kyunam Kim

LEONARDO (Leg ON Aerial Robotic DrOne) is an autonomous bipedal robot with propellers mounted to its torso. The propellers help the robot maintain balance as it walks and act as a failsafe in case it falls. LEO's walking and flight capabilities will hopefully allow it to traverse uneven and dangerous terrain in the future, both on Earth and in space. This project focuses on simulating static walking, one foot in front of the other, while maintaining attitude control using the propellers. We built a 3D model of LEO with accurate inertial properties and leg geometry in MATLAB SimMechanics, a multibody simulation environment. In SimMechanics, we fed angle trajectories which were calculated using inverse kinematics into the hip motors as the nonlinear attitude control for the propellers ran in parallel. After achieving feasible results in simulation and ensuring that LEO could walk within the constraints of the system, we started performing onboard tests to validate our simulation findings. Future work includes iterating on the trajectories and tuning the parameters for the attitude control.

Condensation and Formation of Ice on Planets as a Consequence of Gravity
Maria Vincent
Mentor: David J. Stevenson

The planets in the Solar System formed from accretion of planetesimals and other particles that condensed out of the solar nebula. The condensation can be influenced by the enhancement of the gas pressure near a forming planetary embryo because of its gravity. Thus, the condensation of a particular ice depends not just on distance from the Sun but also on the presence of an embryo. This phenomenon of gravitationally assisted condensation occurs when there is a large enhancement of surface pressure over nebula pressure and a small enhancement of surface temperature over nebular temperature. We can consider an isothermal state, the surface and nebular temperatures being nearly equal. The accretion of an ice shell around the planetary embryo depends on the gravitational energy of these self-gravitating bodies as well as the release of latent heat, both of which affect the surface temperature. For instance, for an embryo of radius 887 km at T = 160K, an ice shell of water is accreted at a rate of 3.23×10^{14} kg/yr. Additionally, as the size of the body increases over time, its surface temperature changes. The accretion rate determines the significance of this phenomenon in condensing different volatiles onto the embryo.

Lightweight Neural Net Implementation for Onboard Control on Small Drone
Anya Vinogradsky
Mentors: Soon-Jo Chung, Michael O'Connell, and Guanya Shi

Ground effect, resulting in aerodynamic lift and drag forces, is known to present a challenge when landing autonomous craft. Prior research to compensate for the effect relied on steady-flow conditions which are rarely seen in practice. Last fall, the Aerospace Robotics and Control Lab proposed a controller called "Neural-Lander" that improved on control performance during landing of a large quadcopter under unknown dynamics. Smaller and lighter drones are more susceptible to near-surface conditions. We implemented the "Neural-Lander" controller on the open-source Bitcraze Crazyflie 2.X Quadrotor, a smaller and lighter drone more susceptible to near-surface disturbances. To minimize latency, we implemented the neural network in the C programming language and ran it directly on the drone's computer. We created a network generator that takes pre-trained weights and biases as inputs and allows for experimentation with different network sizes and activation functions. We expect that the network will improve the control performance of the Crazyflie drone.

Non-Monotonic Decision Making Under Ambiguity via Interval Preferences
Jamie Vinson
Mentor: Luciano Pomatto

A standing question in the theory of decision making is how to act in situations where choices have large uncertainty, such as complex public policy decisions or individuals making difficult everyday choices. One natural principle is to only prefer a choice *f* to a choice *g* if the worst-case scenario for *f* is better than the best-case scenario for *g*. This project normatively examines the underpinnings of this principle by providing sufficient and necessary conditions to ensure a decision maker utilizes the aforementioned criterion. In doing so, we create a novel non-monotonic preference structure with axioms that do not require full knowledge of the outcomes of each act in all situations, and which are viable for decision making under empirical evidence collection. We also find that in the natural case of this preference, the set of situations considered between the two compared acts are unequal. We connect this to standard notions of *loss aversion*.

Safe-Mapping Environments for Drones: A Reinforcement Learning Approach
Abhijeet Vyas
Mentors: Anima Anandkumar and Anqi Liu

Reinforcement Learning (RL) is a paradigm of machine learning which is semi-supervised in nature, i.e. the agent only gets a reward based on the actions it takes but is not trained on the actions themselves. Based on the design of the reward function the RL agent the agent can be trained to accomplish a variety of goals. In this project our agent, physically a drone, is presented with the task of classifying the coordinates of the environment it is in, as safe or unsafe to land. The agent only has access to the ground truth label of the position it is in via executing a query operation. The agent must choose the next query point to obtain the ground truth label from. Our reward function is designed to reward the agent when the agent improves its safe-unsafe classifier and hence learn a policy to decide which point to query next.

Autonomous Docking With Surface Vehicles
James D. Walker
Mentors: Richard Murray and Alistair Hayden

The mapping of river topography using surface vehicles is a rising area that can provide new information for proving and disproving theories about river flow. Using surface vehicles allows for easier and faster mapping processes; making the vehicle autonomous is the best way to achieve this. In order for the boat to be autonomous, there must be a process for it to recharge. A lightweight, portable station must be designed to provide the recharging. I designed an inexpensive, easy to transport, and effective station that can be seen by LiDAR as well as recharge the dock without human intervention. With this ability, the autonomous surface vehicle would be able to function continuously for an extended period of time.

Applying Flow-Based Generative Models to Protein Engineering
Sophie J. Walton
Mentors: Po-Ssu Huang, Niles Pierce, and Namrata Anand

To have full control over the structure and function of engineered proteins it is desirable to be able to design proteins *de novo.* Current computational methods for *de novo* design are slow, based on heuristics, and require human expertise. We seek to apply machine learning techniques to generate viable protein fragments quickly and easily. More specifically, we are adapting a flow-based generative model to generate protein structures encoded as pairwise distances between alpha-carbons on the protein backbone. Not only is the flow model able to generate realistic samples, we can compute the exact likelihood of protein structures under our model and perform exact latent variable inference. These features will give use greater control of the characteristics of proteins we wish to generate.

Hyperfiniteness of Countable Borel Equivalence Relations
Allison Wang
Mentor: Aristotelis Panagiotopoulos

For many countable group actions, it is an open problem to determine whether the orbit equivalence relation of the group action is hyperfinite. Even for actions for which the answer is known, such as the shift action of the free group with two generators, many proofs rely on measure theory. A proof that does not require measure theory might be applicable to determining hyperfiniteness of other countable group actions. We discuss approaches to finding such a proof.

Deep Robust Learning With Simultaneously Trained Classifier and Density Ratio
Haoxuan Wang
Mentors: Anima Anandkumar and Anqi Liu

Reinforcement Learning (RL) is a paradigm of machine learning which is semi-supervised in nature, i.e. the agent only gets a reward based on the actions it takes but is not trained on the actions themselves. Based on the design of the reward function the RL agent the agent can be trained to accomplish a variety of goals. In this project our agent, physically a drone, is presented with the task of classifying the coordinates of the environment it is in, as safe or unsafe to land. The agent only has access to the ground truth label of the position it is in via executing a query operation. The agent must choose the next query point to obtain the ground truth label from. Our reward function is designed to reward the agent when the agent improves its safe-unsafe classifier and hence learn a policy to decide which point to query next.

Multimodal Classification Cascade With Dynamic Routing
Shuxian Wang
Mentor: Mason McGill

For systems performing visual classification, both observations (obtained from sensors) and computation (deriving meaning from observations) may be expensive. We propose a method such that, given an array of sensory and computational modules with known activation costs, and a resource budget, we can construct a cascaded artificial neural network optimized to perform classification within the budget. This way, subnetworks can learn to specialize, and more difficult classification problems can use a greater share of the computational resources. Modules are activated over the course of inference following a policy learned jointly with the network's other parameters. Our networks are benchmarked against comparable non-cascaded networks on multi-sensor tasks synthesized from small image datasets like CIFAR-10.

Thin Film Deposition of Vertical Graphene for Photovoltaic Devices
Stella Wang
Mentors: Nai-Chang Yeh, Deepan Kishore Kumar, and Jacob D. Bagley

Graphene has the potential to be the active layer in solar cells because it has been shown to have good visible light absorption and high electron mobility for a single layer. However, single layer graphene absorbs only about 2.3% of the incident visible light; this absorption can be engineered to nearly 99.99% absorption by growing vertical graphene nanostripes using a plasma enhanced chemical vapor deposition (PECVD) process with a benzene based precursor. The design and testing of a graphene photovoltaic device is predicated on having a reliable method for depositing uniform thin films of exfoliated vertical graphene flakes. This project explores methods for exfoliation and deposition of graphene onto devices using techniques like spray coating and spin coating. We also explore the effect of varying thicknesses on absorption and carrier lifetimes in graphene samples using time resolved photoluminescence (TRPL). These findings serve as a basis for the design and assembly of future devices using pristine vertically grown graphene capable of broad solar spectrum sensitivity and low cost, flexible solar cells.

The Cellular Logic of Mammalian Central Thirst Sensory System
Tongtong Wang
Mentors: Yuki Oka and Allan Hermann-Pool

Maintaining water balance is essential for all animals. In mammals, two brain structures – subfornical organ (SFO) and vascular organ of the lamina terminalis (OVLT) – are responsible for converting circulating physiological need signals into coordinated behavioral responses. The cellular logic for this process however is poorly undertood. Here, we used a combination of behavioral, immunohistochemical and single-cell RNA-sequencing (scRNA-Seq) based approaches to characterize how distinct cell types in SFO and OVLT coordinate adaptive behavioral responses to different internal fluid states. We found that mice react differently to distinct thirst states – loss of body fluid (hypovolemia) leads to indiscriminate intake for both pure water as well as high-osmolarity solutions, while increase in internal osmolarity (hypernatremia) leads to selective preference for water. Results from scRNA-seq analysis revealed 12 and 13 major cell types as well as 7 and 8 neuron types each in these two structures respectively. Importantly, we found that hypovolemia and hypernatremia engage separate and non-overlapping neural populations in SFO and OVLT. These data suggest that mammals have at least two thirst pathways – water thirst and electrolyte thirst, which are detected by dedicated cellular populations in SFO and OVLT. These findings warrant follow-up studies validating the functional role of these neural populations in driving specific thirst behaviors.

Assembly of Synthetic Bacterial Chimeras Through Gene-infered Genome Sequence Assembly Windows (GiGSAW)
Megan Wang
Mentor: Kaihang Wang

The creation of synthetic genomes has been a pursuit limited by the transfer and integration of large segments of DNA (≥500kb). To overcome this, our group previously generated technologies such as **REXER** - an approach that selectively enables the iterative insertion of large (≥100kb) DNA fragments - and **Fission-Fussion**, a technique driving the splitting and transfer of genomic DNA between bacteria. Here we leveraged single gene knockout and transposon mutagenesis studies to identify **Gene-infered Genome Sequence Assembly Windows (GiGSAW)** that would allow us to generate chimeras by interchanging large genomic regions, equivalent in the context of essentiality, between different species. We set out to attempt GiGSAW by targeting lossless essential gene clusters of different lengths in two species of bacteria: *Escheria coli* and *Shigella flexneri.* GiGSAW requires two steps: (i) the splitting or "fission" of a genome into two discrete replicating fragments, and (ii) the conjugation, selection, and integration of an equivalent donor fragment. Currently our group has successfully split genomes into discrete genome fragments, and efforts are on the way to undergo conjugation and integration of said fragments. Completion of this project would yield a bacterial chimera in the true sense of greek mythology - synthetic life crossing the boundaries between species.

Hybrid Neutral Atom and Superconducting Qubits
Daniel Wendt
Mentors: Mark Saffman and Manuel Endres

A combination of neutral atom and superconducting qubit architecture would combine the benefits of the long coherence time and scalability of neutral atom qubits with the high speed and fidelity of superconducting qubits. To achieve a hybridization of these technologies, we aim to couple a single neutral atom qubit to a superconducting resonator. In order to do this, we will trap cesium atoms and excite a single trapped atom to high electronic energy levels (Rydberg states). We set up and prepared lasers for atom trapping and Rydberg excitation of a trapped cesium atom, selecting the necessary laser frequency for the desired electronic transition and performing alignments and modifications to optical setups. A camera was used to monitor atom traps with the goal of performing Rydberg excitations on single trapped atoms.

Generation of Arbitrary Laser Tweezer Patterns Using Spatial Light Modulator
Ryan White
Mentors: Manuel Endres and Ivaylo Madjarov

In the pursuit of quantum computing and precise measurement, there has been significant interest among physicists in creating highly uniform arrays of trapped atoms. One method of generating laser tweezers for trapping atoms in such arrays uses a device called a spatial light modulator (SLM), which imparts a phase difference on many individual segments of an incident laser, resulting in a new intensity pattern after the beam is focused through a lens. However, the selection of what phase pattern to use is highly nontrivial, and thus requires algorithmic approximations. Using a modified version of the Gerchberg-Saxton algorithm, we demonstrate successful generation of highly uniform arbitrary arrays of laser tweezers using an SLM. We also begin work on trying to use an SLM to move tweezers at will, which requires additional considerations to make sure that the tweezer intensities stay level, and no additional false tweezers are produced. Initial results seem to suggest that an SLM is very good at generating stationary arrays, but may not be the best choice for active rearrangement.

Investigating the Mechanism of Response to Magnetic Fields in Flatworms
Remington W. Wichterman
Mentors: Joseph Lynn Kirschvink and Daw-An Wu

Magnetoreception refers to the ability of organisms to detect the earth's magnetic field, which they use to orient themselves to the cardinal directions. Recently, however, professors Joe Kirschvink and Shin Shimojo at Caltech have shown that magnetic fields produce a consistent, measurable response in humans. Understanding the mechanisms of this response is an important first step in understanding its impact on human health. Recent unpublished results presented by Hervé Cadiou at the 10th RIN Conference on Animal Navigation indicate that the planarian *D. dorotocephala* has a magnetotactic response; we suspect that the genes involved are homologous to those in humans, making the planarians a promising model to work with. We have attempted primarily to replicate Dr. Cadiou's results, with the larger goal of identifying the specific genes involved in magnetoreception. However, we have run into technical difficulties adapting the Kirschvink lab's human-sized Faraday cage and Merritt coil apparatus to work with the smaller planarians, causing delays. The project is ongoing.

Medieval Mystics and Female Authorship in the Middle Ages: An Examination of the First Autobiography in the English Language
Amy Windham
Mentor: Jennifer Jahner

The concept of authorship was only just emerging in the Middle Ages and was structured entirely around the notion of a male author. This project explores the unique challenges women in the Middle Ages faced when they sought to publicize their spiritual visions in manuscript form. Through a close study of *The Book of Margery Kempe*, which having been transcribed in 1433 is considered the first autobiography written in the English language, we have explored the societal role of the medieval mystic and the degree to which these surviving documents have influenced the manner in which we interact with literature today. Kempe herself relied on a scribe to document her experiences, providing insight into the differences in language and audience based on the socioeconomic standing of the mystic in question. In this vein, we examined the religious texts that Kempe cites as having been influential to her, such as *The Revelations of St. Birgitta of Sweden*, which St. Birgitta originally wrote herself in her native Swedish. By mapping the intricacies of female authorship in the Middle Ages, we can trace the evolution both of our language and of the concept of authorship that we hold today.

Development of a Palladium-Catalyzed C3-Selective Arylation of Isoquinoline *N*-Oxides
Jonathan Wong
Mentors: Brian M. Stoltz and Fa Ngamnithiporn

3-aryl isoquinolines are a prevalent structural motif in pharmaceuticals and natural products. Usually, they are accessed using activating groups or the multistep functionalization of arenes with subsequent annulation. With this project, our goal is to access this motif through a direct carbon-hydrogen bond activation of an isoquinoline *N*-oxide by way of a Fagnou coupling reaction. Although Fagnou and coworkers have optimized to favor the more sterically hindered C1 position, we seek to invert this selectivity via the alteration of parameters including experimental setup, catalyst loadings, ligands, bases, temperatures, electrophiles, and additives. Quantum mechanical computational methods have also been employed to quantify the properties of these parameters and allow us to fully understand the factors governing this selectivity.

Directed Evolution of Bacteria-Derived Gas Nanostructures as Acoustic Reporter Genes
Katie Wong
Mentors: Mikhail Shapiro and Rob Hurt

A major goal in the field of biological imaging is to noninvasively visualize the function of biological specimens inside opaque samples, including live animals. Ultrasound serves this purpose well because it can penetrate through several centimeters of tissue, and still retain a high spatial resolution. Gas vesicles (GVs)—intracellular gas-filled proteinaceous structures encoded by 8-14 genes that function as flotation devices in many bacteria—can act as genetically encoded ultrasound contrast agents that link ultrasound signal with molecular and cellular functions. Using directed evolution and high-throughput screening, we sought to improve the GV phenotypes of greatest utility for ultrasound imaging and *in vivo* expression: linear and nonlinear contrast, collapse pressure, thermostability, and solubility. After cloning and expressing libraries of GV mutants and homologs in *E. coli*, we used an automated ultrasound screening technique to scan the bacterial colonies and analyzed the data with custom scripts to identify constructs with improved ultrasound contrast. Through this ultrasound screening, we discovered GV variants with >150x higher GV expression and ultrasound contrast than our starting points, and are currently using these mutants for further evolution experiments and integrating them into systems that will allow us to use them for *in vivo* imaging and therapy.

Simulating Molecular Diffusion in a Cryogenically Cooled Buffer Gas Beam
Gabriel Woolls
Mentor: Nick Hutzler

The buffer gas beam is an experimental technique whereby samples of hot molecules thermalize with a cryogenically cooled inert gas and exit into a vacuum chamber as a beam of cold and slow molecules, to be probed spectroscopically or otherwise. Typical applications of the technique employ buffer gas densities too low to be effectively modeled with continuum fluid dynamics, yet too high to allow for individual-particle gas kinetics. This “intermediate” density regime generically can be simulated with Direct-Simulation Monte Carlo (DSMC) statistical methods, but the large discrepancy in densities between the molecular species of interest and the buffer gas the species diffuses through limits the applicability of DSMC algorithms to this particular diffusion problem. An original algorithm developed in the Hutzler lab has shown promise in tackling the issue by splitting the simulation into two distinct stages; a DSMC flow field is generated for the buffer gas alone, and the diffusion of the species through the gas is then simulated one molecule at a time. Here, this novel simulation technique is refined and expanded upon, and molecular beams are simulated employing a variety of buffer gas cell properties and geometries, including a two-stage slowing cell as well as a *de Laval* nozzle. Early results show that the simulations reproduce features of the molecular beam consistent with observations under various implementations of the buffer gas design, suggesting that the new algorithm has captured important aspects of physics in the buffer gas cell, and that with further work the method may prove to be a useful guide for optimizing and characterizing the buffer gas beam.

Statistical Distribution of Pitch Angle Scattering Events in Whistler Waves
Mackenzie R. Wooten
Mentors: Paul M. Bellan and Young Dae Yoon

Circularly polarized electromagnetic waves interact with charged particles in many contexts in plasma physics, including magnetospheric whistler waves, magnetic reconnection, and particle accelerators. This interaction changes the particle's energy and its pitch angle, the angle between the particle's velocity vector and the background magnetic field of the system. Magnetospheric whistler waves in particular can cause a large pitch angle deflection of energetic electrons, scattering them into the ionosphere. Previously, an analytical study showed that perfectly coherent circularly polarized waves can scatter energetic particles and formulated constraints on the initial conditions of a particle that experiences a large increase in pitch angle. The scattering depends only on initial conditions, so the statistical distribution of initial conditions informs the distribution of scattering events. In this study, a Maxwell-Jüttner distribution of initial particle velocity was transformed to a distribution of pitch angle scattering events. Energetic electrons in whistler wave modes were simulated using the particle in cell code, Smilei, which solves Maxwell's equations for the system on a three-dimensional grid using a finite difference time domain method. The statistical distribution of large pitch angle scattering events was then studied using the simulation.

Local Kalman Consensus Filter
Asta Wu
Mentors: Soon-Jo Chung and Kai Matsuka

Multi-robot localization algorithms for robotic swarms should scale well with the total number of robots. To achieve this, the proposed Local Kalman Consensus Filter (LKCF) allows individual agents to carry only a subset of the full dynamical system state vector – unlike existing consensus-based algorithms. Because no robot is responsible for the full state vector, the algorithm is scalable with total state size. The LKCF algorithm is first tested through simulation. Then, LKCF is applied in Caltech's Multi-Spacecraft Testbed for Autonomy Research (M-STAR) in a multi-robot localization problem. The experiment validates the convergence and effectiveness of the algorithm.

Electron Fluid-Like Dynamics in Graphene Sheet
David Wu
Mentors: Nuno Loureiro and Paul Bellan

The recent investigation of vorticity being a macroscopic signature for quantum-critical viscous electron flow has shed light on the connection between electron transport in strongly correlated systems and macroscopic fluid mechanics phenomena. In this work, we examine the validity of the fluid-like description of electrons in graphene sheet by solving the corresponding hydrodynamic and plasma equations numerically. Using both explicit and implicit FTCS schemes, we perform code verifications by studying the nonlinear evolution to turbulence under the Kelvin-Helmholtz instability in graphene. In the presence of turbulence in viscous electron flow, we compare our results with previous hypotheses predicting the behavior of vorticity of a shear flow in viscous electron transport in strongly correlated systems.

Transport Measurements of PECVD-Grown Bilayer Graphene
Tongyao Wu
Mentors: Nai-Chang Yeh and Jiaqing Wang

Bilayer graphene with twisted-angle between two layers presents novel quantum effects, like superconductivity. We are using a plasma enhanced chemical vapor deposition technique to grow bilayer graphenes with different twisted angles. By this mean, we can study the dependency of electronic properties on twisted angles in the future. Hopefully we are able to build a graphene database of twisted angles. Using finite element method, the simulation of electromagnetic field and plasma distribution is instructive on the ongoing and future investigations.

Investigating Two Modified Gravity Theories Using Near-NHEK Basis Functions
Daining Xiao
Mentors: Yanbei Chen and Baoyi Chen

The near-horizon near-extremal Kerr (near-NHEK) spacetime enjoys an enhanced isometry group SL(2,R) x U(1) compared to the general Kerr metric, which inspires the study on its correspondence with a two-dimensional non-chiral conformal field theory. Using the highest-weight methods, we obtain specific scalar/vector/tensor basis functions adapted to the symmetry and achieve separation of variables under this formalism for scalar wave equations, Einstein-Maxwell systems and gravitational metric perturbation equations, leaving only a system of (possibly coupled) ordinary differential equations with respect to the polar angle θ to solve. As an application of this formalism, properties of two modified gravity theories inspired by string theory, the Einstein-dilaton-Gauss-Bonnet (EdGB) and dynamical Chern-Simons (dCS), are investigated in depth in the corresponding weakdecoupling limits. Also, we provide a better understanding of the boundary conditions for the basis functions in (near-) NHEK regarding the gravitational wave forms.

Adjoint Optimization for Inverse Design of Angular Selective Devices
Junyu Xie
Mentors: Andrei Faraon and Gregory Roberts

Angular selective devices have tailored outputs for different angles of plane wave incidence. This has widespread applications in solar cells, angular sensitive pixels, etc. The aim of this project is to implement angular selective functionalities via inverse design using the adjoint variable method. Specifically, a corresponding mode-matching figure of merit (FoM) related to the desired functionality is determined, which turns the design problem into the optimization of a FoM. During optimization, the device permittivity is evolved iteratively based on the gradient of the FoM, which can be obtained from two simulations within each iteration. The first one gives field profile under forward propagating angled wave, while the desired plane wave mode is back propagated in the second simulation. A finite-difference-time-domain (FDTD) solver was used for simulations, which simulates a broadband device response allowing for a final design that works over a wide frequency band.

Application of Molecular-Orbital-Based Machine Learning (MOB-ML) in Predicting Three-Body Dispersion
Yuanzhe Xie
Mentors: Thomas F. Miller and Lixue Cheng

The dispersion effect is a type of weak yet crucial intermolecular interaction, especially prevalent among the non-polar molecular clusters. To capture the dispersion effect, molecular orbital based machine learning method (MOB-ML), which has established validity and transferability with the previous work, has been applied to predict the post Hartree-Fock correlation energy of the acetylene clusters. Based on the reference data achieved by coupled cluster with singles, doubles and perturbative triples theory, MOB-ML successfully can predict the correlation energy of acetylene monomer, dimer, and trimer clusters to the level of accuracy which yields mean absolute error within 0.3 mHartree. The three-body dispersion can be expressed with the differences between correlation energy of the monomer, dimer and trimer clusters. Since the three-body dispersion effect is observed to possess 10^{-2} mHartree order of magnitude, higher level of accuracy of MOB-ML is required to predict it, which constitutes the future direction of the project.

Conditional Guide RNA for Transcriptional Activation Using CRISPR/Cas9 Function in Bacteria
Yuhang Xie
Mentor: Niles Pierce and Jining Huang

CRISPR/Cas9 is a versatile bioengineering tool that can be programmed to edit, silence or activate genes at precise locations by using guide RNA (gRNA) complementary to the target sequence. Recently we created novel programmable conditional guide RNAs (cgRNAs), which can be switched 'off' or 'on' by expressing a short RNA trigger that hybridizes to the cgRNA. Thus, in addition to programming the target of regulation via the guide RNA targeting domain, cgRNAs can also modulate the scope of regulation via the trigger. However, cgRNAs have only been validated with silencing dCas9 (catalytically dead Cas9) in bacteria. In order to increase the repertoire of functionalities that cgRNAs bring to synthetic biology, additional modes of regulation, such as gene activation, should be explored. In this study, we modified cgRNAs to recruit a transcriptional activator via a MS2 loop. Two different cgRNA systems (splinted switch and terminator switch) were designed and two orthogonal cgRNAs were designed and investigated for each. GFP fluorescence tested a median ~6-fold change between absence (On) and presence of trigger (Off) in both splinted switch and terminator switch. Crosstalk for both systems is negligible. Conditional activation expands the functionality and versatility of cgRNAs in bacteria, which can serve as powerful tools for novel technologies in many fields such as synthetic biology.

Investigating Particle Tracks With Graph Neural Networks
Elaine Yang
Mentors: Maria Spiropulu and Jean-Roch Vlimant

The Large Hadron Collider (LHC) is where particles are accelerated and collided, breaking apart into smaller particles that travel through multiple layers of sensors inside the collider. The coordinates of collision are recorded on each sensor, and what is left is an array of points, or hits. Based on this hits, High Energy Physics (HEP) researchers can regenerate the tracks of the particles using various algorithms. In this project, I am focusing on two algorithms in particular: the classic Kalman filter algorithm which works as a baseline algorithm, and the newer graph neural network (GNN) method that uses machine learning concepts to draw the tracks. Through this summer research project, I have investigated and experimented with both algorithms. In this paper, I will describe what I learned about the tracking problem and rough comparisons of purity and efficiency between the GNN and the classic Kalman filter algorithm.

Circuits for Synthetic Pattern Formation
Liang Yao
Mentors: Michael Elowitz and Sheng Wang

Abstract withheld from publication at mentor's request.

Engineering a Permanent Thermoswitch for Remote-Controlled Microbial Immunotherapy
Michael S. Yao
Mentors: Mikhail Shapiro and Mohamad Abedi

Abstract withheld from publication at mentor's request.

Measurement of Nonlinear Properties of Metamaterial-Shell Particles in the Infrared Spectrum
Timothy Yao
Mentors: Alireza Marandi and Joong Hwan Bahng

Metamaterial-shell particles are colloidal particles with a metamaterial shell. The metamaterial-shell particles of interest, nicknamed hedgehog particles, consist of a spherical SiO_2 core with a metamaterial shell of ZnO nanowires. These hedgehog particles exhibit interesting optical properties that their individual counterparts do not possess. This in combination with their mass-producibility and flexibility of engineering makes them particularly valuable for such wide range of applications as biomedical devices and solar cells. We aimed to experimentally characterize the nonlinear properties of the hedgehog particles, particularly their forwardscattering and backscattering second harmonic generation (SHG) conversion efficiencies. To do this, we constructed a two-photon microscope capable of exciting a single hedgehog particle – each with an average diameter of 2.2 µm – with an excitation wavelength of 1550 nm. The normalized SHG conversion efficiency for backscattered power was found to be $\eta_{Refl,EXP} = 4.6 \times 10^{-11}\ W^{-1}$, closely matching a simulated value of $\eta_{Refl,\ SIM} = 1.41 \times 10^{-11}\ W^{-1}$. Further work is being performed to conclude the backscattering results as well as accurately acquire forwardscattering data. The specific design and relative cheap cost of our constructed microscope lends itself well to continued characterization of the hedgehog particles in both the nonlinear and linear regimes.

Reconstructing Galactic Spectra With Machine Learning
Dennis Yatunin
Mentor: Peter L. Capak

Although the principle characteristics of galaxies can be most easily determined from spectroscopic measurements, the vast majority of data on galaxies is in the form of photometric measurements because of their relatively low cost. A spectroscopic measurement contains high-resolution information about the light emitted by a galaxy, specifying differences in flux density between wavelengths roughly 1 Å apart, while a photometric measurement contains low-resolution information, specifying the average flux densities through filters roughly 1000 Å wide. If a spectrum is properly calibrated, it can be integrated against the transmission profiles of several filters to obtain the corresponding photometry, but there is no obvious way to extract a spectrum from photometry. In this project, we organize a large set of spectroscopic and photometric data from galaxies in the COSMOS field and use it to train a neural network to extract limited spectral information from photometry. Specifically, we train the neural network to transform photometric measurements into low-quality spectra, with wavelengths roughly 100 Å apart. If a larger set of training data were assembled, this work could potentially be improved to result in higher quality outputs from the neural network.

Particle Charging Efficiency With Varying Oxidants in Atmospheric Chemistry Experiments to Generate Organic Aerosols
Angelina Ye
Mentors: John Seinfeld and Yuanlong Huang

Atmospheric particles, also known as aerosols, significantly affect both the climate and human health. Most of these particles are secondary organic aerosols (SOA) that are formed via secondary processes. Particle size distribution is a key measurement for estimating the SOA yields of different gaseous precursors and investigating the evolution of aerosols. To evaluate particle size distribution, instruments measure the electrical mobility distribution in three steps: charging, separating, and counting the particles with a condensation particle counter (CPC). The electrical mobility distribution is then converted to particle size distribution. This experiment focuses on the charging step and seeks to observe the effect of the presence of the most common oxidants, e.g., O_3, H_2O_2, NO/NO_2. The presence of these oxidants are predicted to change the ion propagation and ion mobility, affecting the ratio of positively and negatively charged particles produced and deviating from the current ion-particle interaction model prediction.

The Effect of Regulated Neuronal Perturbations on Zebra Finch Singing Behavior
Jessica Z. Ye
Mentors: Carlos Lois and Walter Gonzalez

The zebra finch song is one of nature's most repetitive and stable phenomena. We aim to study the effects of real-time neuronal perturbation in HVC on finch song degradation and recovery. We use both electrodes and optogenetics to perturb HVC. We train artificial neural networks to recognize any part of the zebra finch song with latencies between 30- 160 ms. These neural nets fire with 60-90% accuracy and low rate of false positives (<5%). In order to determine the timing and length of our perturbations, we examine the distribution of bird singing over the course of the day, as well as perform temporal analysis of birdsong in regard to "motif length" and "motifs per bout". We pursue two modes of experimental analysis: (1) characterization of song degradation through spectrogram analysis and (2) the use of miniscopes to visualize neuronal activity during song degradation.

Developing Optimized Gene Circuits for Gas Vesicle Production in Mammalian Cells
Mei Yi You
Mentors: Mikhail Shapiro and Arash Farhadi

Studying cellular function inside intact organisms needs tools that can visualize cellular location and function deep in tissues. Ultrasound can penetrate deep within the body with high spatial-temporal resolution, but it lacks genetically encoded molecular reporters comparable to green fluorescent proteins. To address this, a synthetic mammalian genetic program, called mammalian acoustic reporter genes (mARGs), was recently developed that encodes the expression gas vesicles (GVs) in mammalian cells. Our research focuses on optimizing mARGs such that it is more compact and allows self-sufficient expression of gas vesicles by any mammalian cell type. This is an important step for the viral delivery of mARGs to primary cells such as neurons and immune cells. To measure GV expression yield and their acoustic phenotype inside cells for our circuit constructs, we have developed the protocol for using ultrasound imaging as the readout after transiently transfecting HEK 293T cells with mARG variants. Thus far, we have been able to reduce the number of gene cassettes from three to two. Our work on GV gene circuit optimization is ongoing.

Investigation of the Rheological Transition of Multiphase Flows Subjected to Shear
Arthur B. Young
Mentors: Melany Hunt and Han-Hsin Lin

The properties of multiphase flows are challenging to model generally, and are typically applicable in a limited range of conditions. For example, the Krieger-Dougherty model of effective viscosity is commonly applied to study flows of neutrally buoyant suspensions. In this work, a coaxial rheometer is used to measure the shear stress of an air-fluidized bed of glass beads and glycerin-water suspensions of polystyrene spheres over a range of shear rates and solid fractions. Measurements were compared for numerous fluid-particle mixtures and nondimensionalized using the Krieger-Dougherty model. The results showed that at low shear rates, particulate flows possess high magnitude but rapidly decreasing shear stress, particularly for solutions with settled or floating particles at rest. As shear rate increases, the measured shear stress for all particulate solutions collapse to the same, gradually increasing shear stress profile. This finding supports a hypothesis that the rheology of particulate flows subjected to increasing shear strain transitions from a particle-interaction dominant regime to a fluid-dynamics dominant regime, extending the application of solid fraction based effective viscosity models such as the Krieger-Dougherty to other particulate low Reynolds number flows.

Caliban: Deploying Deep Learning Tools for Cell Tracking and Segmentation
Jannie Yu
Mentors: David Van Valen and Erick Moen

Deciphering the mechanisms of cell motility and morphology is essential to understanding a variety of biological processes, including tumorigenesis, signaling dynamics, and cell fates in embryonic development. Due to the accumulating wealth of data, researchers look increasingly towards deep learning approaches to automate object segmentation and tracking in live-cell images. However, this necessitates efficient annotation tools to assemble and curate high-quality tracking data. To solve this, a desktop software program called Caliban was built to track cells across time-lapse and 3D-spatial frames. Caliban can make predictions on 3D-spatial relationships, as well as allow users to make manual operations on lineage information. For portable deployment and testing, the software and its dependencies were packaged to run inside a Docker container. Furthermore, a pipeline was built to allow for crowdsourced annotations using Caliban from SageMaker Ground Truth and Amazon Mechanical Turk. To make Caliban available for workers, a web application version of Caliban was created using the Python Flask framework and integrated with AWS tools like S3 and Lambda. This application is currently being served on AWS Elastic Beanstalk. These tools will soon be deployed to the scientific community to streamline the process of building large datasets for deep learning models.

Photoinduced, Copper-Catalyzed, Enantioconvergent C-N Bond Formation to Synthesize Aliphatic α-Amino Boronates
Kevin Yu
Mentors: Gregory C. Fu and Suzanne Batiste

Aliphatic α-aminoboronic acids are 〈-amino acid derivatives that are present in pharmaceuticals used to treat conditions ranging from diabetes to cancer. Free boronic acids are often unstable, thus α-aminoboronic acids are commonly handled in their protected ɑ-aminoboronate ester form. However, aliphatic α-aminoboronates are not commercially available, and there are few catalytic enantioselective methods for their synthesis. Recent discoveries in the Fu and Peters labs have revealed that primary carbamates are effective nitrogen nucleophiles in photoinduced copper-catalyzed cross-couplings and are able to undergo copper-mediated C_{sp3}-N bond formation at room temperature with unactivated secondary alkyl halides. As carbamates are among the most widely used protecting groups for amines, further investigation of their efficacy as nitrogen nucleophiles in enantioconvergent, photoinduced, copper-catalyzed C-N bond formation is of particular interest. Using a bisphosphine ligand as a photosensitizer and a chiral diamine ligand to mediate enantioselective bond formation, a variety of carbamates were tested in couplings with an α-chloroboronate electrophile to optimize the enantiomeric excess (ee) and yield of α-aminoboronate products. Preliminary studies have indicated formation of the desired coupling product in moderate yield and moderate %ee. We intend to continue optimization through the examination of reaction parameters as chiral ligands, temperature, and solvent.

On *p*-part of BSD Formula—Control of Selmer Groups
Qiyao Yu
Mentor: Ashay Burungale

The Birch-Swinnerton-Dyer (BSD) formula is a conjecture relating arithmetic invariants of an elliptic curve E over a number field K to the behavior of the Hasse-Weil L-function L(E, s) of E at s=1. After the ideas of Iwasawa Theory were extended to elliptic curves in the language of Selmer groups, the *p*-part of BSD formula was studied as one of the consequences of Iwasawa-Greenberg Main Conjectures. One important step of applying Iwasawa Theory is to recover the Selmer group over a number field K from the Selmer group over its Z_p-extension using Control Theorems. In this project, the case of the rational numbers Q is of primary concern. We study Control Theorems without the irreducibility condition on the *p*-torsion points of the elliptic curve imposed in previous results.

Characterizing a Novel Mouse Model for Ddx3x Syndrome
Rona Yu
Mentors: Silvia De Rubeis and Julien Dubois

The syndrome resulting from mutations in the X-linked gene *DDX3X*, DDX3X syndrome, accounts for up to 2% of intellectual disability (ID) in females. Further, many reported female cases have comorbid neurodevelopmental conditions, including autism spectrum disorder (ASD). By using loxP sites to flank exon 2 of the *Ddx3x* gene and excising with Sox2-Cre, we have developed a novel mouse model for DDX3X syndrome with construct validity. Through a standardized longitudinal battery of behavioral tests, we suggest that the heterozygous females with *Ddx3x* haploinsufficiency (*Ddx3x*$^{+/-}$) have developmental delays that are reminiscent of the physical, sensory, and motor phenotype of DDX3X syndrome. Additionally, we have developed an image processing methodology to incorporate automation into the neurodevelopmental trajectory analysis of *Ddx3x*$^{+/-}$ mice. This combination of behavioral and trajectory analysis may help identify the optimal temporal window for therapeutic intervention, and lay the groundwork for assessing pre-clinical feasibility of pharmacological or gene therapy intervention. More generally, because cortical development has been repeatedly implicated in ID and ASD risk, this comprehensive approach may help define aberrations in cortical development that underlie the behavioral and developmental delays of persistent intellectual disability.

Quantum Fully Homomorphic Encryption and Measures of Non-Classicality
Sean S. Yu
Mentors : Thomas Vidick and Andru Gheorghiu

n this research project we aimed to devise a information theoretic Quantum Fully Homomorphic Encryption (ITS-QFHE) scheme in which the communication scales with the stabilizer rank of the magic state $|T\rangle^{\otimes t}$. Stabilizer rank is a measure of non-classicality and is believed to grow exponentially. At the same time, it is believed that polynomially sized ITS-QFHE schemes are impossible. We were able to devise a two round ITS delegated computing scheme in which the size of communication scales with the Clifford rank of the unitary to be delegated. We also were able to relate the Clifford rank of a unitary and the stabilizer rank of related states.

Effect of Photo-Isomerization and Thermal Relaxation on the Orientation of Solid-State Photoactive Molecules
Xinyue Yu
Mentors: Kaushik Bhattacharya and Ruobing Bai

Photoactive polymers such as azobenzene are promising candidates for actuators in the creation of soft robots. When azobenzene is exposed to light of certain wavelengths, it undergoes photo-isomerization, switching from a trans- to a cis-state. After continuous isomerization and thermal relaxation, the molecules will reach thermodynamic equilibrium and orient themselves in the direction orthogonal to the light polarization. When there is no light, the molecules will reach an ordered nematic state if the coupling between them is strong enough compared to thermal fluctuation. This project presents a model that simulates the photo-orientation process, and derives a mean field approximation of the order parameter. We create a 2-dimensional Heisenberg lattice of spins, and use the Metropolis Monte Carlo algorithm to perform importance sampling of the spins. We then compare the order parameter calculated from the simulation with those predicted by the mean field model. These results are expected to help research on photoactive polymers as well as potential actuators for soft robots.

Visual Memory Encoding and Learned Active Querying for Autonomous Mapping Tasks
Albert Zhai
Mentors: Animashree Anandkumar, Kamyar Azizzadenesheli, and Anqi Liu

Spatial mapping tasks, such as determining what locations are safe for a rotary-wing drone to land at, can be accomplished both through interpolation of a spatial pattern and through visual processing. We consider tasks in which an agent needs to move close to a location to determine the value of the property of interest at that location, but visual input can give information about a much greater surrounding area. In order to combine the two levels of information, we propose a new neural network architecture which combines a long-term memory model with a traditional feedforward network. The latent state of the memory model encodes a task-relevant visual memory vector which provides additional input to assist the spatial mapping performed by the feedforward network. We also examine the possibility of using the encoded visual memory to learn an optimal data-collection trajectory through reinforcement. This entails employing a separate reinforcement learning agent to solve the query decision process while observing the visual memory state of the mapper network. We evaluate the performance of the system on a landing area mapping task implemented using the Robot Operating System (ROS) communication framework and the Gazebo simulator.

Automated Cardiac Valve Plane Localization With Convolutional Neural Networks
Cecilia Zhang
Mentors: Albert Hsiao, Kevin Blansit, Naeim Bahrami, and Michael Vanier

Cardiac MRI is a valuable technique for the clinical evaluation of the heart. However, cardiac MRI planning requires the identification of key landmarks that define standardized imaging planes. To help improve the consistency of cardiac MRI acquisition, we developed a 3D convolutional neural network approach to help identify these landmarks, which include the aortic (AV), mitral (MV), and pulmonary (PV) valves and the apex. Heatmap regression was done using U-Net CNNs for localization of heart valves and the apex of the heart. We trained the model using 1.5 and 3 T axial series obtained with HIPAA-compliance and IRB waiver of informed consent that were annotated by radiologists. We split the data so that 80% went towards training data and 20% went to testing data. In order to evaluate the performance of localization of the model, we calculated in-plane accuracy and the distance between slices between the predicted landmark and the annotated ground truth. Preliminary results show that on average the CNN localized the AV within 3.56 ± 2.96 mm, MV within 4.09 ± 3.93 mm, and PV within 5.47 ± 4.18 mm. Due to the good performance of this model, use of CNNs may potentially benefit cardiac MRI planning.

Direct Influence of Hippocampus on Associative Learning
Hanwen Zhang
Mentors: Thanos Siapas and Stijin Cassenaer

As we understand more about individual brain regions, more studies start to focus on the coordination between different regions. The hippocampus, the center of learning and memory, has connections to most parts of neocortex as well as many subcortical regions. Some recent findings revealed that the hippocampus not only receive input from primary sensory cortices but also provide feedback projection to these areas. Little is known about the function of these projections in sensory associative learning. Our project specifically aims to investigate the role of hippocampus to primary auditory cortex projections in auditory associative learning. We hypothesize that activating these projections will accelerate learning, while inhibiting them will impair learning.

Atmospheric Aging of Molecular Products in Surrogates of 〈-Pinene Secondary Organic Aerosol
Isabella Zhang
Mentors: John Seinfeld and Chris Kenseth

Atmospheric aerosol plays a pivotal role in influencing climate, air quality, and health. A significant fraction of atmospheric aerosol (15-80%) consists of secondary organic aerosol (SOA). The oxidation of monoterpenes, emitted from forested regions, is a dominant source of SOA globally. 〈-pinene is the most abundant monoterpene, and the third-most abundant hydrocarbon, emitted to the atmosphere. The mechanisms leading to SOA formation from 〈-pinene have been extensively studied. However, the processes by which α-pinene SOA transforms in the atmosphere (i.e., "ages") remain poorly understood. In this work, we investigate the molecular-level aging mechanisms of α-pinene SOA in order to improve assessment of its environmental and health impacts. We focus on the oxidation of molecular products in α-pinene SOA by OH. We examine six oxidation products of 〈-pinene, previously synthesized in the Seinfeld lab. We will use chromatographic and mass spectrometric techniques to identify the products of the oxidation and elucidate possible mechanisms by which they form. Additionally, we explore how differences in compound functionality (i.e., acid, ketone, alcohol) and size (i.e., monomer or dimer) dictate the rate and product distribution of the heterogeneous oxidation.

Characterization of Chrome-On-Glass Apodizer Test Sample
Manxuan (Rebecca) Zhang
Mentors: Dimitri Mawet, Jacques-Robert Delorme

With most of today's space-based and adaptive optics-equipped ground based telescopes having obscured aperture systems with secondary mirrors held in place by support vanes that diffract starlight, well-designed custom apodized masks are particularly important in helping coronagraphs directly image exoplanets. A test microdot apodizer with 64 different patterns (step functions, gradients, and sinusoids) made of chrome-on-glass was characterized in optical transmission, infrared reflection, and with microscopy. Results in transmission showed that microdot density and transmission were mostly linear except with anomalously high transmittance around 50% density (where the dot pattern is periodic), which is potentially due to surface plasmon effects. Results from reflection potentially reveal anomalously high reflection at low dot density. Results from microscopy revealed the high craftsmanship of the microdots and thus ruled out poor fabrication as an explanation for the anomalies. Knowing these effects and understanding microdot apodization analytically will be helpful in optimizing future apodizer designs. High-dynamic-range imaging in reflection and further interferometer data will be taken to confirm previous results.

Next-Generation Photoaffinity Probes for Target Identification in Live Cells
Tianyi Zhang
Mentor: Alison Ondrus

Abstract withheld from publication at mentor's request.

Optimizing GANs by Competitive Gradient Descent
Hongkai Zheng
Mentor: Anima Anandkumar

The goal of our project is to implement and analyze scalable and efficient Competitive Gradient Descent for GAN optimization. We mainly use double backward and conjugate gradient for implementation. And we give a careful time cost analysis of CGD and introduce three methods to accelerate CGD. 75\% speedup by these accelerating methods proves their effectiveness. We evaluate CGD on simple non-linear GAN and DCGAN, the standard GAN networks nowadays that has millions of parameters. And we compare CGD with Stochastic Gradient Descent(SGD), the most popular optimizer in deep learning, showing the great balance and convergence properties of CGD. Furthermore, we explore how CGD balances the two players in the zero-sum game of GANs and reduces the typical mode collapse problem in GANs. In the following work, we will work on a new variant of CGD that can adapt the learning rates for the parameters, which may reduce the laborious hyper-parameters tuning and help GANs converge faster.

Enzyme-Catalyzed Lactone-Carbene Insertion Into α-Amino C–H Bonds
Andrew Zhou
Mentors: Frances Arnold and Kai Chen

Enzymes stand out as potent biocatalysts in terms of efficiency and selectivity. As opposed to transition metal catalysts that require sophisticated preparation, enzymes can be genetically assembled from renewable sources and are environmentally friendly. Their unique three-dimensional active sites are capable of stabilizing reaction transition states and precisely controlling key intermediates, and thus allow for extremely high stereoselectivity as well as unprecedented efficiency for their catalytic functions. Here we demonstrate an engineered cytochrome P411 platform that can catalyze lactone-carbene insertion into a myriad of substrates bearing primary and/or secondary C–H bonds with high enantiomeric excess and total turnovers. Not only does this system expand the scope of evolved enzymes in C–H functionalization reactions, but it also generates a multitude of pharmaceutically relevant α-amino lactone motifs.

Quantitative Evaluation of Compositional Origins of Ultralow Velocity Zones
Cijin Zhou
Mentors: Jennifer M. Jackson and Vasilije Dobrosavljevic

The Earth's core-mantle boundary region (CMB), called the D'' layer, exhibits highly-variable localized structure and is likely to be chemically heterogeneous. Since the seismic studies have revealed ultralow velocity zones (ULVZs) adjacent to the CMB, the origin of them remains poorly constrained. Increased attention in recent years has been given in particular to the hypotheses of partial melt and iron enrichment in the (Mg,Fe)O solid solution. In order to provide a quantitative evaluation of ULVZ composition hypotheses, we perform an inverse modeling approach that incorporates estimated uncertainties from both seismic observations and mineral physics results to find the best-fit mineral assemblage that best reproduces a seismic observation. We find that the presence of iron-rich (Mg,Fe)O can explain certain classes of ULVZ observations. Our method provides an opportunity to develop a systematic approach evaluating ULVZ composition hypotheses quantitatively by combining existing seismic data with cutting-edge results from mineral physics.

Design and Characterization of Engineered AAV9 Capsids With Surface-Displayed Tags or Protein Domains
Manxuan Zhou
Mentors: Viviana Gradinaru and Xiaozhe Ding

Recombinant Adeno-associated virus (rAAV), a recombinant non-enveloped single-stranded DNA virus, is now a type of prevalently adopted gene delivery vehicle. However, problems such as broad tropism and labor-intensive, time-consuming purification procedures restricted the application of rAAVs in situations where more precise gene delivery or manufacture in higher throughput is required. Presenting specific protein domain or purification tags on rAAV surface could be a potential solution to problems above. The primary goal of this project is to enable rAAV surface display by modifying rAAV capsid protein. Based on structural information and the co-translational protein folding rate predicted with usage of rare codons, AAV9 capsid proteins with modified topologies were designed and further linked to widely-used surface-displayed tags or protein domains. The yield of the modified capsids was investigated by qPCR titration, and the purification efficiency of corresponding tagged or protein-displayed capsids was characterized through affinity purification. This project is expected to test the feasibility of our topology modification strategy that enables surface presentation of purification tags or big protein domains, and to find out the best sequence design with high yield and high tag presentation efficiency as a potential platform for the rational design of rAAV surface display.

Real-Time Imaging System for Automated, Distributed *Chlamydia trachomatis* and *Neisseria gonorrhoeae* Nucleic Acid Amplification Testing
Selina Zhou
Mentors: Erik Jue and Rustem Ismagilor

The Ismagilov Lab has previously developed a point-of-care diagnostic prototype for the detection of *Chlamydia trachomatis* and *Neisseria gonorrhoeae*. This project designed and validated a real-time fluorescence imager to be used in conjunction with the diagnostic device. The imager detects the presence or absence of amplified DNA using a fluorescent dye molecule Syto-9. Imager setup consists of a photoconductive sensor, LED setup, fluorescence filters, and an Arduino microprocessor for signal processing. The advantage of using real-time imaging as compared to end-point imaging is that it should have greater sensitivity and specificity.

Investigating CpG Methylation Dynamics in Relation to Gene Expression
Junqin Zhu
Mentors: Yitong Ma and Michael Elowitz

It is established in mammalian cells that DNA methylation on CpGs plays an important role in gene regulation, but it remains unclear 1) how the dynamic process of methylation occurs, 2) how CpG distribution affects methylation dynamics, and 3) how the spread of methylation leads to gene repression. To address these questions, our lab has developed a synthetic system that allows us to induce methylation with doxycycline (dox) at a site-specific integrated fluorescent reporter (Bintu, et al.). This system allows us to control the timing of methylation events precisely. Based on this system, we analyzed the methylation dynamic profile at the promoter region with a enzymatic based sequencing strategy (Enzymatic Methyl-seq, NEB). Preliminary data show that gene silencing is only determined by the methylation percentage in the promoter, but not the region flanking the promoter. However, the CpG density of the surrounding region does affect the overall gene silencing rate. To further investigate, we are applying our strategy to different cell lines with identical promoter but different CpG densities surrounding it, and we will identify how surrounding CpG distribution influences methylation and gene silencing.

Machine Learning Methods for Event Reconstruction With Liquid Argon Time Projection Chamber Data

Alexander Zlokapa
Mentors: Tanaka Hirohisa and Maria Spiropulu

Neutrino experiments including MicroBooNE, the Short Baseline Near Detector, ICARUS, and the Deep Underground Neutrino Experiment (DUNE) share a liquid-argon time projection chamber (LArTPC) design. Expected similarities in data between such experiments motivates a unified analysis pipeline for event reconstruction in LArTPC detectors. We focus on machine learning techniques for the clustering of 3D space-points corresponding to electromagnetic showers, which are characterized by sparse and fragmented branch-like charge depositions. Besides the data sparsity posing a challenge for typical convolutional neural network methods, showers may overlap or originate from the same vertex, causing difficulties for most traditional clustering algorithms. Hence, we investigate spectral clustering and graph neural networks for shower reconstruction, which are compared to a cone clustering benchmark that is proposed and implemented. To evaluate performance beyond standard clustering metrics in the machine learning literature, we recover the neutral pion mass from simulated Monte Carlo data. A submanifold sparse convolutional network (SSCN) is developed and trained to improve energy reconstruction and estimate inefficiencies from prior 3D space-point reconstruction procedures, yielding a corrected mass estimate. Ultimately, both the shower and energy reconstruction methods proposed provide necessary components to the event reconstruction pipeline in LArTPC analysis.

Creating Communication Architecture for Autonomous Multi-Drone Network With Considerations for Locational Accuracy
Sarah Zou
Mentors: Soon-Jo Chung and Kyunam Kim

The advancement of drone technology will have important impacts in diverse sectors such as search-and-rescue, surveillance, and shipment of consumer goods. The objective of my research is to facilitate autonomous drone swarm development particularly in the areas of communication and locational accuracy. In this report, the hardware and software changes required to migrate from a single autonomous drone system to a multi-drone system are researched and methods for implementation are discussed. These changes are specifically aimed at a network with two drones and one ground station; however, the network architecture is designed to be scalable. In this report, considerations for multi-drone communication are discussed along with the method of choosing the appropriate the hardware and software to facilitate this communication. To improve locational accuracy, different RTK GPS devices were tested and bandwidth needed to support GPS and other drone components were considered in the implementation of a multi-drone network.

First-Principles Investigation of Magneto-Transport Phenomena in Advanced Functional Materials
Bahdan (Bogdan) Zviazhynski
Mentors: Marco Bernardi and Jin-Jian Zhou

Electron transport in solids is governed by Boltzmann Transport Equation (BTE); solving the BTE in presence of magnetic field from first principles would allow to obtain the values for Hall mobility and magnetoresistance of the real material, which is crucial for understanding its potential applications. However, adding the magnetic field term makes the BTE more complicated; the situation is even more complex when Berry curvature is taken into account. In this work, we focus on modifying the relaxation time approximation (RTA) solution of the BTE and an iterative BTE solver to include magnetic field. This provides a starting point for investigating the magneto-transport phenomena in materials with non-trivial Berry curvature from first principles using fast and accurate algorithms.

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Editing the Gut Microbiota to Reduce Huntington Disease Pathology in *Drosophila* Models
Ngozi Damilola Akingbesote
Mentors: Ali Khoshnan and Anjalika Chongtham

Changes in the homeostasis of intestinal microbiota (dysbiosis) are implicated in many human diseases including neurodegenerative disorders. Previous studies have shown that dysbiosis may influence the progression of Huntington's disease (HD) in *Drosophila* models. These studies showed that HD flies expressing full-length mutant Huntington develop time-dependent dysbiosis, which coincides with motor deficits. Importantly, elimination of gut microbiota improves the progressive motor defects in HD flies, whereas inclusion of inflammatory bacteria such as *E.coli* in the fly food accelerates motor defects and decreases the life span**.** To better understand gut-brain interactions in HD, we are investigating how certain neuroprotective prebiotics may affect microbiota-mediated changes in HD. Preliminary data suggest that HD flies treated with flavonoids that have prebiotic properties may alter the composition of gut bacteria. A notable observation was reduction in the levels of Acetobacteria, which are a class of gram negative bacteria with complex lipopolysaccharide capable of causing inflammatory reactions. Interestingly, treatment of HD flies with other gram negative bacteria such as *E.coli* appears to increase the growth of Acetobacteria in the gut. Thus, abundance of inflammatory gram negative bacteria in the HD flies may influence Huntington disease progression.

Optimization of Flux Bias Line Design for the Operation of Superconducting Qubits
Aziza Almanakly
Mentors: Oskar Painter, Eunjong Kim, and Xueyue Zhang

Superconducting circuits incorporating Josephson Junction based qubits offer a promising platform for quantum computation and simulation. Because qubit control inevitably results in energy loss and the relaxation of the quantum mechanical state, the mechanisms of control must be carefully designed. The qubit frequency is tuned with a flux bias line, which introduces decoherence channels. A widely-utilized flux bias line design consists of a transmission line shorted to the ground plane of the device, introducing noise and the potential for crosstalk between qubits. Alternative designs implementing a differential line introduce other problems, such as a capacitive decoherence channel or a strict reliance on symmetry. The goal of this work was to optimize the coherence times of a superconducting qubit through the design of a new flux bias line. We iterated through many different designs, some which focused on manipulating the geometry to minimize the capacitive coupling between the flux bias line and the qubit. Another approach was to implement a filter directly onto the line to contain the qubit's energy, preventing decoherence and eliminating the dependence of the coherence times on the geometry of the flux bias line.

Investigation of the Quantum Coherence of Oxovanadium(IV) and Copper(II)-Based Molecular Qubits for Quantum Information Science
Grace Chen
Mentors: Ryan Hadt and Ryan Ribson

Transition metal complexes constitute emergent platforms in quantum information science, as their magnetic spin (M_s) sublevels formally constitute a quantum bit (qubit). With their energetically isolated pair of M_s sublevels, S=1/2 oxovanadium(IV) and copper(II) complexes have received particular attention. While long-lived coherent superposition states can be formed in these complexes, a new mechanism of decoherence opens up at temperatures above ~100 K. This mechanism involves the coupling of molecular vibrations with the M_s sublevels (i.e., spin-phonon coupling) of a transition metal on an ultrafast timescale and prohibits the potential room temperature applications of qubits. Furthermore, the nature of the spin-phonon coupling is not well understood. Here, we study the steady-state and dynamical properties of a series of S=1/2 vanadyl phthalocyanine (VOPc) and copper phthalocyanine (CuPc) complexes diluted in diamagnetic host lattices. Continuous wave (CW) and pulsed electron paramagnetic resonance (EPR) spectroscopies are used to determine molecular g-values, hyperfine coupling constants, and spin-lattice (T_1) and spin-spin (T_2) relaxation times. By comparing multiple S=1/2 complexes, we investigate the roles geometric and electronic structure in spin-phonon coupling and relaxation lifetimes. Elucidating the role of spin-phonon coupling in transition metal-based qubits may allow for the development of new classes of materials for room temperature applications in quantum information science.

Designing Novel Hepatitis C Immunogens Based on a Conserved Epitope on the E2 Surface Protein
Rebekah Costello
Mentors: Pamela Bjorkman and Andrew Flyak

Chronic Hepatitis C infection is a leading cause of liver disease and cancer, yet no vaccine has been developed against HCV due to its extremely high genetic diversity. Previously, several broadly neutralizing antibodies (bNAbs) were isolated from HCV-infected individuals and found to target conserved epitopes on HCV surface proteins, including the AS412 motif on the E2 protein. Exposing the immune system to AS412 neutralizing epitope could elicit an immune response that confers immunity against many different strains of HCV. Here, we developed new AS412-based immunogens and evaluated the ability of several bNAbs to bind to these immunogens by ELISA. The first were virus-like particles decorated with multiple copies of the AS412 motif to increase the avidity of B cells binding to the immunogen. Secondly, we replaced a non-neutralizing ß-hairpin region in the E2 surface protein with the flexible AS412 epitope, which is bound by several bNAbs in a similar ß-hairpin conformation. For both immunogens, various glycosylation patterns were also tested. Future work includes animal immunization studies to determine if our engineered immunogens are able to elicit a strong immune response against HCV *in vivo*.

Transsynaptic Mapping of Downstream Circuitry of the Sexually Dimorphic star1b Neurons
Maeve Coughlan
Mentors: David Anderson and Hui Chiu

Drosophila melanogaster show sex-specific aggressive behaviors. Males have a lower threshold for aggression, engage in longer conflicts and exhibit a tendency to lunge and box. Conversely, females have a higher threshold, engage in short conflicts, and a tendency to headbutt. Such stereotyped aggressive behaviors suggest the presence of distinct, sex-specific neural circuits. **Star1b** neurons, upon optogenetic activation with the effector csChrimson, produce a robust aggressive phenotype in both males and females; acting as a conserved circuit motif for aggression. There are two morphological classes of star1b neurons, class 1 being present in both sexes and class 2 exclusive to males. It is unknown whether their downstream connections are likewise sexually dimorphic. Utilizing the transgenic tool **trans-tango**, we are able to fluorescently label both star1b neurons and their downstream targets. We can then register these images with the CMTK registration suite and identify GAL4 drivers for the revealed downstream hits in NBLAST. Further elucidation of this sex-specific aggression circuit allows us to tease apart discrete neurons that mediate sexually distinct behaviors.

Trajectory Following for Autonomous Underwater Vehicles
Daniela Davalos
Mentors: Beverley McKeon and Morgan Hooper

The Antarctic is fundamental to the Earth's climate and marine ecosystems, yet a large portion of its oceans are poorly understood due to the tremendous challenges of exploring the harsh environment. Autonomous underwater vehicles (AUVs) provide an important avenue for the exploration of the ocean by requiring little to no human control (Thompson et al., 2016). This research project focuses on designing and implementing an autonomous planning algorithm for an underwater vehicle with potential application toward ocean gliders. In the interest of testing autonomous features for the AUV, a virtual simulation was created to match the motion of the physical vehicle in the water. A successful algorithm will provide the groundwork for research into future AUVs that can easily and quickly collect data for poorly understood regions of the ocean.

Water Flow Characteristics Through an Ice-Walled Channel With Evolving Shape
Denise Garcia
Mentors: Michael Lamb and Flavien Beaud

Climate change is increasing global temperatures leading to faster glacier melting. Understanding glacier melting is critical because glacial melt contributes water to many parts of the world and causes hazards, such as glacier-induced floods. Water movement beneath glaciers affects ice flow processes, therefore understanding subglacial water flow is important for the future of glaciers. However, we have limited understanding of how subglacial water movement affects ice melt. To address this, we conduct experiments that quantify the heat exchange between turbulent water flow and ice. Our set-up consists of a block of ice capped by a lid with roughness elements, with water recirculating at the interface between the lid and ice. My project focuses on quantifying the evolution of water flow characteristics, which is important in understanding heat exchange between water and ice. We use dilution gauging to measure and calculate discharge, flow area, and velocity. Dilution gauging is a technique that measures discharge by injecting a salt tracer with a known electrical conductivity at the beginning of the ice block and detecting the change in electrical conductivity downstream. After continuous monitoring of discharge over the ice block, this data will aid in understanding heat exchange between water and the ice.

Autonomous Conversion of a Polaris GEM
Gabriel Goch
Mentors: Soon-Jo Chung and Anthony Fragoso

The greater sophistication of computers in motor vehicles brings the possibility of automotive autonomy. However, a great deal of testing must be done to ensure the safety of commuters. The autonomous conversion of a Polaris GEM is intended to create a platform that can be used for experimentation. Complete steering, throttle, and braking control will be given to the computer. This is accomplished by accessing the circuitry of each system and bypassing manual control with computer inputs. In some instances, the hardware is incompatible with wire control and must be replaced. With additional circuitry modification, the computer can be connected to the lights, turn signals, and various minor controls. The central computer will be a Linux based ROS (Robot Operating System) machine. This will simplify programming and further modification.

Iterative Genome Minimization of *Escherichia coli*
Laura Guerrero
Mentor: Kaihang Wang

Synthetic biology aims to develop novel biological systems through the building on pre-existing knowledge in order to create cells that can function as factories. In particular, engineering minimal cell systems such as that of the workhorse of synthetic biology, *Escherichia coli*, is instrumental in facilitating future experimentation by eliminating redundant components that impact background noise, increase genome stability, and allow for easier manipulation of biological circuits. In this project, we aim to delete a 100 kb region of *E. coli's* genes from its 4.6 Mb genome through an iterative approach for deleting identified non-essential genes that additionally serves as a diagnostic tool for determining pseudo-essential genes or those that can become essential when put in a different environment. In our top-down approach for minimization, we insert antibiotic selection cassettes followed by single guide RNAs that aid in cutting into the genome after each essential gene. Thus far, we have developed a proof of concept design and have begun to test the first iteration of deleting a non-essential region. Following this design, we can effectively identify essential genes while in conjunction deleting non-essential genes.

On the Ratio of Olson's Constant Over Davenport's Constant
Roberto Hernandez
Mentors: Dinakar Ramakrishnan and Christopher Lyons

The Davenport constant D(G), of a finite Abelian group G is defined as the smallest positive integer such that every sequence of elements of that length contains a non-empty subsequence summing to zero. The problem of finding an explicit equation for what this constant should be for any group G was first proposed in 1966 and to this day remains open. The aim of this study is to find an explicit solution for D(G) for a particular group. In addition, it should be noted that there does exists literature on other invariants such as Olson's constant which is defined similarly as Davenport's constant except that Olson's requires the elements in the sequence to be completely distinct.

Construction and Implementation of an Athermal Fabry-Perot Cavity
Jacquelyn Ho
Mentor: Nick Hutzler

Lasers are typically sensitive to their ambient conditions and will experience frequency drift due to thermal and pressure fluctuations. This is undesirable for precision measurement experiments, thus requiring a method for frequency stabilization. For this purpose, we constructed a confocal Fabry-Perot cavity which can be used to lock the frequency of an unstable laser to that of a stable helium-neon (HeNe) reference. The cavity is theoretically athermal—it is constructed out of multiple materials in a geometry such that the thermal expansion of the various components cancels out under temperature fluctuations, keeping the mirror separation invariant. It also features an adjustable endcap, which allows us to fine-tune the cavity length until the confocal condition is met. To implement the Fabry-Perot, we aligned the HeNe and a 577 nm laser simultaneously into the cavity and viewed the transmission on a photodiode and camera. Having achieved proper alignment and optimization of the cavity finesse, we will lock the frequencies using an electronic system that measures the frequency separation of the two lasers and keeps it constant within 1 MHz. Experiments to monitor the stability of the cavity itself are also under way.

Improving the Predictions of the Formation of Soot Precursors in the Combustion of Ethylene
Michelle Le
Mentor: Guillaume Blanquart

The combustion of fuels introduces pollutants in the atmosphere, detrimental to our air quality. These emissions include soot - black carbon particles that are produced due to the incomplete combustion of organic matter. The principal elements in designing a simulation model for sooting flames is determining a detailed chemical model for the oxidation of the various hydrocarbon fuels and the formation and transport of soot precursors, namely Polycyclic Aromatic Hydrocarbons (PAHs). This project aims to create an accurate model of PAH formation using counterflow diffusion flames to gain a better understanding of how soot precursors are formed.
The FlameMaster code computationally simulates the combustion of a diffusion flame created from opposing jet streams of oxidizer and of ethylene-air mixture at various equivalence ratios. The results are compared with experimental results from Carbone *et al.* to quantify the uncertainty in PAH mole fractions. Important intermediate PAH species and reactions that play a significant role in the combustion and soot formation are identified. Modifications are made to these reactions in the chemical model to optimize the predictive simulations of the formation of soot precursors.

Using Remanence FORCs to Test for Magnetofossils in Martian Meteorite ALH84001
Zoe Levitt
Mentors: Joseph Kirschvink and Isaac Hilburn

It has long been debated whether the carbonate blebs in ALH84001 contain fossil remnants of magnetite crystals from magnetotactic bacteria, known as magnetofossils. While one study identified apparent linear chains of iron-rich particles and others have found discrete magnetite cystals with the size, shape, chemical purity, crystallographic orientation, and crystal morphologies characteristic of those generated by the magnetotactic bacteria (particularly strain MV-1), clear magnetofossil chains have not yet been identified. In this study we use first order reversal curves (FORCs), which are now used routinely for identifying magnetofossil chains by a characteristic central-axis ridge, as a test of the biogenicity of the magnetic remanence carriers in ALH84001 orthopyroxene aggregates containing carbonate. We ran remanence FORCs on a RAPID / Vertical 2G SQUID magnetometer as well as standard FORCs on a MicroMag 2900 AGFM (courtesy of Lisa Tauxe at Scripps Institute of Oceanography, UCSD) to search for the characteristic fingerprints of magnetofossil chains in samples of ALH84001. Preliminary data from both remanence FORC and regular FORC experiments suggest that ALH84001 contains a population of single domain magnetite crystals that form an elongated central ridge. We have compared this to reference FORCs that we ran on freeze-dried MV-1 magnetotactic bacteria samples with both intact and collapsed magnetosome chains. Though these initial remFORC and FORC results could be interpreted as evidence for biogenic magnetite in this Martian meteorite, alternative hypotheses (e.g. magnetite present in terrestrial volcanic glasses, which yield FORC results highly similar to magnetotactic bacteria, but also contain a significant fraction of super-paramagnetic SPM grains), cannot be ruled out based on these FORC results alone. Additional rock magnetic, thermomagnetic and thermosusceptibility experiments are needed to confirm our results and distinguish between these competing hypotheses.

Experimental Investigation of Thrust Efficiency of Coaxial Propeller Set Up for Small Drones
Katia Luis Diaz
Mentors: Moretza Gharib and Emile Oshima

Unmanned aerial vehicles (UAV) commonly known as drones, are becoming very versatile and used in military, industrial and recreational applications. Drone ambulances can be the future of how support and rescue can reach patients that with today's technology can be very challenging or impossible. The end goal is to have autonomous flying drone ambulances that are able to withstand different weather conditions and each areas with geographical constraints without putting other humans in danger. The focus of this project is to test and measure the output thrust created by coaxial propeller set ups. We carried propeller diameter and set up combinations while keeping the smallest propeller size constant throughout. Other variables are different designs of manufacturing, and the structures of which the propellers are mounted on. Experimental results show that the most beneficial set up thus far is a double mount, where each propeller is held by an individual mount, with propellers with a ratio of 2:1 in size, having the smaller propeller upstream and the larger propeller downstream.

Characterization of Mechanical Properties in Genetically Modified *Arabidopsis thaliana* as a Function of Plant Cell Developmental Stage
Jenny Martinez
Mentors: Chiara Daraio and Eleftheria Roumeli

All plant cells are surrounded by a multilayered cell wall which to a large extent determines their mechanical performance. In our project we use a special type of plant cells, a genetically modified line of *Arabidopsis thaliana* which upon exposure to a chemical stimuli, develops a secondary cell wall. This project, for the first time, investigates the mechanical properties of this genetically modified plant cells during their differentiation process. We use optical microscopy to study the physical characteristics, cell shape, size, secondary cell wall formation patterns, and characterize the bulk mechanical behavior of transgenic *Arabidopsis thaliana* using micro-compression experiments.

Studying the Boundary Theory of the 2D AKLT Model
John Martyn
Mentors: John Preskill, Kohtaro Kato, and Angelo Lucia

The AKLT model is a model of antiferromagnetism initially devised as a modification to the Heisenberg model. In 2D, the AKLT model is particularly interesting because it exhibits symmetry protected topological order, and can act as a resource for universal quantum computation. Despite extensive analyses of the AKLT model, many of its properties remain to be understood on 2D lattices. One can deduce interesting properties of this model, such as its spectral gap, by analyzing its boundary theory via a tensor network formulation of the ground state. In this work, we present a method to calculate the boundary state of the 2D AKLT model in terms of a classical loop model, where loops, edges, and crossings are each given a weight. We use numerical techniques to sample configurations on a square lattice and subsequently evaluate the boundary state and boundary Hamiltonian. By varying these weights and then studying correlation functions on the boundary and various loop properties, we are able to evidence a spectral gap and indicate the presence of a phase transition in our model.

Corroles: Potential Compounds for Cancer Theranostics
Maryann Morales
Mentors: Harry Gray, Scott Virgil, and Jill Clinton

Corroles are fascinating molecules that have a chemical structure similar to porphyrins yet whose potential remains untapped. Corroles have the capacity to serve as theranostic compounds due to their metal-ion coordination core, ability to functionalize of various sites on the corrole ring, and their photodynamic properties. Research into corroles is fairly new, the first facile synthesis of a corrole being discovered only a couple of decades ago. There is a remarkable opportunity to use these tunable macrocyclic metal derivatives for site-specific anticancer therapeutics. Several derivatives of ABA corroles were synthesized as a means of targeting the acidic intracellular environment of cancer cells. These derivatives have shown that at a low pH they are protonated, suggesting that they would be adequate for selective uptake by cancer cells. These corroles aggregate into nanoparticles and dissociate into their monomeric form based on their environment. Their metal complex holds the capability of being cytotoxic in their monomeric form but lose this characteristic as they form nanoparticles. The derivatives synthesized have proven to form both the monomeric and nanoparticle structure further advocating for their potential as cancer theranostic compounds.

Stormwater Runoff Remote Sensing Analysis in Southern California
Emelly Ortiz-Villa, Jet Propulsion Laboratory, California Institute of Technology
Mentors: Emily Pui-Yee Seto and Benjamin Holt, Jet Propulsion Laboratory, California Institute of Technology

The urbanization of coastal regions has directly influenced environmental decline and ocean pollution from stormwater runoff. During rain storms, the runoff cleans the streets and collects contaminated material which is directly released into the coastal zones without treatment. Stormwater runoff leads to bacterial overgrowth harming beach water quality off of highly populated coastal cities. Besides the growing bacterial contamination, runoff adds health hazards to the greater portion of the coast. Heal the Bay (HTB) is a non-profit organization committed to making ocean conditions optimal along California. They have provided us with FIB (fecal indicator bacteria) data obtained along beaches in the Santa Monica Bay and the San Pedro area during rain events occurring in Southern California. We used satellite SAR imagery and other satellite optical imagery to allow for spatial and temporal evaluation of surface particles that potentially pollute ocean ecosystems. In this study, we evaluated SAR data using Heal the Bay FIB points to reflect shoreline fecal matter contamination affecting the SCB. The primary objective of this project is to further analyze Heal the Bay fecal matter contamination and evaluate the effectiveness of using SAR-detected stormwater plumes as a useful method to determine contaminated coastlines. The locations analyzed for bacterial contamination include Los Angeles River, San Gabriel River, and Ballona Creek. We evaluated the coast in short time series from winter 2018 to the present. Sentinel-1 SAR images were used to observe targeted plumes. Turbidity, rain events, and bacterial data were the parameters accounted for connecting the presence of a plume image to sewage spill.

Simulation and Optimization of Thermoacoustic Tomography System for Stroke Classification
Shivani Pandey
Mentors: Lihong V. Wang and David C. Garrett

Thermoacoustic tomography (TAT) is an emerging medical imaging modality which aims to provide high-contrast and high-resolution images in a convenient and low-cost manner. Our group, the Caltech Optical Imaging Lab (COILab), is in the process of designing a new TAT system with the objective of in vivo human-scale imaging, particularly towards stroke classification. This report aims to address several design challenges and performance evaluation through simulation and measurement. We developed an automated simulation pipeline to evaluate optimal system parameters, to guide to design of physical TAT systems in . We also conducted preliminary skull phantom tests and characterized how the skull affects the returning TAT acoustic signal. At 3 GHz and with a horn antenna, our TAT system achieves imaging depths of 3-5.5 cm. At 1.1 GHz, we expect our TAT system to achieve imaging depths of 7-13 cm. The acoustic effects of the skull remain a key challenge in obtaining high-fidelity images within the brain. With the aim of evaluating and overcoming these effects, we characterized the angular acoustic transmission of a human cadaver skull. It was found that transmission losses and radial spreading in the skull are highly location dependent. Ultimately, we present a combination of simulation, analytical estimation, and physical system testing to characterize and optimize the two TAT systems present at COILab.

Synthesis and Exploration of the Reactivity of a Chiral Ansa-bis(indenyl) Zirconocene Bearing a Chiral Backbone Derived From L-tartaric Acid
Elizabeth Park
Mentors: Brian Stoltz and Zachary Sercel

Zirconium ansa-bis(indenyl) metallocene complexes are of considerable interest as catalysts for the stereoregular polymerization of olefins due to their planar chirality and selectivity for enantioriched polypropylene. The reactivity of these complexes can be further explored for olefin isomerization to achieve industrially and pharmaceutically relevant products as well as asymmetric olefin polymerization of racemic compounds to achieve kinetic resolution. We sought to explore the reactivity of a zirconium ansa-bis(indenyl) metallocene bearing a chiral backbone derived from L-tartaric acid, an inexpensive, C_2 symmetrical building block from the chiral pool. Our goal is to isolate and characterize the zirconium ansa-bis(indenyl) complex and investigate the catalyst's reactivity towards olefins for kinetic resolution and isomerization. Future work includes exploration of the production of industrially and biologically important molecules using the tartarate-derived catalyst.

Utilizing Dual Readout Silicon Photomultipliers to Determine Scintillator Bar Uniformity, Characterize Cosmic Rays, and Influence Design Parameters for a Hadronic Calorimeter
Emrys Peets
Mentors: Frank Porter and James Oyang

The primary motivation for the Light Dark Matter Experiment (LDMX) is to discover the particle nature of dark matter by probing the sub-GeV mass region. As part of research and development of a Hadronic Calorimeter for LDMX, this study utilizes a dual Silicon Photomultiplier (SiPM) assemblage to determine: *a*. the light yield uniformity along a scintillator bar, *b*. the average number of photoelectrons from cosmic ray events, and *c*. important design parameters of a prototype Hadronic Calorimeter. Light yield uniformity measurements are performed by placing the beta emitter Sr-90 along the scintillator bar and determining average photoelectron yields. Two photomultiplier tubes are positioned in multiple geometries to act as a trigger for the SiPMs in detecting cosmic ray events. By varying the wavelength shifting fiber positioned along the inside of the scintillator bar, this study concludes that larger diameter fiber is able to propagate more, on average, light to the SiPM. This study provides necessary information in determining design parameters for LDMX and illustrates useful methods in utilizing multiple SIPMs to construct a Hadronic Calorimeter.

Photonic Design of Effectively Transparent Catalyst for Higher Efficiency Photoelectrochemical Solar Fuel Generators
Andrea Perry
Mentors: Harry A. Atwater and Wen-Hui Cheng

Efficient, solar-driven CO_2 reduction via a photoelectrochemical (PEC) device provides a sustainable avenue for the production of fuels typically obtained from fossil resources. Ideal device performance relies on optimal photon management to minimize losses at the device front contact while simultaneously maintaining control of the catalytic properties to achieve optimal faradaic efficiency for the CO_2 reduction reaction. We report successful fabrication of a front contact scheme using copper nanoparticles to constitute triangular grid fingers, which acts to redirect incident light to the active absorber layer of the PEC device and functions as the catalytic site for CO_2 reduction. COMSOL Multiphysics simulations of a device with 35% copper grid coverage reveal a reduction in reflection loss at the front contact by 20% with respect to bare silicon, while experimental measurements show a reduction in reflection loss by 11%. Furthermore, exposing the device to simulated AM 1.5G irradiation reveals a high photocurrent of 25 mA/cm^2. Dark catalysis measurements additionally demonstrate the copper's oxidation state strongly affects its faradaic efficiency towards higher-value reduction products and can be manipulated through annealing and oxidation steps. Further improvement to the device efficiency is possible via optimization of the copper triangle configuration and refinement of the fabrication procedure.

Using Polarization in Digital Holographic Microscopy for Life Detection
Alexander Ramirez, Jet Propulsion Laboratory, California Institute of Technology
Mentors: Christian Lindensmith, J. Kent Wallace, and Eugene Serabyn, Jet Propulsion Laboratory, California Institute of Technology

When searching for life on other planets, a greater spectrum of information is needed to further deduce the composition of a sample and decipher whether an object is mineral or biological. Digital holographic microscopy (DHM) is used within microbiology where raw data is detected by a camera sensor and reconfigured algorithmically, instead of using a traditional microscope image forming lens. DHM normally produces fringe patterns by splitting a laser beam through two offset sample chambers (sample and reference). We propose a less common method of DHM which records multiplexed holograms at 3 separate orientations on the detector. The data acquired through this process can be processed into separate images using a combination of Fourier transforms and equations for light propagation. To determine polarizing properties of the sample, which can help discriminate minerals from cells, we put polarizing filters at crossed orientations in the reference arms for two of the orientations. These filters enable us to record (and later reconstruct) simultaneous images using multiple polarizations of light, giving us polarization characteristics of the sample under observation. Variations in polarizer combinations will be reported on from a polarized and unpolarized laser beam light. The best overall waveplate construction will next be utilized in testing on mineral and bacterial samples to provide realistic data sets for reference in future astrobiological uses.

A Robotic Fly With Integrated Pressure Sensors for Aerodynamic Analysis
Ciara Sypherd
Mentor: Michael Dickinson

The flight mechanisms of insects have long been intensely scrutinized for their seeming defiance of conventional aerodynamics. Standard aerodynamics relies on assumptions derived for fixed airfoils at low angles-of-attack in steady flow. Insects, however, radically contradict the traditional approach to flight by employing independent wing motion, rotational lift generation, wake capture, and powerful delayed stall effects. The Dickinson Lab seeks to understand the novel ways in which *Drosophila melanogaster* utilizes these mechanisms through physical and computational modelling. Previously, researchers in the lab constructed a dynamically-scaled robotic *Drosophila* wing to precisely reenact the observed kinematics of flies during various maneuvers. The efficiency of these maneuvers was assessed using a force-torque sensor which was unfortunately susceptible to undesired mechanical vibrations in the system. To improve the robustness of the analysis and broaden the study, we have implemented a new wing composed of a contoured circuit board with an integrated array of pressure sensors. These sensors are used to quantify the pressure distributions which occur over the wing during flapping flight to elucidate the behavior of generated vortices on *Drosophila* wings. The findings of this project also inform the validity of the prior force sensor measurements and computational fluid dynamics models.

High Strain Rate Compressive Behavior of 3D Printed Aluminum 6061 of Varying Porosity
Valeria Villa
Mentors: Guruswamy Ravichandran and Suraj Ravindran

Aluminum alloy 6061 is extensively used in industrial applications due to its strength, weight, and corrosion resistance. Recently, metal additive manufacturing technology has gained attention as a faster, cheaper, more efficient process for fabricating aluminum alloy 6061. One major limitation of additive manufactured materials is the porosity formed due to the keyhole as a result of melt pool depression, which significantly affects the mechanical properties of 3D printed materials. In this study, different strain rate experiments are conducted on 3D printed aluminum 6061 samples of varying porosity, 0.00%, 0.42%, and 1.00% respectively. Quasi-static experiments are conducted in a material testing system, whereas, the dynamic experiments are conducted in a split Hopkinson pressure bar (SHPB). The true stress-true strain curves of porous, non-porous 3D printed, and wrought samples are compared and discussed. Preliminary results on nonporous 3D printed sample at a strain rate of 2600 ± 50 /s showed a yield strength of 250 MPa.

GUI for Spacecraft Simulators and Pose Estimation for Autonomous Landing With Drones
Brad Villacis
Mentors: *Soon-Jo Chung and Sorina Lupu*

The GUI (Graphical User Interface), written in Python, uses ROS to obtain data from battery and pressure sensors to create a functioning and aesthetically pleasing computer window. The goal is to display all relevant information for onlookers while testing is being done on the spacecraft simulators. The script uses PyQT 5 to create the visual pieces on the window and ROS to publish and subscribe to a topic containing the relevant battery and pressure data. The pose estimation project contains camera-to-desktop image processing, Aruco marker detection, and autonomous landing algorithms to be able to create an autonomous landing drone that will be sent to a Caribbean island. The code will be tested on a Jetson Nano but will be finalized onto a Jetson TX2. The original source code correctly identifies the markers, but the pose estimation is inaccurate and must be modified by using matrix transformations with quaternions on the coordinate axes of the drone, camera, and marker. Once the code has been updated, it will be finalized on the TX2 for the real drone that will travel to the Caribbean island.

A Fully Optical and Scalable Network With All-to-All Programmable Connections
James Williams
Mentors: Alireza Marandi and Christian Leefmans

Optical networks present a fundamentally new approach to computation and simulation. Previous partially-optical networks have been demonstrated which can solve the Ising problem with all-to-all connections. These networks are limited by the electronics required to simulate the optical interactions. Combined with a novel network design, a new generation of electronics enables an all-optical, scalable network configuration which circumvents problems encountered in the old design. This architecture can be adapted to solve the Ising problem as well as simulate other physical models. We present the aforementioned network along with the cross-domain FPGA used to implement the high bandwidth signals which control the interactions within the network.

Improving the Descent Performance of Small-Scale Rotorcraft Through Added Geometries
Daniel Yos
Mentors: Morteza Gharib and Marcel Veismann

The descent stage of all rotor vehicles—from helicopters to drones—results in a significant loss of thrust and increased fluctuations with respect to the system in hover condition. These losses are believed to derive from the reinjestion of the rotor flow that causes an accumulation of tip vortices at the rotor plane: often referred to as the vortex ring state (VRS). An approach of utilizing additional geometries within the proximity of the rotor plane was investigated by using enclosed shrouds and various props (with enhanced blade tip designs), in order to improve the stability and performance of rotorcraft in descent. These geometries were aimed to prevent the interaction between the blade tip vortices and the rotor disk. Results from single rotor thrust tests indicate that it is possible to reduce the thrust losses within the VRS by adding geometries in distinct locations relative to the rotor disk, while additional PIV analysis potentially outlines the underlying flow mechanism that causes these performance improvements.

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Flexible Top Contact for a Freestanding Tapered Silicon Microwire Array Solar Cell
Amar A. Bhardwaj
Mentors: Nathan Lewis, Harold Fu, and Paul Kempler

Flexible solar cells expand the applications for photovoltaics and eliminate many balance of system costs associated with conventional solar panels. A tapered silicon microwire array, which has shown highly efficient light absorption, can be embedded in a polydimethylsiloxane (PDMS) support film as a flexible solar cell. Transparent conducting top contact materials such as indium tin oxide (ITO) and PEDOT:PSS are ill-suited because ITO is brittle and PEDOT:PSS is subject to a tradeoff between sheet resistance and transparency. Our approach is to deposit a flexible, reflective metal film top contact near the base of the microwires, such that reflected light is absorbed by the wires above. The silver mirror reaction has been used for deposition, in which a diamine silver reacts with an aldehyde to plate metallic silver on the container of the liquid phase reaction. Infilling the microwires with formaldehyde, then submerging in diamine silver solution, has been found to create localized silver films along the base of the microwires. This is likely due to the environment of reductant-activated substrate exposed to excess silver precursor for facile nucleation of silver deposits. Future research will characterize the reflectance, sheet resistance, and flexibility of the top contact design.

Generating a Translationally-Active *in vivo* Modified RNA Replicon
Donovan Jay Brown
Mentors: Kaihang Wang, Charles Sanfiorenzo, and Bryan Gerber

Viral genomes have long presented intricate accessories for Darwinian evolution. Qβ replicase, the polymerase complex utilized by the bacteriophage Qβ to replicate its viral RNA genome, has displayed tremendous ability to replicate an array of RNA templates. Through *in vitro* systems, the Qβ replicase has shown 10^{10}-fold replication of small RNAs in as little as ten minutes, demonstrating the replicase's efficiency in extracellular environments. In addition to the specificity required of its template RNAs, Qβ replicase is known to lack a replication proofreading mechanism, allowing mutations to drive the evolution of a robust RNA replicon. Here, we engineer a novel *in vivo* replication system in *E. coli*, introducing the Qβ phage replication machinery to extensively replicate synthetic replicase templates. Molecular cloning techniques and recombinant expression were exercised to successfully construct ten unique replicons, which were exponentially replicated *in vivo*. RNA sequencing was applied to characterize modifications in essential and non-essential components of the RNA replicons.

Characterizing the Temporal Profile of the piRNA Pathway during *Drosophila melanogaster* Embryogenesis
Kyley Burkey
Mentors: Katalin Fejes Toth and Peiwei Chen

PIWI-interacting RNAs (piRNAs) are a class of small silencing RNAs that are responsible for guiding Piwi-clade proteins to and defending the genome against parasitic transposable elements. Active transposons cause genomic instability in the germ line and ultimately sterility. In *Drosophila melanogaster*, transposon silencing involves the establishment of repressive chromatin at transposable element sequences through Piwi-induced histone3 lysine9 trimethylation (H3K9me3). Maternal Piwi and maternal piRNAs are deposited into developing oocytes. These maternally deposited materials, as well as the H3K9me3-binding protein Rhino, play an important role in establishing the piRNA pathway in the zygotic genome and mounting an effective transposon silencing response. To better understand the mechanisms of the piRNA pathway in the *Drosophila melanogaster* embryo, it is necessary to determine the stage of embryogenesis at which maternal Piwi transitions to zygotic Piwi, as well as the stage of embryogenesis at which Rhino expression begins. The expression of Rhino, maternal Piwi, and zygotic Piwi were monitored throughout embryogenesis using fluorescently tagged proteins and confocal microscopy. It is also important to determine the point at which Piwi is no longer necessary to maintain fertility. This was determined by using a temperature-sensitive version of the inhibitor GAL80 to temporally control the knock-down of Piwi. The knock-down of Piwi was accomplished via the GAL4-driven expression of a short hairpin RNA (shRNA) complementary to the sequence coding for Piwi (shPiwi). These are the first steps towards characterizing the developmental dynamics of the piRNA pathway, as well as understanding the epigenetic regulation of transposable elements.

The Role of HuR in Regulating the Neural Crest Epithelial-to-Mesenchymal Transition
Jose Chacon
Mentors: Marianne Bronner and Erica Hutchins

Neural crest (NC) cells are a vertebrate specific cell population that undergo an epithelial-to-mesenchymal transition (EMT). During neurulation, NC gather along the dorsal region of the neural tube and begin their migration into various derivatives. Canonical Wnt signaling is a critical regulator of NC specification and delamination. Recent data from the Bronner lab indicate that a transient pulse of intermediate Wnt signaling mediated by the secreted molecule Draxin is required for proper NC EMT. *Draxin* expression is mediated by its

3’ UTR and the Bronner lab has identified an RNA-binding protein (RBP)—HuR—with various target sites within the *Draxin* 3’-UTR. To understand if HuR mediates the stability of *Draxin,* we conducted immunohistochemistry experiments on wild type chicken embryos to identify at what stages HuR was being expressed. Using a translation-blocking antisense morpholino to knockdown HuR, we identified a potential role for HuR in NC EMT. We are in the process of confirming the *in vivo* binding of *Draxin 3’* UTR by HuR through RNA-coimmunoprecipitation assays.

The Role of Fis1 in Pexophagy
Julia Dierksheide
Mentors: David Chan and Yogaditya Chakrabarty

The protein Fis1 was identified as the major mitochondrial fission factor in yeast but its role in mammals is poorly understood, though its deletion leads to a variety of severe phenotypes. Fis1 was recently discovered to localize to peroxisomes in addition to mitochondria. Peroxisomes regulate levels of reactive oxygen species and perform β-oxidation of fatty acids, two functions shared with the mitochondria. Based on recent evidence that Fis1 may mediate mitophagy, we hypothesized that Fis1 may function in pexophagy, the selective degradation of peroxisomes. Using expression of an acid-sensitive fluorescent marker to mark peroxisomes undergoing pexophagy, I compared the level of pexophagy in wild-type and $fis1^{-/-}$ mouse embryonic fibroblast cultures under a variety of conditions predicted to induce pexophagy, including different growth conditions, treatment with pharmacological agents, and overexpression of Pex3. While several conditions tested did induce pexophagy, the level of pexophagy observed was similar in WT and $fis1^{-/-}$ cells. This indicates that Fis1 does not play a critical role in pexophagy, but further analysis is necessary.

Investigating Charge Transfer Pathways in Yeast Primase
Andrew J. Dorfeuille
Mentors: Jacqueline Barton and Siobhan MacArdle

DNA charge transport chemistry offers a means of long-range, rapid redox signaling in the cell. Previous work has shown that the [4Fe4S] cluster in yeast DNA primase can utilize this chemistry to coordinate the first steps of DNA synthesis. Electron transfer between the protein and DNA occurs through tyrosine residues, whereby oxidation of the cluster acts as a redox switch affecting DNA binding and synthesis of de novo primers at the replication fork. By making specific tyrosine to phenylalanine mutations between the [4Fe4S] cluster and the DNA binding site in the C-terminal domain of primase, the charge transfer efficiency can be decreased which alters the initiation and elongation activity of primase. Since some mutations of the tyrosine pathway did not have an effect on the CT efficiency, subsequent mutants were generated to determine which tyrosine residues are must essential for CT between the cluster and DNA. Studying additional tyrosine mutants in comparison to WT protein using DNA modified gold electrodes will elucidate the specific tyrosine residues most crucial for the charge transfer pathway.

Using Engineered Colicin Domains to Synthetically Transfer Protein Between *E. coli*
Leah Keiser
Mentors: Richard Murray and Reed McCardell

Current synthetic systems for transferring information between microbes in a population usually rely on either a small molecule, like AHL, or DNA. Small molecules lack the complexity to share more than simple commands, and DNA transfer events are typically irreversible. Transferring protein allows for the sharing of more complex information, and protein degradation allows the signal to decrease and disappear over time. Additionally, since the effector is delivered already, there is no delay for transcription and translation and the response is immediate. In this work, we are engineering a convenient way to transfer protein between cells within a population. Colicin, or *E. coli* secreted antibiotics, already use a protein system that transfers toxin from a producer cell to a target cell. We have taken colicin, made it non-toxic, and attached a protein of interest. By using both toxic and reporter proteins, we have demonstrated that the colicin import machinery can effectively bring protein from a producer cell to a target cell. These protein transport peptides allow for the transfer of protein between *E. coli* in a microbial population.

Identifying Novel Motifs in Morphogen Proteins
Divya Kolli
Mentors: Alison Ondrus and Rahul Purohit

Abstract withheld from publication at mentor’s request.

Spatial Barcoding for Single-Cell Analysis of Pooled CRISPR Screens
Sai Kottapalli
Mentors: David Van Valen and Edward Pao

CRISPR/Cas9 is a targeted gene-editing system that allows for the alteration of a DNA sequence. CRISPR knockdown pools that target thousands of genes are being used to probe the effects of genetic perturbations in a single experiment. However, large-scale pooled CRISPR experiments are reliant on sequencing to generate an averaged readout of the population, thus, limiting single-cell analysis. Imaging-based pooled CRISPR screens are made possible with a barcoding scheme to (1) integrate the high throughput of pooled screens without compromising single-cell resolution (2) reduce labor significantly that is otherwise present in an arrayed context. Microscopy screening of pooled perturbations with barcoded guide RNAs allows a readout of phenotype and the perturbed gene concurrently. Here, we introduce a spatial barcoding scheme with a microscopy-readable synthetic antibody tag localized to a subcellular compartment. The spatial barcode will be paired with a CRISPR interference guide RNA that targets a particular gene. As a proof of concept, the barcode can be 'scanned' with an immunofluorescence stain to readout whether a defined guide RNA is present or absent in an individual cell. The spatial barcoding scheme optimizes the efficiency of pooled library microscopy screens to achieve single-cell resolution on even a rudimentary microscope setup.

Perturbation Analysis of Key Genes Expressed During Early T Cell Development
Ethan Mondell
Mentors: Ellen Rothenberg, Mary Yui, and Wen Zhou

T cell development can be divided into three phases: Pre-commitment (phase 1), T cell identity commitment (phase 2), and post ß-selection (phase 3). Much of the gene regulatory networks involved in phase 2 of development have been elucidated, however, there has yet to be sufficient investigation of the regulatory networks that play a role in priming early thymic progenitor cells (ETPs) for commitment. In order to investigate how progenitor cells make early decisions towards cell fate commitment, we utilized the CRISPR/Cas9 system to knockout potential regulatory genes in purified primary bone marrow progenitors and, over several time-points, observed the phenotypic and kinetic effects of these genes on development. Although *Tyrobp, Stat3, PU1, Pkib, Pecam1, Oasl2, Nrarp, Mycn, Itga9, Hoxa9, Car2, Evl, Fog1, Cd7,* and *Meis1* were investigated as potential candidates, it was found that a select number of gene knockouts, including *Nrarp, PU.1,* and *Fog1* elicited a phenotype characterized by an increased progression along the T cell developmental trajectory. These initial experiments help explain the roles of early expressed genes in ETP differentiation and provide insight for further investigation into the mechanisms involved in these key genes.

Functional Characterization of the *Neisseria meningitidis* MetNIQ Methionine Transport System
Jacob Parres-Gold
Mentors: Douglas C. Rees and Naima Sharaf

The MetNIQ methionine transport system belongs to a class of integral membrane proteins known as ATP-binding cassette (ABC) transporters, which conformationally couple ATP hydrolysis to distinct substrate translocation events. The MetNI system in *Neisseria meningitidis,* an obligate human pathogen responsible for meningococcal disease, comprises a homodimer of the ATP-binding cassette domain MetN and the transmembrane domain MetI, as well as a triacylated periplasmic protein MetQ that delivers methionine to the MetNI transporter. Here, we investigate the role of MetQ in transporter activity using a colorimetric assay to measure ATP hydrolysis by MetNI. A low amount of basal ATPase activity was observed for the detergent-solubilized transporter, even in the absence of MetQ or methionine. Addition of MetQ or methionine alone marginally increased this activity. However, in the presence of MetQ and L-methionine, the observed ATPase activity increases more than three-fold. This effect is eliminated by mutating MetQ to prevent addition of the triacyl lipid modification. These results suggest that the triacylation of MetQ facilitates substrate-driven stimulation of ATPase activity. However, further work is needed to understand the evolutionary purpose of this lipid modification and its role in *N. meningitidis* survival.

Elucidation of the Nup93-Nup35 Interactions Within the Human Nuclear Pore Complex
Jimmy Thai
Mentors: André Hoelz, Stefan Petrovic, and Dipanjan Samanta

Nuclear pore complexes (NPCs) are multi-protein channels that span the nuclear envelope, serving as the sole gateway between the nucleoplasm and the cytoplasm. Proteins that constitute the NPC are known as nucleoporins (nups), and 34 classes of nucleoporins constitute the approximately one-thousand proteins in a typical NPC. This project focuses on elucidating the structural interactions between two nucleoporins within the inner ring of the NPC: the scaffold nucleoporin Nup93 and the linker nucleoporin Nup35. In order to elucidate the interactions that stabilize the hsNup93-hsNup35 heterodimeric complex, monomeric proteins will be expressed recombinantly in *E. coli*. These monomeric proteins will be co-crystallized, and the structure of the heterodimeric complex will be resolved using X-ray crystallography, thereby revealing the key residues that stabilize the heterodimeric interaction. Then, the project seeks to verify these findings by mutagenesis of the aforementioned key residues, which should abolish the heterodimeric interaction, thereby confirming the crystallographic findings of the project.

Stereotyping Grooming Behaviors of Symbiont Rove Beetles
Joycelyn Yiu
Mentors: Joseph Parker and Julian Wagner

Although interspecies social behavior plays a fundamental role in many ecosystems, how it evolves is a mystery. Past research on different species (for example, cleaner fish, cuckoo, and dogs) is limited because the repertoire of interactions cannot be fully recapitulated in a laboratory setting. Symbiont rove beetles, on the other hand, have reproducible behaviors. In particular, *Sceptobius* rove beetles are highly social organisms that have evolved grooming interactions with host ants, stealing cuticular hydrocarbons (CHCs) from the ant's body to gain social acceptance inside nests. To analyze how this complex behavior may have evolved from simple stigmergic behavioral modules, we probed the beetle's behavior in the presence of a dead ant. As the beetle mounts, antennal-grabs, and grooms the ant, a dual camera-and-lights setup captured dynamic rearrangements of the beetle's posture. This project will accelerate our ability to exploit rove beetles as a model for social interactions, allowing us to integrate modern deep learning approaches with quantitative behavioral analysis. It will be one of the first studies to yield insights into how stringing together simple stigmergic behavioral modules leads to the evolution of complex social interactions.

Sequential Minimization of the *Escherichia coli* Genome With Cas9 Mediated Homologous Recombination of Long Synthetic DNA Fragments
Raymond Zhang
Mentor: Kaihang Wang

Efforts in the large-scale identification of the set of essential genes, the "essentialome" of an organism, allows for a better understanding of the fundamental genetic pathways and regulatory elements critical for life. Genome minimization - the systematic removal of segments of non-essential genetic material from a bacterial genome - gives us a better understanding of an organism's essential gene map to a degree that cannot be achieved with single gene knockout or transposon mutagenesis studies of gene essentiality. Here, using molecular cloning techniques to generate the components for **R**eplicon-**EX**cision **E**nhanced **R**ecombination (REXER), we have attempted the excision of a 100 kilo-base pair segment of the *Escherichia coli* MDS42 genome that contains non-essential segments interspersed with essential genes and its simultaneous replacement with an analogous 7.8 kilo-base pair stretch of essential genes. The methods developed should enable extensive minimization of the *E. coli* genome and troubleshooting of genomic sequences that are recalcitrant to compression. Furthermore, we developed a Cas12a-mediated ligation system analogous to Cas9 in REXER as an alternative method in the toolbox for genome minimization.

LIGO

The Laser Interferometer
Gravitational-Wave
Observatory

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Exploration of Metamaterial Designs for Mechanical Isolation Systems
Mahiro Abe
Mentors: Christopher Wipf and Aaron Markowitz

This project studies metamaterials for filtering mechanical vibration in the 10Hz-1kHz regime. We are interested in designing a metamaterial layer that can mechanically isolate a silicon disk while maintaining thermal contact. Such a system will enable accurate high-Q measurements of silicon at cryogenic temperatures, which are necessary for characterizing the test mass noise in next-generation gravitational detectors such as LIGO Voyager. Silicon metamaterials comprised of locally resonant structures are explored for producing bandgaps in the frequency range of the silicon disk modes, with analytical and numerical studies conducted on various resonant structure candidates. Finite element analysis done on a combination of these structures shows promising filtering behaviors. Future work for this project will involve fabricating and testing of candidate isolation systems. The metamaterial studies can potentially also be applied to LIGO noise evasion, including the filtering of parametric instabilities in the test masses and seismic noise isolation.

Data Clustering Techniques for the Correlation of Environmental Noise to Signals in LIGO Detectors
Jacob Bernhardt
Mentors: Anamaria Effler and Rana Adhikari

Similar states of environmental noise in LIGO detecters were investigated by clustering two-hour segments of physical environment monitoring (PEM) band-limited RMS sensor values via the k-means algorithm. The ability of the algorithm to identify interesting noise states was verified by clustering seismometer data, where known types of noise are present (earthquakes, microseism, anthropogenic ground motion), and examining cluster time series and spectra for familiar characteristics. Clustering microphone data from each VEA yielded a recurrent multi-hour acoustic noise too quiet to cause a lockloss, and a quick, loud, lockloss-causing noise. The former noise state was found not to couple to DARM via comparing DARM spectra in-cluster and otherwise. Clustering accelerometer data primarily yielded a benign 58 Hz vibration at the mid-stations increasing throughout the day, attributed to the HVAC system.

Reduction of Optical Cavity Losses Using Actively-Tunable Adaptive Optics
Edita Bytyqi
Mentors: Jon Richardson, Rana Adhikari, and Aidan Brooks

Optical cavities play an important role in laser interferometer gravitational wave detection. To increase the interferometer's sensitivity, the operating power in the cavities needs to be proportionally increased. Nevertheless, due to point absorbers in the end mirrors, light is scattered into higher order modes limiting the amount of power that can be reached inside a cavity. Here, we propose an adaptive optics approach in reducing optical losses by residual aberration correction using focused heat. We use a spherical reflector and cartridge heater to focus radiant heat to a 1.5 cm spot near the center of the mirror. The reflector radius of curvature does not significantly affect the focus, however the distance of the heater from the mirror and the coating of the reflectors make a paramount difference. We will vary the distance from the mirror and use Aluminum foil and potentially, polished gold, to get as small of a focus as possible. Obtaining a good focus will allow better control in the projected heat pattern and can be used to actuate the coupling of different modes.

Observing and Modeling Ultracompact Binaries Detectable by LISA
Olivia Cooper
Mentors: Michael Coughlin and Shreya Anand

Our galaxy is rich with a menagerie of binary stellar remnants, many of which emit both gravitational and electromagnetic (EM) radiation as they rapidly orbit each other in ultracompact binary systems (UCBs). According to general relativity, UCBs strongly emit low frequency gravitational-waves (GW) detectable by the future Laser Interferometer Space Antenna (LISA). To predict and verify UCB GW detections and maximize LISA's scientific potential, we observe a sample of UCB candidates using instruments including Palomar Observatory's Triple Spectrograph and Kitt Peak's Electron Multiplying CCD. With orbital periods on the order of minutes to hours, we observe multiple orbital phases or even full orbits, and measure orbital parameters such as radial velocity, mass, and inclination. With collaborators at Northwestern University, we also generate a catalog, informed by Galactic binary population models, of gravitational waveforms and light curves for white dwarf UCBs in decaying orbits. These simulations constrain the range of UCBs we expect to detect with time domain surveys such as the Zwicky Transient Facility and Large Synoptic Survey Telescope, which will contribute to the sample of LISA verification binaries.

Digging Deeper: Finding Sub-Threshold Compact Binary Merger Events in LIGO Data
Sierra Garza
Mentors: Jonah Kanner, Alan Weinstein, and Liting Xiao

The LIGO and Virgo detectors have collected gravitational wave (GW) data from three separate observation runs since 2015, with the third run presently collecting data. There have been 10 signals from binary black hole mergers and one binary neutron star merger detected from the first two observation runs and many more from the third run. These detections were all confirmed due to high confidence in their signal-to-noise ratio (SNR); however, there are likely many more unconfirmed signals in the data due to lower SNRs. A limitation in the SNR criteria arises when accidental coincidence of “loud” glitches or other rare noise fluctuations in the LIGO detectors can result in high SNRs but are not the product of real GWs. We hope to improve the detection or rejection of sub-threshold events with lower SNRs by computing the Bayesian coherence ratio (BCR): the odds between the hypothesis that the data comprise either a coherent compact-binary-coalescence signal in Gaussian noise or incoherent instrumental features, using parameter estimation. BCR analysis was done on Observation Run 3 (O3) events and background data. Initial results provide confidence that the BCR can distinguish between signal and incoherent noise given appropriate parameters, indicating potential to improve sub-threshold event detections.

A Directed Search for Continuous Gravitational Waves From the Neutron Star Candidate Fomalhaut b in the Second Observing Run of Advanced LIGO Using a Hidden Markov Model
Dana Jones
Mentor: Ling Sun

The detection of continuous gravitational waves (CWs) will provide invaluable information about the nature of their astrophysical sources, namely spinning neutron stars with small nonaxisymmetries. These sources often have an intrinsic, stochastic frequency wandering, or “timing noise,” associated with their spin-down. Hence tracking a CW signal coherently over a long observing time using a matched filter can degrade the search sensitivity. We conduct a semi-coherent search for CWs from a nearby neutron star candidate, Fomalhaut b. A frequency domain matched filter ($\mathcal{F}$-statistic), calculated coherently over 5-day time stretches, is combined with a hidden Markov model scheme capable of tracking signal frequency evolution from secular spin-down and stochastic timing noise simultaneously to analyze the data from the second observing run of Advanced LIGO. The frequency band from 100 Hz to 1000 Hz is searched. We report the analysis results and place constraints on the properties of the astrophysical source.

High Fidelity Probe of Optical Scatter From Point Defects
Kruthi Krishna
Mentors: Gautam Venugopalan, Koji Arai, and Rana Adhikari

Currently, LIGO is capable of detecting Gravitational Waves in the band of 10Hz to 1 kHz, with a strain sensitivity of more than $10^{-23}\ 1/\sqrt{Hz}$ around 100Hz. But to further increase LIGO’s sensitivity at lower frequencies in the upcoming LISA and effectively implement optical squeezing in the Voyager upgrade, it is important to understand the noise sources and optical losses well enough. Scattered light from the surface of test masses/cavity mirrors is one such critical noise source that limits our sensitivity below 30Hz. It reduces the power circulating in the Fabry-Perot cavities leading to a lower signal to noise ratio and might also couple back into the main beam tube introducing a random phase noise. This project focuses on in-situ studies of scattered light in the LIGO 40m prototype, using an existing camera system that is being used to monitor the beam spot on the mirrors/test masses. During this project, we installed a digital CCD camera (GigE camera) attached to a suitable telescopic lens, into the camera system and obtained images of a cavity mirror at a given large angle. By performing a radiometric calibration of the GigE camera, we were able to measure the power of scattered light at a certain large angle to the main beam using these images. We also obtained High Dynamic Range (HDR) images of cavity mirrors, using which we can extract a great deal of information about point defects of the mirrors. With the infrastructure that has been set up, we further aim to study the sources of scattering - point defects and other surface imperfections, estimate the optical loss due to scattering and characterize the random phase noise introduced due to scattered light. And thereby, gain an overall understanding of the effects of scattered light in the LIGO interferometers.

Rates and Populations of Compact Binary Mergers
Phoebe McClincy
Mentors: Alan Weinstein, Jonah Kanner, and Liting Xiao

The LIGO and Virgo detectors have been searching for gravitational waves (GW) since 2000. All three detectors were upgraded to Advanced versions, which for LIGO began observing in 2015, and for Virgo in 2017. In Advanced LIGO's first and second observing runs (O1 and O2, respectively), the detectors found 10 GW signals from binary black hole (BBH) mergers, and 1 from a binary neutron star (BNS) merger, all with high significance, or low probability of being due to noise. Already in the first several months of O3, which began in April 2019, dozens of candidates have been seen with such high significance. The two aforementioned categories, along with neutron star/black hole mergers (NSBH), are collectively known as compact binary coalescence (CBC). As the detectors’ sensitivities are improved, we expect to accumulate tens, hundreds, or thousands of CBC events. From these, we can infer the underlying population of CBC systems as a function of their masses, component black hole spins, and redshift. We may then better understand the astrophysical processes governing the formation and evolution of such systems, as tracers of the most massive stars. We aim to develop tools and techniques to accomplish this through detailed simulation and Bayesian inference.

Temperature Measurement and Control for High-Q Mechanical Resonators
Shubhabroto Mukherjee
Mentors: Rana X. Adhikari, Aaron Markowitz and Duo Tao

Brownian motion generated by mechanical losses is a limiting source of noise in a broad class of optomechanical measurement devices operating at or near their quantum limits. Improving the sensitivity of future generation of gravitational wave detectors will require optical coating with significantly lower mechanical losses. It is well known that at cryogenic temperatures, near 123K, the coefficient of thermal expansion(α) for silicon vanishes. As the linear spectral density of thermo-elastic noise is directly proportional to α, the calculated thermo-elastic noise at this temperature effectively goes to zero. It is important to note that even near the zero crossing temperature, the cumulative thermal losses never goes down to zero due to the presence of other dissipation principles, dominantly phonon-phonon scattering or Akhiezer damping.

To take advantage of low thermal noise properties of silicon at cryogenic temperatures, the Cryo-Q experiment was developed. It is effective in testing the candidate coating by comparing the internal friction Q^{-1} of the coated disk to bare silicon disk. Since the friction increases away from the zero crossing, it becomes essential to maintain a low- temperature gradient across the disk, the threshold for which was obtained using finite element modeling. It is known that the eigenfrequency of the resonator has a temperature dependence, which is primarily due to the variation in Young's modulus. Therefore shifts in eigenfrequencies provide an accurate temperature readout. Owing to very low emissivity of the resonator, cooling it becomes a challenge. This paper proposes a methodology to modulate and control the temperature of the resonator using a heating laser.

Extending the Reach of Gravitational-Wave Detectors With Machine Learning
Morgan Nanez
Mentors: Michael Coughlin and Rana Adhikari

Fundamental noises determine the ultimate design sensitivity of the interferometer. We will use different neural network architectures, such as recurrent neural networks and convolutional neural networks, and algorithms to reduce the overall noise floor of the LIGO detectors by considering the physical attributes of the instrument. There will be a hard emphasis on techniques that analyze time series data, such as utilizing long short-term memory and nonlinear regression algorithms. Once trained, the neural network will increase sensitivity in the detectors by subtracting linear and non-linear noise coupling mechanism.

Optical Cavity Inference Techniques for Low Noise Interferometry
Jorge L. Ramirez Ortiz
Mentors: Rana Adhikari and Craig Cahillane

Gravitational waves are being detected more and more frequently by the Advanced LIGO interferometers due to the improvements made to their precision. To improve the rate at which we detect gravitational waves, one method would be to reduce the noise that is intrinsic to these signals, so that more signals can be extracted with confidence. To achieve this, a deeper understanding of the noise couplings that mask these signals is necessary. This project seeks to develop statistically rigorous methods of analyzing signals from Fabry-Perot cavities and recovering otherwise difficult to measure parameters which govern these noise couplings using interferometer modeling software and Bayesian inference techniques.

Acoustic Loss Tomography: Identification of Phonon Attenuation in High-Q Mechanical Resonators
Anna Roche
Mentors: Aaron Markowitz and Rana Adhikari

Thermal noise is important in areas such as gravitation wave detection and mechanical resonators since they rely upon extremely precise measurements. When measurements become extremely precise, quantum observables are being measured. These quantum observables can be measured in an isolated system, but in an environment with uncontrolled degrees of freedom, classical noise becomes a limiting factor of precision. This precision is limited by thermal fluctuations, prompting our focus on improving the quality factor of mechanical oscillators in the Gentle Nodal Suspension system. In order to minimize energy loss, we must better understand how competing frequencies depend on different mechanical losses. The resonator oscillation frequency can couple with different sources throughout the system. We will work to isolate these mechanical losses in the system, model and experimentally verify their frequency dependence, in order to lower this loss in the suspension system.

Optimal Mass, Spin, and Orientation Parameters for Detecting Higher Order Gravitational-Wave Modes From Binary Black Hole Mergers
Tiffany H. Shi
Mentors: Yang Chen and Andrew Johnson

Thus far, the Advanced Laser Interferometer Gravitational-Wave Observatory (aLIGO) and Advanced Virgo have detected gravitational waves (GWs), or ripples in the curvature of spacetime, from dozens of binary black hole (BBH) and binary neutron star (BNS) mergers. In order to detect the GWs from these mergers, aLIGO data are optimally searched using matched filtering against a bank of model waveform templates which are well-described by General Relativity (GR). Currently, such searches only utilize waveforms for the dominant Y22 mode, neglecting higher order modes (HOMs). However, these HOMs carry information about the source and the radiation it emits, and are therefore of great interest to study. Our goal is to identify the presence of HOMs in signals found in the data in order to test GR. Using a newly-released catalog of BBH simulations with HOMs developed by the Simulating eXtreme Spacetimes (SXS) Collaboration, we will assess the capabilities of aLIGO for detecting HOMs. Such detections are currently very unlikely, as HOMs are at least half an order of magnitude lower in amplitude than the dominant mode, and tend to lie outside of LIGO's sensitive frequency band for low-mass systems. Constrained by this strain sensitivity, we aim to determine the range of BBH mass, spin, and orbital orientations which maximizes the ratio of SNR for templates with and without HOMs. We will then calculate the maximum effective luminosity distance to the source, thus finding the optimal likelihood of detecting HOMs and paving the way for a powerful test of GR in the strong-field highly dynamical regime.

2-micron, HIGH QE Photodetector for Quantum Metrology
Shalika Singh
Mentor: Koji Arai

To characterize the external quantum efficiency, internal quantum efficiency, dark noise, dark current, linearity and shot noise at 2um for extended. These were InGaAs photo-diodes from Laser components and Thorlabs, GPF photo-diode and InAsSb photo-diode from NASA JPL. One of the large problems with the extended InGaAs photo-diodes is the considerably large amount of 1/f noise produced when a reverse bias voltage is applied across them. We will investigate the temperature dependence of dark noise by placing the diodes in a cryostat. The dependence of quantum efficiency will also be tested. The circuitry that will be used for this experiment uses a trans-impedance amplifier, differential circuit, whitening filter, 15V voltage regulator circuit and a low pass Sallen key filter. We have made the circuit in such a way that the noise present in the circuit doesn't dominate our measurements.

Data-Driven Modeling of Peak Luminosity of Black Hole Mergers
Afura Taylor
Mentor: Vijay Varma

During the final moments of LIGO's first detection, more power was radiated than the power radiated in light from all the stars and galaxies in the Universe combined! This remarkable claim is based on models that predict the luminosity of a black hole merger. Current models for the peak luminosity follow a phenomenological approach, which involves making some assumptions based on perturbation theory and intuition and then calibrating free parameters to numerical relativity simulations. In this work, we take a more powerful approach and train our model directly against numerical relativity simulations, without any underlying phenomenological assumptions. We develop a purely data-driven model for the peak luminosity using Gaussian Process Regression and show that our model outperforms existing models by at least an order of magnitude.

Optimal Non-Linear Control for LIGO Interferometers
Milind Kumar Vaddiraju
Mentors: Rana Adhikari, Gautam Venugopalan, and Koji Arai

LIGO interferometers used to detect gravitational waves achieve extremely high sensitivity through precise angular control of suspended optics that direct the laser beam. A host of sensing techniques, ranging from optical levers and wavefront sensors to suitably positioned quadrant photodiodes are used to detect the angular position and deviation of optics. This work attempts to introduce the use of Gigabit Ethernet (GigE) cameras capturing images of light scattered from optics to determine the position of the laser beam on the optic. A number of approaches based on tools from image processing are employed to discern the motion of the beam spot from video. They are found to be unreliable and discarded in favour of convolutional neural networks which can, in theory, learn any complex, non-linear mapping. These are trained on data generated at the 40m laboratory at Caltech and the results are analysed. Future work will rely on the use of data augmentation using simulated data and sequence to sequence models incorporating RNNs and LSTMs.

Understanding Interferometer Lock Losses With Machine Learning
Laurel White
Mentor: Jameson Rollins

The Laser Interferometer Gravitational-Wave Observatory (LIGO) detectors are complex systems that must be extremely stable to detect gravitational-wave signals. Numerous control loops are used to maintain detector stability, or "lock," but a detector can lose lock. A time-consuming lock acquisition process must be undertaken to regain it, reducing the amount of time during which the interferometer is recording data. The causes of some lock losses are unknown. In this project, we use machine learning to analyze time series data from the auxiliary channels in the LIGO Hanford detector, which can indicate changes in the states of various detector components as well as environmental factors such as seismic noise. We first determine features that characterize the data and then perform a regression to identify which of these features can distinguish between data preceding lock losses and data from stable times. We run a clustering algorithm on the predictive features to identify groups of similar lock loss events. The ultimate goal is to minimize the number of lock losses in the future.

Radio Frequency Noise Reduction in the LIGO Hanford Observatory
Matthew Withers
Mentors: Keita Kawabe and Herold Gustafson

In aLIGO, many critical subsystems are dependent upon the reliable operation of a carefully designed radio frequency (RF) distribution system. The RF distribution system produces and delivers a variety of RF signals, most derived from a base frequency of 9.10023 MHz. These signals are used to both modulate and demodulate the interferometer's (IFO's) various input and output channels, making control of the IFO possible. Given the RF distribution system's importance in the proper operation of aLIGO's IFOs, noise arising from its constituent components has the potential to increase the noise present in the IFOs' differential arm motion (DARM), the primary output used to detect gravitational waves. This project focuses on characterizing two potential RF noise sources present in LIGO Hanford Observatory's IFO: a series of unwanted harmonics in the LIGO RF Distribution Amplifier and an array of noise signals present of the shielding of the IFO's RF transmission lines. By developing methods for quantitatively evaluating the influence of these noise sources on DARM, I am able to reach important conclusions about their ability to negatively impact the IFO's output channels, helping the electrical engineering group make important decisions about improvements to the RF distribution system's design.

Constructing Echo Waveform From Kerr-Like Background
Shuo Xin
Mentors: Ling Sun and Baoyi Chen

Gravitational wave echoes have been intensely discussed in the last few years. In this article, we constructed echo waveforms based on Teukolsky-Sasaki-Nakamura formalism, with two phenomenological parameters characterizing the surface of the compact object, reflectivity $\tilde{R}(\omega)$ and compactness ϵ. Plunging geodesic orbits are used to simulate realistic ringdown sources. The effect of reflecting boundary on the energy flux is also presented. Superradiance is seen for waves with angular frequency lower than twice the angular frequency of spinning Black Hole. We studied the ingoing part of gravitational waves sourced by plunging geodesics and see a GW version of "sound barrier". Some examples of echo waveforms are presented. This work will help produce realistic waveform templates for a comprehensive search of echo signals.

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Climate Change Projections of Ridging Events for Western North America
Preston Ancello (Jet Propulsion Laboratory, California Institute of Technology)
Mentors: Duane E. Waliser (Jet Propulsion Laboratory, California Institute of Technology) and Peter B. Gibson (Jet Propulsion Laboratory, California Institute of Technology)

Anthropogenic climate change has not only led to gradual sea level rise and rapidly shrinking Arctic glaciers, but is also expected to lead to changes in extreme weather and climate variability across the world. The impacts of extreme climate variability can especially be seen across the western region of the US in the form of extreme and long-lasting drought spells. These drought spells are caused by ridging events, large synoptic high-pressure systems associated with dry and warm weather. The main goal of the project is to determine to what degree ridging events are expected to change in the western US throughout the rest of the 21st century. Data analysis from the CEMS-LENS and CMIP5 experiments will be done to determine if these ridging events are expected to change in frequency or intensity throughout the rest of the 21st century. Our focus on investigating links between ridging and climate change is urgently needed to better understand, and plan for, the changing nature of drought in the Western US.

Multi-Processor System-on-Chip Deployment of Real Time Viewing and Handling Software for Hyperspectral Imagers
Joshua Anderson, California Institute of Technology
Mentors: Didier Keymeulen and Jacqueline Ryan (Jet Propulsion Laboratory, California Institute of Technology)

Currently deployed technology used for handling Hyperspectral Imagers and viewing data from these imagers is several generations old and may not be able to process the increasing amount of data that comes from higher resolution images and higher frame rates. Multi-Processor System-on-Chip (MPSoC) technology promises to solve this emerging problem with lighter, smaller, cheaper, and significantly more powerful systems that can be deployed as an all-in-one package to control the imagers as well as view the incoming data simultaneously on the same system. This is possible due to a custom Yocto operating system able to take full advantage of the Xilinx Zynq Ultrascale+ based MPSoC. The versatility of Yocto also allows data to be read from any source including the MPSoC itself, a remote data server, or straight from the imaging instrument. This project focuses on the creation of such a Yocto system as well as the performance improvements gained from using an MPSoC.

Rock Data Analysis for Mars 2020 Landing
Dawson Beutler (Jet Propulsion Laboratory, California Institute of Technology)
Mentor: Matthew Golombek (Jet Propulsion Laboratory, California Institute of Technology)

Data regarding Jezero crater has been collected by the Mars Orbiter Camera (MOC), Mars Orbiter Laser Altimeter (MOLA), Thermal Emission Spectrometer (TES), Thermal Emission Imaging System (THEMIS), High Resolution Imaging Science Experiment (HiRISE), and the Context Imager (CTX). From this data, the surface geology must be characterized to determine the safety of potential landed points. In this project, a systematic approach was developed using HiRISE imagery to analyze visible rocks and quantify their size-frequency distribution. Over 68,000 candidate sites within the approx. 214 km^2 of the landing ellipse were inspected for their safety quality, while hazardous features were mapped for use in Terrain Relative Navigation and future rover traversal. Mapping of features to a 25 cm/px scale was performed in ArcGIS Pro software. A subsequent combined hazard map that incorporates rocks, steep slopes, inescapable ripple fields, and large craters will be created and put aboard the rover computer. This map will be continually refined until Mars 2020 arrives.

Kronoseismology: Oscillations of Saturn Due to Baroclinic Instability
Katherine Broad, Purdue University
Mentor: Jim Friedson, Jet Propulsion Laboratory, California Institute of Technology

Anomalous spiral density waves in Saturn's C-ring can be attributed to nonradial oscillations of Saturn itself. The measurement of these oscillation frequencies provides new information about Saturn's interior. This is because the C-ring acts as something like a seismometer in the sense that the frequencies of Saturn's normal mode oscillations equal the frequencies of the spiral density waves they force in the C-ring. Inertial modes (i-modes) and rotational modes (r-modes) are particularly sensitive to small departures of the internal density stratification from adiabatic, as compared to the more common fundamental acoustic modes (f-modes). Knowing this, we set out to determine whether or not the oscillations that induce a subset of slow-moving i-mode and r-mode frequencies arise via baroclinic instability in Saturn's interior. To approach this question, we generalized an existing energy principle that can be used to explore the linear stability of differential rotation in Saturn against the baroclinic growth of the oscillations. We then determined if the slow-moving frequency modes of interest are baroclinically unstable.

The MISR Plume Height Project: Digitizing Smoke Plumes
Angela I. Ceja, Cal Poly San Luis Obispo and Jet Propulsion Laboratory, California Institute of Technology
Mentor: Abigail M. Nastan (Jet Propulsion Laboratory, California Institute of Technology)

MISR (Multi-angle Imaging SpectroRadiometer) is an instrument aboard the NASA Terra Satellite. It consists of nine cameras, which are positioned at different angles. These nine cameras capture images of the Earth. The MISR Plume Height Project focuses on providing information regarding aerosol heights, aerosol properties, and wind corrected height values. It requires a trained technician to observe the scenes containing the plumes, and then digitizing them to obtain height data. Furthermore, this project has achieved digitizing plumes from past years. The goal of this project for the summer of 2019, is to digitize plumes from June 2017, August 2017, and July 2018. The technician corrects the misregistration, draws a polygonal shape around the plume, and indicates wind direction. Fundamentally, scientists can have access to plume data that have been digitized and use it for fire radiated energy models, climate models, aerosol models, or air quality forecast models.

Analysis of Cost-Effective Particulate Matter Sensors
Peter Chea (Jet Propulsion Laboratory, California Institute of Technology)
Mentors: David Diner (Jet Propulsion Laboratory, California Institute of Technology), Richard Flagan (California Institute of Technology), Sina Hasheminassab (Jet Propulsion Laboratory/South Coast Air Quality Management District)

The cost-effective sensors evaluated during this project are the Purple Air II, Alphasense OPC-N3, and APT. The most cost-effective sensor will be used in the Multi-Angle Imager for Aerosols (MAIA) mission and deployed in Ethiopia and other target areas throughout the world to work with MAIA satellite data. The first part of analysis is outdoor testing since these sensors will be deployed outdoors during MAIA. The GRIMM 164, a high-quality optical particle counter, was used as the reference sensor. An outdoor testing station will be built with 80/20 aluminum and wooden pallets on a roof at JPL and used by MAIA personnel to answer technical questions. The second part of the analysis consists of laboratory experiments to generate aerosol particles under controlled conditions and compare the results from the above sensors with the Condensation Particle Counter (CPC). Dr. Flagan's Differential Mobility Analyzer allows for the differentiation of particles based on size. An airtight aluminum box is used to ensure that the sensors are taking in the same source of desired particles rather than ambient air. In both settings, the Purple Air showed the best correlation and the APT had the worst correlation compared to the GRIMM and CPC.

Jupiter Data and Image Archival Through the Planetary Data System
Jennie Chung, Jet Propulsion Laboratory, California Institute of Technology
Mentors: Glenn Orton and Tom Momary, Jet Propulsion Laboratory, California Institute of Technology

The primary objective of this project was to archive multiple sets of data from different astronomical observatory instruments according to standards given by NASA's Planetary Data System (PDS). The purpose of archiving these data is to allow the observations from these missions to be used in future scientific inquiries. Moreover, the specific requirements of the PDS allow for these archives to be easily accessible even after long periods of time, which leads to longevity of the scientific results. These data include thousands of infrared images and scientific observations of Jupiter, collected at several ground-based facilities through various programs tracking variability in Jupiter. One such instrument is NASA's Mid Infrared Spectrometer and Imager (MIRSI), a 320x240 Si:As array with a 85 x 64 arcsec field of view and spectral coverage over the 8-14 micron and 17-26 micron range. Images were also taken at the National Astronomical Observatory of Japan's Subaru Telescope with the Cooled Mid-IR Camera and Spectrograph (COMICS), among other instruments. Using FORTRAN-based Interactive Data Language (IDL), UNIX, and Python, data from these instruments were labeled with XML template files following the PDS's specific up-to-date requirements. This included an overall introductory User's Guide to each data set.

Probabilistic Models and Multivariate Analysis for the Prediction of Material Outgassing for Spacecraft Contamination
Savannah Cofer, Jet Propulsion Laboratory, California Institute of Technology
Mentors: William A. Hoey and John M. Alred (Jet Propulsion Laboratory, California Institute of Technology)

Spacecraft contamination control is critical for achieving a wide variety of mission objectives in space exploration. The upcoming Mars 2020, Europa Clipper, and Psyche missions, which involve organic compound detection and sample acquisition, face unique challenges resulting from molecular contaminants released from spacecraft materials and potentially deposited onto sensitive surfaces. This project aims to develop a quantitative model to predict outgassing behavior of mission-specific materials in situations that are challenging to measure experimentally. A new probabilistic model has been developed based on data collected from the standard ASTM E 1559 test method measuring outgassing rates using quartz crystal microbalances (QCMs). This multispecies model highlights the dependencies of outgassing rate on time, temperature, activation energy distribution, and material specific properties. One practical application is the prediction of the total outgassing rate coefficient of the Mars 2020 rover, which is difficult to determine using experimental methods. This data driven method overcomes previous limitations faced by classical reaction kinetics models, which have been shown to be lacking for heterogeneous reactions involving multiple constituent species.

Time-Series Methods for Onboard Analysis of PIMS Data
Ameya Daigavane, Indian Institute of Technology, Guwahati
Mentors: Kiri Wagstaff and Gary Doran, Jet Propulsion Laboratory, California Institute of Technology

The upcoming Europa Clipper mission consists of several instruments that will coordinate to investigate the salty, subsurface ocean on Europa. One of these is the Plasma Instrument for Magnetic Sounding (PIMS) - responsible for measuring the charge and densities of particles found in the plasma around Jupiter. PIMS operates in four different modes, with different energy ranges and temporal resolution. The default mission planning process will pre-schedule mode transitions based on best guesses for the location of the boundary between Europa's magnetosphere and ionosphere. My project aims to facilitate switching between these modes responsively, based on observations as they are collected, increasing the science return of the instrument. Further, we are developing algorithms for identification of electromagnetic anomalies. Similar anomalies captured by the Cassini Plasma Spectrometer (CAPS) have been shown to be evidence of previously unseen phenomena - such as electromagnetic coupling between Saturn and Enceladus, and negative ions in the Titan atmosphere. We test the algorithms we are developing on their ability to detect these anomalies within the original CAPS data files, using an evaluation framework that we have developed.

Multiple Frequency-Shift Keying Design and Detection for Europa Clipper
Noelle Davis, California Institute of Technology
Mentors: Melissa Soriano, Lisa Mauger, and Alessandra Babuscia, Jet Propulsion Laboratory, California Institute of Technology

Multiple Frequency Shift Keyed (MFSK) tones are a simplified deep-space communication scheme used during periods of very low signal strength from the spacecraft. During high-range, restricted-orientation, or high-dynamics situations, spacecraft signal power is often too low for conventional frame-based telemetry. MFSK communication is typically used during critical periods of spaceflight, including orbital maneuvers, entry, descent and landing, and fault-triggered safe modes. This assessment evaluates the trajectory-based communication signal levels and validates MFSK tones detection probabilities for these scenarios. A baseline MFSK tones design for Europa Clipper is constructed by evaluating the flight system and communication priorities for JOI and Outer Cruise against several proposed tones architectures.

Analysis of PARVI's Photon Throughput After Commissioning
Clarissa Do Ó, Jet Propulsion Laboratory, California Institute of Technology
Mentors: Gautam Vasisht (Jet Propulsion Laboratory, California Institute of Technology) and Christopher Matthews (Jet Propulsion Laboratory, California Institute of Technology)

PARVI (Palomar Radial Velocity Instrument) is an exciting new instrument that will search for orbiting planets around M stars by looking for induced stellar radial velocities. This problem started with the attempt to detect extrasolar planets around nearby stars in order to find Earth-like planets. After commissioning in Palomar during June 2019, the goal of this project is to analyze PARVI's photon throughput calculations for its components, the CRED and the spectrograph. The analysis consists of a theoretical program that calculates the expected throughput using the surface reflectivities and transmission coefficients that the starlight goes through, as well as programs that perform aperture photometry on the CRED and on the spectrograph data. After getting both theoretical and experimental results, we are performing simulations to analyze how the single mode fiber coupling efficiency changes by introducing aberrations on our PSF. With those simulations, we will be able to improve our throughput calculation precision and our instrument itself.

Low-Drift Solar-Visual-Inertial Odometry for a Mars Science Helicopter
Harel Dor, Jet Propulsion Laboratory, California Institute of Technology
Mentor: Jeff Delaune, Jet Propulsion Laboratory, California Institute of Technology

We implement and test a modification to an extended Kalman filter-based navigation algorithm being developed for use on a proposed follow-on to the Mars Helicopter Scout being launched along with the Mars 2020 Rover next year. In order to reduce the slow drift of the algorithm's predicted yaw about the local gravity vector, we augment the existing filter with measurements from a sun sensor, providing information about the helicopter's orientation relative to a fixed global frame. We perform tests of the augmented filter's accuracy on simulated sensor data of flight-like conditions, and demonstrate a significant reduction in yaw drift.

Delensing the Cosmic Microwave Background Using Deep Learning

George Driskell (Cornell University)
Mentors: Olivier Doré (Jet Propulsion Laboratory, California Institute of Technology) and Chen Heinrich (Jet Propulsion Laboratory, California Institute of Technology)

The Cosmic Microwave Background Radiation (CMB) acts as a powerful source of information on the physics of the early universe; however, gravitational lensing obstructs our ability to peer back at the surface of last scattering. For upcoming experiments with lower noise levels, such as CMB-S4, traditional methods of delensing the CMB involving the quadratic estimator will no longer perform optimally. Other methods such as iterative maximum a posteriori estimates are computationally expensive and require assumptions on the prior distributions of the unlensed CMB data. Therefore, we seek to use a Residual U-Net model, which has found success in image segmentation problems, to predict lensing potential maps from simulated CMB polarization data. We aim to improve upon previous efforts via incorporating our knowledge of the quadratic estimator into our training data and using the gradient of the potential maps to improve the smoothness of the output. Furthermore, we develop tools for analyzing the performance of the neural network by visualizing the output maps and power spectra of the data. This project acts as a stepping stone towards building a model capable of making accurate predictions on observed data, which would require dealing with masked data and inhomogeneous noise levels.

Calibrating Near-Infrared SpeX Spectra of Jupiter's Atmosphere

Hannah Fan, Jet Propulsion Laboratory, California Institute of Technology
Mentor: Glenn Orton, Jet Propulsion Laboratory, California Institute of Technology

SpeX is a medium-resolution 0.8- to 5.5-micron cryogenic spectrograph at the NASA Infrared Telescope Facility (IRTF). It supports prism, single-order and cross-dispersed modes, which use simultaneous wavelength coverage to image planetary features. Through near-infrared spectra captured by SpeX, diverse physical processes in Jupiter's atmosphere can be investigated, including high-altitude aurora, reflected solar radiation from the troposphere, and thermal emission from the deep atmosphere. In this project, the IRTF-supplied Spextool software is used to implement telluric correction and wavelength calibration into the reduction process of raw spectral data into maps of radiance flux per wavelength. A0V standard-star spectral data taken contemporaneously with the Jupiter spectra are used for the calibration. Software was also developed to generate the mean flux per wavelength of Jupiter images, in order to be compared with standard spectra taken from spacecraft.

Multi-Agent Deep Reinforcement Learning for Satellite Formation Flying Trajectory Planning

Alex Gao, University of California, Berkeley
Mentor: Shahrouz Ryan Alimo, Jet Propulsion Laboratory, California Institute of Technology

With the advancement of autonomous systems, the concept of a group of agents cooperating to perform an assigned task has emerged for practical use in a wide range of areas. In particular, the concept of multi-agent coordination and control has significant applications to formation flight of swarms of satellites. This research focuses on designing and implementing a hierarchical deep reinforcement learning framework for low-level satellite formation trajectory planning alongside a concurrently developed high-level formation assignment system for a target use case of synthetic aperture radar for mapping Earth forest topography. The satellite agents were trained using a custom OpenAI Gym environment with passive relative orbit dynamics defined by the Clohessy-Wiltshire equations. Two multi-agent framework approaches were considered and explored: a centralized "super-policy" controlling all agents trained with PPO, and semi-decentralized Multi-Agent Deep Deterministic Policy Gradient (MADDPG). To speed up learning of desired behavior, training was distributed on AWS clusters with hyperparameter search using Ray Rllib and Tune. The results demonstrate the potential of deep reinforcement learning and explore its advantages over traditional control methods.

Resampling JPL Radar Image Data of Greenland's Sea-Terminating Glaciers

Matthew Gonzalgo, Jet Propulsion Laboratory, California Institute of Technology
Mentors: Ian Fenty and Ala Khazendar, Jet Propulsion Laboratory, California Institute of Technology

To further investigate the possible explanation of the increased melting of the marine-terminating glaciers, NASA's Ocean Melting Greenland (OMG) mission seeks to quantify the amount of ice melting due to the heat of the ocean, as opposed to air, by monitoring the ocean-ice sheet interaction under the influence of increased oceanic and atmospheric temperatures. OMG uses NASA's airborne high-resolution Glacier and Ice Surface Topography Interferometer (GLISTIN-A) to directly measure surface elevation and frontal positions of the sea-terminating glaciers.

A program was developed that can take the ice surface elevation data collected by GLISTIN from all available years for each sea-terminating glacier surveyed and resample them on a common grid such that the slight location variations in measurements from year to year can be negated. This re-gridding process allows for the annual changes in ice surface height to be quantifiably measured for sea-terminating glaciers, and by combining ice elevation change and the frontal position of the glaciers with an estimate of granular snow air content of the air column, the overall changes in glacier mass can be inferred. Based on preliminary trials of difference plotting, it is evident that the Greenland surface elevation is generally decreasing over the last 4 years.

Resampling JPL Radar Image Data of Greenland's Sea-Terminating Glaciers
Forrest Graham, California Institute of Technology, Jet Propulsion Laboratory
Mentors: Ian Fenty and Ala Khazendar, Jet Propulsion Laboratory, California Institute of Technology

NASA's Oceans Melting Greenland (OMG) mission seeks to increase our understanding of the interactions between the ice sheet and the ocean and to provide critical information about the loss of mass in the ice sheet in order to predict the future effects of Greenland Ice Sheet to global sea-level rise. OMG collected annual ice surface elevation data using NASA's airborne high-resolution Glacier and Ice Surface Topography Interferometer GLISTIN-A. Using the GLISTIN-A data from the OMG mission, a python program was written to resample data swaths of glacier height over several years and place them onto a single, common grid. This enables the slight variations in latitude and longitude of swaths between years to be negated and quantitative differencing of ice height to be completed. Preliminary results at a lower resolution and data size on two swaths in Southeast Greenland show a lowering of ice height, however, full-size differences have not yet been made throughout Greenland, and so a holistic analysis is unavailable.

GPU Accelerated Tour Design & Numerical Station View Period Integral
Andrew Graven, Cornell University
Mentor: Martin W. Lo, Jet Propulsion Laboratory, California Institute of Technology

Project 1: Spacecraft tour design requires exploring a vast design space of different trajectories. Each trajectory is typically broken up into a series of close flybys with different planets and moons; computing the effect of these flybys on the trajectory is a central problem in tour design. We explored several different techniques of computing this effect, such as the patched-conic and pseudostate methods, completing much of the preliminary analysis of which method is optimal. Ultimately, a tool for computing flybys using the pseudostate method was designed and implemented in Matlab. Work was begun on moving the tool into C as preparation for putting the tool onto the GPU. This will enable the computation of thousands of flybys per second.

Project 2: Calculating mean satellite-ground station visibility typically entails integrating the satellite trajectory over long time scales, often taking over an hour of computation. Using Ergodic Theory, a volume integral was discovered which yields the mean satellite-ground station visibility within seconds. This result was further improved by reducing the volume integral to a surface integral via Stokes' theorem. We expect this technique to be particularly useful for satellite trajectory optimization and extendable to use in the planning of constellations of satellites.

Development of OH Electrodeless Discharge Lamp for Heterodyne OH Lunar Miniaturized Spectrometer (HOLMS) Calibration
Kiran Hamkins, California Institute of Technology, Jet Propulsion Laboratory
Mentor: Seyedeh Sona Hosseini, Jet Propulsion Laboratory, California Institute of Technology

A miniaturized spectrometer known as the Heterodyne OH Lunar Miniaturized Spectrometer (HOLMS) is being developed to detect lunar hydroxyl (OH) and deuteroxyl (OD) emission bands at 308.6 nm and 307.9 nm, respectively. These molecules would indicate the presence of water in the lunar exosphere, and measuring the ratio of OH to OD would improve our understanding of the evolution of water in the solar system. Due to the weakness of the OH emission bands and its short lifetime, calibration of the spectrometer to the specific OH emission band rather than calibration to the general wavelength range is necessary. A commercial OH calibration lamp does not currently exist; as such, an electrodeless discharge lamp is in development to calibrate HOLMS to the proper wavelength, as well as prove that it can detect the faint emission band. A design for an OH electrodeless discharge calibration lamp was created, altered, and improved based on an evolving understanding of the specific requirements for the lamp. Many of the lamp's components will be custom-made, and vendors for each of these specialized parts were identified and contacted to acquire each piece. A description of the operation conditions for the lamp as well as the experimental tests that will be carried out before the lamp will be used for calibration has been developed. Additionally, a comprehensive document of the nature of OH and the conditions necessary to observe it was created and will be used to inform further design changes and the eventual operation of the lamp.

Remote Sensing of Canal Leaks Using Synthetic Aperture Radar (SAR) Data

Meena Hari
Mentors: Seungbum Kim and Piyush Agram, Jet Propulsion Laboratory, California Institute of Technology

Many irrigation canals in the Western United States have aged beyond their intended life-spans and leak up to 50 percent of their water cargo. A pilot study using ground-range-detected (GRD) C-band SAR data found that both spatial and temporal analysis of the radar backscatter coefficient could successfully pinpoint canal leaks with 30 percent and 40 percent accuracy, respectively. The goal of this study was to improve accuracy in detecting soil moisture due to canal leakage in the same region targeted by the pilot study. Instead of GRD, single-look-complex (SLC) images were geometrically coregistered and spatially despeckled using the local neighborhood of every pixel for improved ground resolution. Maps of backscatter behavior for pixels in known seepage locations were recorded for the unspeckled and despeckled stacks. We utilized a change detection approach to isolate only changes in soil moisture over the time-series. We expect that this method will yield a higher accuracy and reduce false positives. In the future, we seek to employ alternative despeckling techniques, develop a deep-learning approach, and automate the remote sensing process.

Supercritical CO_2 Extraction and Chiral Supercritical Fluid Chromatography for Ocean Worlds

Julia Herman, Jet Propulsion Laboratory, California Institute of Technology
Mentor: Bryana Henderson, Jet Propulsion Laboratory, California Institute of Technology

As future *in situ* missions to Ocean Worlds, such as Enceladus or Europa, become increasingly attainable, fully developed instrumentation technologies are needed for the extraction and analysis of biomarkers. This project is focused on the development and optimization of a technique to retain charged polar analytes, specifically amino acids, by the use of solid-phase extraction by ion-exchange interactions, without retaining any inorganic salts. Solid-phase extraction and liquid chromatography (SPE-LC) with water as the solvent can be used to separate and detect amino acids. Five key instrumental parameters have been optimized to produce chromatograms with high resolution and high signal-to-noise ratio for each analyte. This technique was successful in detecting eighteen of nineteen important amino acids at the level of 500 μg/L. Furthermore, of the eighteen chiral amino acids in the sample, nine amino acids showed chiral separation. This technique has the potential for addressing life detection challenges in a unique way that eliminates many of the risks of current state-of-the-art analysis techniques used in solar system exploration. Once completed, the polar extraction and separation instrumentation will be completely free of extreme temperatures, organic solvents, and derivatization additives, making it a viable and green instrument for planetary applications.

A Realistic Determination of Observational Completeness Using the Starshade

Saehui Hwang, Jet Propulsion Laboratory, California Institute of Technology
Mentor: Sergi Hildebrandt, Jet Propulsion Laboratory, California Institute of Technology

The Starshade is a rising tool to be used in exoplanetary imaging to look for Earth-like planets. Positioned between the telescope and the star, the Starshade blocks the starlight from the telescope's mirrors. Previous studies have estimated the Earth-like exoplanet yields of future missions using average models of astrophysical parameters. This project aimed to produce a more precise completeness estimate using the Starshade Imaging Simulation Toolkit for Exoplanet Reconnaissance (SISTER), a software that produces predicted images of what will be observed through the telescope. To utilize SISTER, we have devised an algorithm that distributes a cloud of synthetic Earth-like planets around target stars. This cloud contains planets with various astrophysical parameters, including planet radius, atmosphere, eccentricity, and inclination. From these simulated images, we compute a regression fit against the Point Spread Function of each planet at each position. Ultimately, we obtain a count of detectable planets over the number of distributed planets, also known as *completeness.* This algorithm, for the first time, derives a realistic estimation of observational completeness from simulated images, much akin to what an astronomer would do from an observation. This algorithm will be useful for future JPL starshade mission planning, to calculate the probability of a successful mission.

Non-Cooperative Spacecraft Pose Estimation via Convolutional Neural Networks

Daniel Jeong, Columbia University
Mentor: Shahrouz Ryan Alimo, Jet Propulsion Laboratory, California Institute of Technology

Robust and accurate real-time vision-based pose, i.e., the relative position and attitude, determination of spacecraft is a key capability to support proximity operations in missions of on-orbit servicing (OOS), active debris removal (ADR), and formation flying (FF) (Capuano et al., 2019). With advances in space-ready equipment and hardware acceleration opening the path to deep learning in space, more and more traditionally computation-heavy approaches are being adapted to the space domain to solve these key problems. Estimating the pose of an uncooperative target object, from images acquired by a chaser camera, can be particularly difficult when working with a spacecraft in the orbital environment. Due to poor or extremely variable illumination conditions, space imagery can contain high image contrast and low signal-to-noise ratio, which hinders effective feature detection and renders vision-based pose estimation especially challenging. The dearth of available training data is another obstacle to successfully training a robust pose estimation system with good generalization. Some state-of-the-art pose estimation methods utilize transfer-learning-based convolutional neural networks (CNN) to make up for the lack of data and leverage the feature extraction capabilities of pre-trained networks (Sharma et al., 2018, 2019), while others often create synthetic image datasets for training (Ren et al., 2019) for the purpose of domain adaptation. Recently, approaches that employ encoder-decoder networks which directly learn to associate the three-dimensional orientation of an object with its 2D projection image have also been introduced (Esteves et al., 2019). The main objective of my work is to design and evaluate novel deep-learning-based approaches for on-board spacecraft pose estimation and integrate the functionality into a deployable embedded system for technology demonstration.

Machine Learning Techniques for Extraction of the Cosmic Microwave Background

Yash R. Kankanampati, Indian Institute of Technology, Dhanbad
Mentors: Olivier Doré and Daniel Lenz, Jet Propulsion Laboratory, California Institute of Technology

The Cosmic Microwave Background (CMB) is the leftover radiation from the Big Bang and is a powerful probe of the early universe. With the information obtained from the CMB, we can better understand the formation of the structure and matter in the Universe. However, measurements of the CMB are contaminated by other sources of radiation such as the synchrotron emission and free-free emission from our galaxy, as well as radiation from compact sources such as other galaxies and galaxy clusters. Machine learning Techniques have been shown to produce promising preliminary results and this project entails tailoring and developing machine learning models and testing their viability in estimation of the sources of contamination. Specifically, this project explores the techniques to estimate the dust foreground from the measurements of the Galactic neutral atomic hydrogen (HI) column density. These sources of contamination, when estimated accurately, can be used to extract CMB maps with reduced foreground contamination.

Developing a New Inlet System for Underwater Methane Detection

Jocelyn Kho, Jet Propulsion Laboratory, California Institute of Technology
Mentors: Max Coleman and Lance Christensen, Jet Propulsion Laboratory, California Institute of Technology

The introduction of Capillary Absorption Spectrometry (CAS) offers an alternative approach to extracting a gas sample from water for analysis This method involves a vacuum to degas a sample of liquid into a head-space, compared to the older technique of extracting the gas through a semipermeable membrane. I constructed a prototype sampling system consisting of several connected volumes, a series of solenoid-controlled valves and a vacuum pump, that extract gas from a water sample. To test the system, I used an IR tunable laser spectrometer, rather than a CAS, to determine the methane concentration. During this process, the speed at which a sample can be processed and moved through the inlet system leading up to analysis was evaluated and tested with three water sample sizes. The average time taken to extract methane from samples of 0.24g, 0.42g, 0.95g was 55, 60 and 81 seconds, respectively, while the time to pump away the sample was 150, 200 and 310 seconds, respectively. As expected, larger quantities of methane were measured in the larger samples but the increase was not linear. Also, the calculated yield was greater than theoretical and will need further investigation.

Differential Architecture for Dark Count Reduction of Superconducting Nanowire Single Photon Detectors (SNSPDs)

Hyunseong Linus Kim (Jet Propulsion Laboratory, California Institute of Technology)
Mentors: Matthew Shaw (Jet Propulsion Laboratory, California Institute of Technology) and Boris Korzh (Jet Propulsion Laboratory, California Institute of Technology)

Superconducting nanowire single photon detectors are the fastest single photon detectors with high detection efficiency, record time-resolution, and ultra-low dark count rate. However, for applications in dark matter search and quantum information, the dark count rate of SNSPDs must be further improved. In order to push these limits, we implemented a cryogenic differential bias-tee circuit, which filters high frequency noise from the current source and reduces electromagnetic noise coupling into the circuit thanks to a balanced architecture. We demonstrate that this differential architecture exhibits lower dark count rates compared to a single-ended device referenced to ground. We show, using a gaussian noise model, that the difference in dark counts for these two configurations can be attributed to electromagnetic noise.

Identification, Characterization, and Preservation of Mars 2020 Spacecraft-Associated Organisms Using MALDI-TOF Mass Spectrometry

(Emily) Yue Liang, Occidental College
Mentors: Wayne Schubert and Emily Seto, Jet Propulsion Laboratory, California Institute of Technology

The Mars 2020 mission seeks to find evidence of conditions in the past that were habitable for life. To preserve scientific integrity, Planetary Protection works to prevent both forward and backward contamination of celestial bodies. This includes frequent monitoring, sample collecting, and sample processing during assembly and throughout the spacecraft lifecycle. In particular, archiving involves identifying and characterizing the microbial isolates present in spacecraft-associated environments to help us further understand microbial contamination.

Microbial identification was performed using Matrix-Associated Laser Desorption/Ionization Time-of-Flight Mass Spectrometry (MALDI-TOF MS) to determine both the genus and species of bacteria. Furthermore, the morphology, consistencies, and growth periods of bacteria were recorded to identify trends in the isolates. Because select bacteria had difficult morphologies that inhibited protein extraction, investigation of the cell lysing procedure was necessary. A wide range of spore-formers and non-spore formers have been identified and continue to improve our custom-built MALDI-TOF library. Results suggest that certain isolates with various morphologies, such as a slimy/mucoid consistency or a hardened consistency, require a modification of the protocol in order to improve the resolution of the data.

PanFTS Frame Conditioning: Development and Testing

Iman Lulla, Princeton University
Mentor: Maxwell B. Bryk, Jet Propulsion Laboratory, California Institute of Technology

The PanFTS (Panchromatic Fourier Transform System) is an FPGA-based system designed to be flown in a geosynchronous satellite and process atmospheric data from a camera in real-time before downlinking, resulting in a data reduction factor of roughly 20, which is highly desirable to allow more data to be collected than ever before and advance atmospheric science. My work has been focused on developing and thoroughly testing cores for the camera board which take raw data from the camera and perform preprocessing and frame conditioning, such as flat field calibration, binning to reduce data rate, and application of a pixel mask. I have developed the Flat Field core and am working to develop a test suite and format to extensively test each of these cores. The test suite works with the Flat Field and Binning cores and requires a simple adaptation to work with the Pixel Mask core.

Searching for Gravitational Wave Progenitors: Supermassive Black Hole Binaries

Emma McGinness, University of California, Berkeley
Mentors: Joseph Lazio and Joseph Simon, Jet Propulsion Laboratory, California Institute of Technology

Most large galaxies contain supermassive black holes at their core, and galaxies, as they evolve, merge. It is predicted that, as a result of such a merger, the two galaxies' central supermassive black holes (SMBH) converge into a new central region, forming a binary that emits gravitational waves as they spiral together. Thus, further investigation of SMBH binaries may reveal the relationship between galaxy merger astrophysics and gravitational wave physics. Analyzing follow-up observation data collected by the Very Long Baseline Array (VLBA), which consists of 50 radio galaxy sources (imaged at 2.3, 4.3, 7.0 and 8.5 GHz) whose original images suggested the existence of SMBHs, allows further identification and observation of likely SMBH binaries. The analysis of the VLBA data involves the collection, refinement, and processing of measurement data at X-band frequency (8~15 GHz) using an established pipeline and CASA functions to generate high angular resolution images at the parsec level. Close study of these images to identify sources exhibiting characteristics consistent with two proximate point sources allowed for the creation of a concise list of SMBH binary candidates for additional observation with the goal of providing further evidence to support the theory that galaxy evolution and gravitational wave emissions are linked.

Real-Time Co-Verification and Data Processing Firmware/Software for Next Generation Imaging Spectrometers (NGIS) With Embedded Multi Processor System-on-Chip (MPSoC) Instrument Avionics

Vanessa Mechem (California Institute of Technology)
Mentor: Didier Keymeulen (Jet Propulsion Laboratory, California Institute of Technology)

Through the integration of all necessary computational power onto a single chip containing both an energy efficient ARM Cortex-A9 processor and a Xilink 7-series FPGA, the emergent technology of Multi Processor System-on-Chip (MPSoC) for next generation imaging spectrometers (NGIS) promises a smaller, more efficient, and more powerful space electronic system. The MPSoC developed for this project will be integrated with imaging spectrometer flight missions and instrument testbeds. Displaying the data transmitted by an imaging spectrometer on a computer relies heavily on the ability to discern instrument behavior in real time, leading to the development of LiveView, a software originally designed for real time calibration of focal plane arrays that has been adapted as a co-verification tool for hyperspectral imaging. The objective of this project is to implement new features and optimize current features in LiveView. Features that allow LiveView to be compiled without an EDTpdv driver, enables the dragging and dropping of files into LiveView have been completed. Additionally, a feature to enable subframe sampling rates in the fast Fourier transform widget is in the process of being implemented.

Moonquake-Triggered Mass Wasting Processes on Icy Worlds
Mackenzie M. Mills, Johns Hopkins University
Mentors: Robert T. Pappalardo (Jet Propulsion Laboratory, California Institute of Technology) and Mark P. Panning (Jet Propulsion Laboratory, California Institute of Technology)

Severe tectonization is evident on many icy satellites of the outer solar system, and normal faults are common. We consider whether seismic events could trigger mass-wasting to create smooth material between structural ridges. Using mapping software, we study sites on Europa, Ganymede, and Enceladus to create analogous high-resolution geologic maps. After cataloging 93 faults, we find fault populations behave approximately as normal faults extending through the elastic layer. We then calculate seismic moment magnitude in order to estimate energy available for mass wasting. To do this, we measure length and area for each scarp, calculate scarp width corrected for spatial distortion, infer a slip:length ratio = $5e10^{-4}$, and estimate fault dip, slip for a single event, and depth to the brittle-ductile transition. We return a moment magnitude range 4.7-7.1, using a shear modulus for ice (here adopted as 3.521 GPa [Gammon et al. 1983]) and units are mks. Using high frequency seismic models, we will explore previous estimations of seismic accelerations, which are comparable to gravitational accelerations. This will indicate the potential amount of material moved by seismic events, and therefore the extent of resurfacing caused by tectonic activity.

Data Rate Reducation via Binning Process for PanFTS
Henry Morales, University of Southern California
Mentor: Maxwell Bryk, California Institute of Technology, Jet Propulsion Laboratory

The Panchromatic Fourier Transformer Spectrometer (PanFTS) is an instrument concept that is designed for remote sensing from geostationary orbit. It will be capable of detecting the spectral content of many trace gases such as air pollution, greenhouse gases, and weather sounding. A camera on the instrument receives atmospheric data and in order to process the incoming information in real time, the data rate received from the camera must be reduced. This can be done by binning together several pixels throughout a frame to form a new frame consisting of less, but more vibrant pixels. The project is implemented on a Xilinx UltraScale FGPA and programmed in Verilog.

Creating and Optimizing the Mesh Quality Assessment Tool (MQAT) for Mars 3D Surface Reconstruction
Ajay Natarajan, Jet Propulsion Laboratory, California Institute of Technology
Mentor: Oleg Pariser, Jet Propulsion Laboratory, California Institute of Technology

3D surface reconstructions of Martian terrain rely on the ability to quickly and quantitatively compare 3D point clouds and meshes. Fast comparisons allow software engineers to efficiently optimize 3D Surface Reconstruction software parameters, and high-precision analysis allows the Mars surface mission operations team to identify problems in generated products. The objective of this project is to provide a quantitative visualization of differences between two terrain models. The primary visualization relies on a k-d tree-based computation of the differences between Hausdorff distances of adjacent test model points and the reference model. This analysis provides key insight into test-reference local region compatibility. Vertices on the mesh are colored according to this metric and normalized by a user-set constant to identify problematic regions. This combined with other supporting features aid the user in establishing an intuitive sense of the mesh compatibility. The software was primarily developed to be used for Mars 2020 during its development and operations phases, but the software is general enough to be applied seamlessly to many current and future missions at JPL. Future work on this software aims to broaden its applicability, most notably introducing horizontal alignment measures through the Iterative Closest Points Algorithm.

Evaluation of the Mars 2020 Spacecraft and JPL Spacecraft Assembly Facilities Using the NASA Standard Assay
Christina Nguyen, California State University, Dominguez Hills
Mentors: Sarah Cruz and Gayane Kazarians, Jet Propulsion Laboratory, California Institute of Technology

The Mars 2020 rover has been designed to perform investigations that may answer some of the NASA Mars Exploration Program's key scientific questions. It is crucial for Planetary Protection to adhere to NASA Category IV mission requirements to ensure cleanliness of the spacecraft before launch in order to prevent forward microbial contamination, and to preserve the scientific integrity of the mission. The objective of this project is to assess spacecraft hardware cleanliness levels using the NASA Standard Assay (NSA) and mastering this technique for independent processing of the samples collected in cleanrooms. Samples are acquired from a spacecraft surfaces using sterile moistened wipes or swabs. Sampling devices are subjected to sonication and heat shock at 80°C, and sample aliquots are added to petri dishes containing TSA media. Colony forming units, or CFUs are observed at 24, 48, and 72 hours in order to quantify bioburden. Software is used to track the samples, and CFU counts that are performed, to determine if the hardware has passed the biological contaminant assessment. An extremely low bioburden is observed on spacecraft samples. Passing bioburden assessment results allowed for progression of the hardware into its next stage of the build of the Mars 2020 rover.

Flight Software and Communication for Signal of Opportunity on Airborne Platforms
Luan Nguyen, University of California, San Diego, Jet Propulsion Laboratory/California Institute of Technology
Mentors: Ryan Alimo, Adrian Stoica, Chrishma Derewa, Jet Propulsion Laboratory, California Institute of Technology

Signal of Opportunity (SoOp) is a new area of radio science that uses the existing transmissions from space and aerial radio systems to replace the need of a new transmission platform. SoOp has been successfully implemented on offshore platforms in the application of capturing direct and water-bounced signals from GEO satellites to calculate the ocean's wave height. To show the feasibility of SoOp on an airborne platform, we demoed this system using a tethered balloon at a height of 50 m. We used two C band antennas mounted on top of gimbals for accurate pointing. One receiver was pointed at Galaxy 15 to collect the direct signal and the other receiver was pointed at a swimming pool to collect the bounced signal. To stabilize the structure, we tethered the balloon and payload to the ground. We also used a pulley system between the balloon and payload. SoOp has been theorized to work on CubeSats in space by augmenting larger satellites. For a tech demo, we launched a high altitude balloon attached to a CubeSat and tested the system's communications by sending downlink live video. This launch was the first time a Qualcomm board was used for near-space atmosphere. The initial tests prove the feasibility of using SoOp on airborne vehicles and using the Qualcomm Snapdragon as a flight computer in a space environment.

Stormwater Runoff Remote Sensing Analysis in Southern California
Emelly Ortiz-Villa, Jet Propulsion Laboratory, California Institute of Technology
Mentor: Benjamin Holt, Jet Propulsion Laboratory, California Institute of Technology

The urbanization of coastal regions has directly influenced environmental decline and ocean pollution from stormwater runoff. During rain storms, the runoff cleans the streets and collects contaminated material which is directly released into the coastal zones without treatment. Stormwater runoff leads to bacterial overgrowth harming beach water quality off of highly populated coastal cities. Besides the growing bacterial contamination, runoff adds health hazards to the greater portion of the coast. Heal the Bay (HTB) is a non-profit organization committed to making ocean conditions optimal along California. They have provided us with FIB (fecal indicator bacteria) data obtained along beaches in the Santa Monica Bay and the San Pedro area during rain events occurring in Southern California. We used satellite SAR imagery and other satellite optical imagery to allow for spatial and temporal evaluation of surface particles that potentially pollute ocean ecosystems. In this study, we evaluated SAR data using Heal the Bay FIB points to reflect shoreline fecal matter contamination affecting the SCB. The primary objective of this project is to further analyze Heal the Bay fecal matter contamination and evaluate the effectiveness of using SAR-detected stormwater plumes as a useful method to determine contaminated coastlines. The locations analyzed for bacterial contamination include Los Angeles River, San Gabriel River, and Ballona Creek. We evaluated the coast in short time series from winter 2018 to the present. Sentinel-1 SAR images were used to observe targeted plumes. Turbidity, rain events, and bacterial data were the parameters accounted for connecting the presence of a plume image to sewage spill.

Microbiological Assessment of Mars 2020 Hardware and Spacecraft Assembly Facilities Using the NASA Standard Assay
Ishank Pahwa, Indian Institute of Technology, Delhi
Mentors: Sarah Cruz and Gayane Kazarians (Jet Propulsion Laboratory, California Institute of Technology)

The Mars 2020 rover, which is to be launched next year, builds on decades-past Mars exploration missions and will go one step further to assess important scientific goals. The rover will search for materials with high biosignature preservation potential and demonstrate significant technical progress towards the potential future return of scientifically selected samples to Earth. Since one of the goals of this mission is ancient life detection and assessment of past habitability, one of the most important aspects to preserve the scientific integrity of the planet Mars is preventing harmful contamination by Earth borne microbes by the very robotic space vehicles intended to land on it or orbit around it. This form of contamination is called *forward contamination*.

Planetary Protection is interested in the prevention of biological contamination from *spores*. NASA biological burden requirements for Category IV missions are satisfied in part by assaying of surfaces by the NASA Standard Assay (NSA). The NSA selects for spores due to their ability to survive harsh environments and potentially spaceflight, and is performed on flight hardware, ground support equipment, and spacecraft assembly facilities using wipes or swabs. Samples are processed aseptically and colony counts are recorded after 24, 48, and 72 hour time points and recorded into a software program . Counting and processing of a total of 104 assays took place over seven weeks was performed to determine if samples were within Planetary Protection bioburden requirements.

Characterization of REASON Sounding Radar Aboard Europa Clipper

Vivienne Patwardhan, Jet Propulsion Laboratory, California Institute of Technology
Mentors: Mark Fischman and Elaine Chapin, Jet Propulsion Laboratory, California Institute of Technology

NASA's Europa Clipper mission is planned to launch in 2023 to investigate the Galilean moon Europa. The REASON (Radar for Europa Assessment and Sounding: Ocean to Near-surface) instrument will be used to characterize the ice shell and subsurface ocean. The instrument includes both a high frequency (HF) radar operating at 9 MHz, and a very high frequency (VHF) radar operating at 60 MHz. One important use of the radar will be to characterize the composition of the ice layer and ocean using the power of the received radar echoes, which vary based on the dielectric permittivity of the reflecting material. Currently, an Engineering Model of the HF radar hardware is undergoing testing at the Jet Propulsion Laboratory. My research focuses on determining the precision and accuracy of the HF receive hardware's power measurement. This research was conducted by injecting test signals into the antenna ports using an arbitrary waveform generator. The data collected will be analyzed in order to establish the baseline level of uncertainty in power measurement due to the HF stack, which in combination with similar data from the antenna and other components will allow scientists to determine a threshold above which variations in measured power can be considered to be significant indicators of variation in dielectric permittivity.

Using Polarization in Digital Holographic Microscopy for Life Detection

Alexander Ramirez, Jet Propulsion Laboratory, California Institute of Technology
Mentors: Christian Lindensmith (Jet Propulsion Laboratory, California Institute of Technology), J. Kent Wallace (Jet Propulsion Laboratory, California Institute of Technology), and Eugene Serabyn (Jet Propulsion Laboratory, California Institute of Technology)

When searching for life on other planets, a greater spectrum of information is needed to further deduce the composition of a sample and decipher whether an object is mineral or biological. Digital holographic microscopy (DHM) is used within microbiology where raw data is detected by a camera sensor and reconfigured algorithmically, instead of using a traditional microscope image forming lens. DHM normally produces fringe patterns by splitting a laser beam through two offset sample chambers (sample and reference). We propose a less common method of DHM which records multiplexed holograms at 3 separate orientations on the detector. The data acquired through this process can be processed into separate images using a combination of Fourier transforms and equations for light propagation. To determine polarizing properties of the sample, which can help discriminate minerals from cells, we put polarizing filters at crossed orientations in the reference arms for two of the orientations. These filters enable us to record (and later reconstruct) simultaneous images using multiple polarizations of light, giving us polarization characteristics of the sample under observation. Variations in polarizer combinations will be reported on from a polarized and unpolarized laser beam light. The best overall waveplate construction will next be utilized in testing on mineral and bacterial samples to provide realistic data sets for reference in future astrobiological uses.

Rock Detection and Terrain Analysis for Jezero Crater, Mars, the 2020 Rover Landing Site

Venezia Ramirez, University of California, Los Angeles
Mentors: Matthew Golombek (Jet Propulsion Laboratory, California Institute of Technology), Nathan Williams (Jet Propulsion Laboratory, California Institute of Technology), Heather Lethcoe, California State University, Northridge, Marshall Trautman (Jet Propulsion Laboratory, California Institute of Technology), Richard Otero (Jet Propulsion Laboratory, California Institute of Technology)

Out of numerous candidate landing sites proposed for the Mars 2020 Rover mission, Jezero crater (18.47°N, 77.438°E) was selected due to its lithologic diversity. Additionally, it contains smooth regions that will allow the Mars 2020 Rover to land and traverse safely. To sample the diversity of lithologies within Jezero crater, the rover must navigate around and avoid potential hazards during landing and once on the ground. These hazards include ripples too large to traverse, steep slopes, and large rocks. These hazards are analyzed, mapped, and combined into a single hazard map to aid in landing. The focus of this research is to support landing site terrain characterization by confirming the distribution and sizes of rocks previously mapped using 25 cm/pixel images taken by the Mars Reconnaissance Orbiter High-Resolution Imaging Science Experiment (HiRISE) to minimize the risk to the Mars 2020 Rover. We compare automated, semi-automated, and machine learning rock detection results and manually identify previously unidentified or falsely identified rocks within the landing ellipse that appear suitable for landing. Areas with no detectable rocks indicate locally safe targets for the rover to divert to and land at. After landing, this will effectively contribute to the collective effort of obtaining a diverse suite of lithologic samples that could potentially be returned to Earth by a later mission to test for potential biosignatures and ancient habitable environmental conditions.

Optimizing Solid-Phase Extraction and Superheated Water Chromatography for Chemical Analysis of Polar Species of Astrobiological Relevance
Anahut Sandhu, University of California, Davis
Mentor: Bryana Henderson, Jet Propulsion Laboratory, California Institute of Technology

The development of a chemical analytical method complete with efficient extraction, preconcentration, separation, and detection techniques is essential in the potential identification of different biomarkers that may be encountered in the icy regions of Europa and Mars. Interfacing solid phase extraction (SPE) with superheated water chromatography (SHWC) is a safe and robust method for the potential discovery of astrobiological molecules. This method can detect negative and neutral polar analytes by trapping the desired analytes from a sample onto a graphitic carbon trap column and running superheated water (at 200 ° C) through the trap column to carry the analytes for detection by electrospray ionization coupled with mass spectrometry (ESI-MS). The focus of this work is the initial optimization of an efficient heating system for the superheated water and finding the parameters that yield the best elution profiles of the analytes. The detection of nucleobases, nucleosides, nucleotides, and biogenic amines is projected for the capabilities of this method.

P2serialcmds Co-Verification Software Development for NGIS and Embedded MPSoC Instrument Avionics
Eugene Shao, Jet Propulsion Laboratory, California Institute of Technology
Mentors: Didier Keymeulen and Jacqueline Ryan, Jet Propulsion Laboratory, California Institute of Technology

The emergent technology of System-on-Chip (SoC) and Multi-Processor System-on-Chip (MPSoC) devices promise lighter, smaller, cheaper, and more capable and reliable space electronic systems that could help to unveil some of the most treasured secrets in our universe. This technology improves upon the current space application electronics, which lag behind state-of-the-art commercial-off-the-shelf equipment by several generations, and allows for the high-performance computing required by next-generation space exploration science instruments. This paper introduces the Qt-based p2serialcmds graphical user interface (GUI), a comprehensive tool that serves as the platform for interacting with LiveView software, Next-Generation Imaging Spectrometers (NGIS), and supporting devices. Moreover, it will detail its development, which includes implementation of many new features and enhancements on its recording and scripting abilities. The recording and scripting capabilities of p2serialcmds allow users to automate lengthy sequences of actions with precision, eliminating human error and decreasing data analysis and testing time. Thus, advancements in this crucial feature have made p2serialcmds more useful and optimized for scientists.

Investigating Image Post Processing Error in the Mars 2020 Lander Vision System Field Tests
Tiffany Shi, Stanford University
Mentor: Yang Cheng, Jet Propulsion Laboratory, California Institute of Technology

The Mars 2020 Lander Vision System (LVS) allows for groundbreaking precision in the Entry, Descent, and Landing (EDL) of the rover in Jezero Crater, a scientifically interesting but geographically challenging landing site. The use of image post processing in field tests conducted in the Death Valley region have revealed limitations within the LVS in two major areas: (1) optical range and (2) landmark detection at varying times of day. Using statistical models and manual calculations of reject stages, this work identifies camera calibration, specifically in focal length, as well as shadow variations to be primary sources of error. This suggests routine manual camera calibration and further work in off-nominal flight landing, especially at varying times of day, as the LVS team continues with field tests.

Weak Lensing Constraints on Scale-Dependent Models of Cosmological Growth
David Shlivko, California Institute of Technology
Mentors: Jason Rhodes and Agnès Ferté, Jet Propulsion Laboratory, California Institute of Technology

The Standard Cosmological Model describes the Universe in the framework of General Relativity, assuming the existence of a cosmological constant and cold dark matter. While this model is highly successful in describing a vast array of cosmological phenomena, our failure to understand the nature or provenance of the cosmological constant has motivated the exploration of alternative models of cosmology that offer new ways of explaining the observed cosmic acceleration. One popular approach in this endeavor is to propose modifications to GR itself. In this work, we analyze the Year-1 data collected by the Dark Energy Survey to place constraints on a particular family of models proposing scale-dependent modifications to GR. In particular, we adapt the numerical Boltzmann Solver MGCAMB to compute shear correlation power spectra under the dynamics of these new models, and we utilize the cosmological parameter estimation code CosmoSIS to perform a Markov-Chain Monte Carlo analysis comparing the computational results to DES observations. Our current objective is to determine whether this family of modified-gravity models is more consistent with DES observations than the Standard Cosmological Model; any such indications would require a more precise follow-up analysis to hone in on the optimal scale-dependent model.

Process Monitoring for Additive Manufacturing
Eric Smith, Jet Propulsion Laboratory, California Institute of Technology
Mentors: Richard Otis and Andre Pate, Jet Propulsion Laboratory, California Institute of Technology

Additive manufacturing (AM) of metal parts is an emerging manufacturing technology with the potential to drastically reduce the cost of high-complexity, low-volume parts for JPL missions. AM allows for the construction of components with complex geometries impossible to achieve with traditional machining and enables novel manufacturing techniques such as functionally graded materials (gradient alloys). Metal AM demonstrates sensitivity to small changes in environmental conditions. Thus, the monitoring of conditions during the AM process is crucial to characterizing the final product and improving the process.

I develop a microcontroller-based process monitoring system for the Additive Manufacturing Center (AMC) which collects, displays, and records key environmental parameters, including temperature and humidity, inert gas pressure and flow rate, and machine vibration. Telemetry collection is uninterrupted by other system functions through the use of a multithreaded approach. A visualization of recent telemetry is displayed on a monitor in the AMC and contains interactive functionality enabling immediate examination of recent data. All telemetry is recorded to a storage drive, where it can be transferred to a workstation computer for more thorough analysis. In addition, I demonstrate the feasibility of programmatically collecting live telemetry directly from the metal printer's internal sensors.

Metal Properties of CIV Systems in the BOSS DR12 Quasar Catalogue
Marlena SmithJet Propulsion Laboratory, California Institute of Technology
Mentors: Tzu-Ching Chang and Lluis Mas-Ribas (Jet Propulsion Laboratory, California Institute of Technology)

Metal absorption lines in the spectra of background quasars provide valuable information about the structure and composition of galaxies. However, in low resolution and low signal-to-noise spectra, these lines are often too weak to be detected. We use approximately 69,000 CIV systems detected in the BOSS DR12 quasar spectra and generate stacked mean absorption spectra, which represent statistical averages of the absorber population. Several stacks are made for a broad range of absorber parameters, such as redshift, doublet equivalent widths and detection strength. These stacks are used to track the metallicity with respect to these parameters and determine how these parameters affect the presence and state of the metals. We focus on determining the equivalent widths of many associated hydrogen and metal lines. We also focus on the Lyman series and quantifying the hydrogen column density to reveal the nature of the CIV systems within the galactic environment.

Studying the MUSE-Wide Field in Lyman-α Polarization
Isabel Swafford, Jet Propulsion Laboratory, California Institute of Technology
Mentor: Lluis Mas-Ribas, Jet Propulsion Laboratory, California Institute of Technology

Lyman-α photons can be scattered by neutral hydrogen gas when escaping from galaxies, resulting in the polarization of the radiation. Thus, polarization indicates areas occupied by neutral hydrogen with characteristic properties that facilitate the scattering and escape of photons. We model the Lyα intensity and polarization in the MUSE-Wide Field Survey by creating maps and computing the power spectra of this signal. This is done to investigate the detectability and potential physical information that can be extracted from such observations. The study of polarization is an encouraging new viewpoint from which to analyze light and can provide details about the structure of a source and its neighbors, beyond just intensity alone.

Atmospheric Aerosol River Detection
Sophie Uluatam, Cornell University
Mentors: Duane Waliser (Jet Propulsion Laboratory, California Institute of Technology) and Bin Guan (Jet Propulsion Laboratory, California Institute of Technology)

Aerosols play an important role in global climate, with impacts extending to air quality, precipitation patterns, and global energy balance. This goal of this project is to identify atmospheric aerosol rivers (AARs), elongated, jet-like regions of aerosol transport. In order to do so, we adapt the algorithm used in Guan and Waliser [2015] to detect atmospheric rivers, or outstanding regions of water vapor transport. The study examines five species of aerosols—black carbon, organic carbon, dust, sulfate, and sea salt— using integrated aerosol transport (IAT) data. For each timestamp, the algorithm creates a threshold IAT value based on the 85th percentile specific to each grid cell and month. It then identifies contiguous regions of grid cells which exceed this threshold, have consistent direction, have sufficient length, and fulfill other characteristics associated with AAR conditions. These regions are labeled as AARs. The AARs detected in this project can later be analyzed from a climatological perspective, tracked, and investigated to find links to global air quality and weather patterns.

Creating a Genetic Inventory of Microbes on Mars 2020 Spacecraft
Kathryn Van Artsdalen, Middlebury College
Mentors: Lisa Guan and Parag Vaishampayan, Jet Propulsion Laboratory, California Institute of Technology

The Mars 2020 rover will search for biological signatures and collect samples to determine if the Martian environment once supported life, but organisms from Earth could be transmitted to Mars and falsely indicate the presence of life there. The Genetic Inventory (GI) project aims to identify and document microorganisms on the rover prior to launch in order to discriminate potential Martian DNA from that of terrestrial origins. Samples were obtained from Mars 2020 hardware surfaces in a cleanroom with cotton swabs and wipes. DNA was extracted using an ultra-clean protocol for low biomass samples to maximize DNA yield. Whole-genome sequencing and metagenomic analysis were used to provide a comprehensive profile of the microbial communities present on the Mars 2020 rover. This taxonomic catalog can be used when analyzing returned Martian soil samples in order to preserve mission scientific integrity.

Reduction of Near- to Mid-Infrared Images of Jupiter
Adrienne Vescio, Jet Propulsion Laboratory, Arizona State University
Mentor: Glenn Orton, Jet Propulsion Laboratory, California Institute of Technology

Over the past 25 years, Dr. Glenn Orton and his team have been collecting ground-based observations of Jupiter, ranging between 5 and 25 μm, from NASA's Infrared Telescope Facility (IRTF), the Gemini Telescope, the Very Large Telescope, and the National Astronomical Observatory of Japan. While these data have the potential to create the first quasi-continuous record of Jupiter's climate and atmospheric motions, they must first be properly calibrated before they can be analyzed and archived for public use. After undergoing basic geometric calibrations that establish the center and size of the planet on the image, by use of IDL programs written by previous SURF interns Jagath Vytheeswaran and Mikhael Semaan, images taken by the IRTF's MIRAC and MIRAC2, the Gemini Observatory's T-ReCS, and the ESO Very Large Telescope's VISIR can be reduced and prepared for archival. Properly calibrated images have geometric calibrations further improved by more stringent guidelines and have header values adjusted to properly account for any radiance perturbation caused by influence of Earth's atmosphere, established by comparison with data collected from the Cassini CIRS and Voyager IRIS instruments. Once all images are fully calibrated, they will be archived and made publicly available using NASA's Planetary Data System.

Weak Gravitational Lensing as a Probe of Dark Matter
Jenny Wan (California Institute of Technology)
Mentors: Jacqueline McCleary and Jason Rhodes (Jet Propulsion Laboratory, California Institute of Technology)

Galaxy clusters are the largest virialized structures (e.g. a system of gravitationally interacting particles that is stable) in the universe, and it is estimated that 80% of their mass is dark matter. Thus, they pose as ideal subjects with which to study dark matter. Weak gravitational lensing measures minute distortions of radiation from distant galaxies behind these clusters and analyzes the correlation between the distortions. With this data, we can create "maps" of the distribution of dark matter throughout the cluster. The current paradigm underlying galaxy formation is Cold Dark Matter (CDM), which reflects our current knowledge of cosmological large-scale structure, but among other problems, predicts much larger numbers of small satellite galaxies. Two alternative theories, warm dark matter and self-interacting dark matter, both predict a reduced abundance of substructure. In this project, we take raw DECam imaging data of the cluster Abell 2029 in the u, g, r, i, and z bands and utilize the LSST Science Pipelines to obtain catalogs and stacked images of this cluster. Foreground galaxies are filtered out based on their photometric redshifts, which are found using the Bayesian Photometric Redshift algorithm. A weak lensing algorithm is then applied and the cluster mass is determined with a code developed by Jacqueline. Once we obtain the weak lensing map of the cluster, we can examine the substructure abundance, both by inspection and using certain geospatial techniques for finding signal concentrations, to help further constrain our understanding of dark matter and its properties.

MISR Smoke Plume Digitization and MINX's GUI
Elizabeth Yam, Jet Propulsion Laboratory, California Institute of Technology
Mentor: Abigail Nastan, Jet Propulsion Laboratory, California Institute of Technology

Wildfire smoke plumes have a significant environmental impact, decreasing air quality and affecting aerosols' influence on climate. Scientific studies (such as aerosol modeling) about smoke plumes utilize information on plume top height (height of the upper surface of a smoke plume), wind speed, and types of particulates. Data concerning smoke plumes is collected by Multiangle Imaging Spectroradiometer (MISR) aboard NASA's Earth Observing System's Terra satellite and processed using MISR INteractive eXplorer (MINX). However, such studies cannot be conducted extensively due to limited number of information in the dataset. The limited number of data is due to the partial manual analysis required for each individual plume, as MISR satellite imagery requires a high level of pattern recognition skills and intuition that is difficult to develop into a successful algorithm. In addition, MINX's Graphical User Interface (GUI) did not provide an efficient way to digitize a list of plumes. Thus, there is great number of MISR-captured smoke plumes to analyze; only data from the years 2008-2011 have been digitized, leaving 2012-2018 to be digitized. Therefore, this project aims to contribute to the MISR Plume Project database by digitizing smoke plume images captured in July 2017, December 2017, June 2018, and August 2018. The smoke plumes have been successfully digitized despite challenges with low/distorted visibility of smoke plumes and the appearance of clouds covering and contaminating the data. In addition, MINX's GUI was improved to contain a "Previous Orbit" and "Next Orbit" buttons to allow the users to go through the list of orbit-and-block-ranges in a more efficient manner than before.

Abstracts

Student–Faculty Programs

2
0
1
9